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Towards a Design Science for Information Systems

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Editors

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PROCEEDINGS
RCIS 2019

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Introduction

An Overview of Scientific Areas in *Research Challenges in Information Science*

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***Abstract*—Welcome to RCIS, the "Research Challenges in Information Science" community and its annual conference! In this short article, we introduce newcomers to this field and to its community with an overview of what RCIS is and how it positions with respect to other venues existing in the domain, like CAiSE, MODEL, and ER, highlighting its legacy. We also take this opportunity to enumerate and define the eight major RCIS areas of scientific contributions and exemplify them with some representative papers published during this 13th edition or before, which we hope to guide researchers and practitioners towards making their future RCIS submissions successful and impactful in the RCIS community.**

***Index Terms*—RCIS, RCIS 2019, Conference, Information Science, Information Systems, User-Centered Approach, Data Management, Business Processes, Data Science, Infrastructures, Research Challenges, Practices, Publications.**

WHAT IS RCIS?

The scientific field and community of Research Challenges in Information Science (put shortly, "RCIS") first refers to the central area of *Information Science*, which is often defined as the area "concerned with the analysis, collection, classification, manipulation, storage, retrieval, movement, dissemination, and protection of information" [12]. A precise definition from [9] defined it as the science and practice concerned with recordable information and knowledge, and the technologies and related services that facilitate their management and use. More specifically, information science is a field of professional practice and scientific inquiry addressing the effective communication of information and information objects, particularly knowledge records, among humans in the context of social, organizational, and individual need for and use of information. The domain of information science is the transmission of the universe of human knowledge in recorded form, centering on manipulation (representation, organization, and retrieval) of information, rather than knowing information. Roughly speaking, RCIS could then be associated to any action manipulating information in a computer-based system. The term "information" is itself defined in many different ways which can be found in several domains, and not just information theory, computer science, and informatics [15]. For this purpose, RCIS addresses mainly **eight research topics** or research fields defined as follows:

(A_1) **Information Systems and their Engineering**. An *Information System* consists of the Information and Communication Technology (ICT) that an organization uses to support its own business processes, but also includes how people belonging to an organization may interact with this system. An information system should therefore not be reduced to the computer science aspects of it, since it also addresses organizational, business, and human aspects. This area hereby covers the following topics: Requirements Engineering (which is also relevant to the RE conference), Software Testing (also overlapping with the IEEE International Conference on Software Testing, Validation and Verification), Information Security and Risk, and Method Engineering (which is also part of software engineering venues). Consequently, this area primarily covers the following aspects in the above definition: "analysis", "collection", "classification", "manipulation".

(A_2) **User-Centred Approaches**. These approaches share a major trend: involve end users, actual ones, future ones, or their representative, into the development life cycle, usually as soon as possible, e.g. as of the requirements engineering phase. This area hereby covers the following topics: social computing and social network analysis, User-Centred Design (UCD) covering probably the most frequently addressed sub-topic of user-centred approaches (although other phases of the development life cycle could also be user-centred), Collaborative Computing which touches all aspects of information science where any form of collaboration is studied (such as Computer-Supported Collaborative Work), and human factors in Information Systems to address how people actually carry out their interactive tasks with the system. Consequently, this area primarily covers the following aspects in the above definition of information science: "manipulation", "movement", "dissemination".

(A_3) **Data and Information Management**. This area subsumes the following sub-topics: databases and information, Information Search and Discovery, Conceptual Modelling and Ontologies. Again, the entry point for these sub-topics is the focus on information

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itself, not the underlying technological aspects on how to implement them. For instance, the logical and/or physical development of databases is more relevant to conferences in database management systems. Similarly, conceptual modelling is often covered by the flagship "International Conference on Conceptual Modelling" (ER). While ER covers the entire spectrum of conceptual modelling ranging from pragmatic to syntactical aspects of concepts, methods, models, and software tools for any domain, RCIS prefers to concentrate on these aspects when they are relevant to Information Science. Consequently, this area primarily covers the following aspects in the above definition of information science: "analysis", "collection", "classification".

(A_4) **Business Process Management**. This area subsumes the following sub-topics: Business Process Engineering and Re-engineering, Process Mining, and Enterprise Engineering. Again, these topics are often addressed in their broader sense in venues like the "International Conference on Business Process Management" (BPM), including its technological aspects. Consequently, this area primarily covers the following aspects in the above definition of information science: "analysis", "manipulation", "movement", "dissemination", and "protection" of information.

(A_5) **Domain-specific Information System Engineering**. This area momentarily subsumes the following domains of human activity touched by information science: E-Health, E-Government, E-Commerce, Industry 4.0, Web-Based Applications and Services Smart Cities. In principle, any domain of human activity could be concerned by information science, especially when information science is also handled by other disciplines such as linguistics, communications, and social sciences, which may have little or no intersection. In this case, all aspects of the definition are potentially covered since it depends of the domain.

(A_6) **Data Science**. This area subsumes the following sub-topics: Big Data Business Analytics, Decision Information Systems, Knowledge Management, Knowledge Discovery from Data. These sub-topics are also of course relevant to other journal and venues, such as "International Conference of Decision-Support Systems" (ICDSS), which is "about any type of decision support, knowledge management or data management system intended to support managers and decision makers". Consequently, this area primarily covers the following aspects in the above definition of information science: "analysis", "collection", "classification", "manipulation", "storage", "retrieval".

(A_7) **Information Infrastructures**. This area subsumes the following sub-topics: Cyber-Physical Systems (CPS), Web Information Systems (WIS), Grid Computing and Cloud Computing, Internet of Things (IoT), Pervasive and Mobile Computing. All these sub-topics also have their own venue and journal. This area primarily covers the following aspects in the above definition of information science: "analysis", "collection", "classification", "manipulation", "storage", "retrieval".

(A_8) **Reflective Research and Practice**. This area subsumes the following sub-topics: Research Methodologies in Information Science, Impact of Information on the Enterprise and the Individual, Lifecycle Models, Design Science and Rationale. In this area, any methodological research question related to information science could be addressed, with its impact on stakeholders taken in isolation or as a whole. In this case, all aspects of the definition are potentially covered since it depends of the methodological question.

Consequently, *RCIS focuses on models, languages, notations, methods, techniques, and tools that support any activity related to the following phases of information science: analysis, collection, classification, manipulation, storage, retrieval, movement, dissemination, and protection of information [12].*

WHAT IS RCIS NOT?

While the RCIS conference partially overlaps with other venues existing in other areas, such as those of information systems, it does not necessarily address the technological aspects underlying information science, but rather how it is actually designed, modeled, perhaps programmed, deployed, used, and tested. For instance, RCIS could address aspects related to data storage, but not really its physical questions that are typically found in dedicated conferences, like Very Large Data Base (VLDB). In the aforementioned eight reference research topic, we identified several other venues that are overlapping with RCIS, actually at least one conference with each topic. The major difference resides in the focus on information science first and the adherence to the socio-technical perspective, including therefore the human and social perspectives. For example, in the domain of Data Science and Business Intelligence, a paper focusing purely on algorithm performance would be considered out of scope, whereas a paper focusing on optimising an algorithm's parametrization for a specific context of use would be in scope. Similarly, a paper focusing on the technical implementation of a business process enactment engine would be rather out of scope whereas a paper focusing on how to consider human and organisational aspects when implementing processes would be in scope.

RCIS 2019

RCIS stands for Research Challenges in Information Science. As such, the goal of RCIS is to bring together scientists, researchers, engineers and practitioners from a wide range of information science fields and provide opportunities for knowledge sharing and dissemination. RCIS has become a recognised conference on research challenges

in information science since its first edition back in 2007. Organised for the 13th time in a row, RCIS 2019 (see www.rcis-conf.com/rcis2019/) was held from May 29-31, 2019, in Brussels, Belgium, Capital of Europe. Since its inception, RCIS[1] is ranked as a B-class conference according to the Australian Computing Research and Education Portal (CORE) [2]. As such, it is ranked in major indexing engines, such as Scopus (with 682 papers indexed), DBLP [3], etc. This year, we ran the 13th edition of this conference, the first one organised in Belgium. For this purpose, it was jointly organized by two historic universities, which are sister universities: KU Leuven (www.kuleuven.be) and UCLouvain (www.uclouvain.be). Both universities have research teams actively involved in Information Science in general and Information Systems in particular. For example, LIRIS, the Research Center for Information Systems Engineering at KU Leuven (feb.kuleuven.be/research/decision-sciences-and-information-management/liris) and CEMIS at UCLouvain (uclouvain.be/cemis) both co-directed by the conference and program co-chairs. We hosted this 13th conference in Brussels, an ideal place for people to meet, exchange ideas, discuss, explore new avenues, strengthen existing collaborations, and establish new ones. RCIS 2019 was the first RCIS conference to obtain the technical endorsement of the Computer Society of IEEE (Institute of Electrical and Electronics Engineers). This competitive endorsement represented a great achievement to promote RCIS as a high stand conference in the scientific community.

We were happy to receive for this edition 66 submissions for the main conference, including research papers, practitioner/experience papers and work-in-progress papers. Submissions were received from literally all corners of the globe through EasyChair, an open source conference management system. There were submissions from newcomers to the field as well as from established scholars in the domain. Each paper was sent to three anonymous reviewers who scrutinised them using rigorous criteria of scientific quality to uphold the standard we are used to for RCIS. In total 123 program committee members were involved in the review process. Each paper received at least 3 reviews and, in case of doubt, a meta-review by a member of the organizing committee. All papers submitted to RCIS were carefully discussed during the Face-to-Face Program Committee meeting, which took place in Leuven on Friday March 29th, 2019. Their serious work eventually resulted in the acceptance of 45 papers broken down as follows:

- 19 full papers, 2 short papers, and 13 Work-in-Progress papers from a total amount of 66 submissions, i.e., an acceptance rate of 28% (or 35% including the short papers). This acceptance rate is quite aligned with the previous editions.
- 5 posters.

[1]See http://portal.core.edu.au/conf-ranks/1192/ for more information.
[2]See http://portal.core.edu.au/conf-ranks/
[3]See https://dblp.org/db/conf/rcis/index.



Fig. 1. The 110 most frequent keywords used in RCIS'2019.

- 2 tutorials accepted form their respective submissions.
- 4 Doctoral Consortium papers accepted from their respective submissions.

Fig. 1 gives an idea of the contents of the RCIS'2019 proceedings based on the 110 most frequently used keywords in the 46 papers published.

A Submitter's Guide to RCIS conference

While RCIS is in progress, future editions of this conference await contributions from the community. As the community is growing and attracting new researchers and practitioners interested in aspects that relate to engineering interactive systems, we believe that it is important to present them with an overview, in the form of a practical guide, regarding the types of contributions that are usually expected by the members of the RCIS community. We provide in the following a list of contributions relevant to RCIS together with example of papers published at previous RCIS events or in this edition:

1) **Information Systems and their Engineering**.

> ✍ **Example:** Corentin Burnay and Ivan Jureta. 2019. How Do Judgmental Heuristics Influence Elicitation In Requirements Engineering? A Research Roadmap. In *Proceedings of the 13th International Conference on Research Challenges in Information Science (RCIS '19)*. IEEE Computer Society Press, USA.

> ✍ **Example:** Yves Wautelet, Samedi Heng, Manuel Kolp, Isabelle Mirbel and Stephan Poelmans. 2016. Building a rationale diagram for evaluating user story sets. In *Proceedings of the 10th International Conference on Research Challenges in Information Science (RCIS '16)*. IEEE Computer Society Press, USA.DOI: http://dx.doi.org/10.1109/RCIS.2016.7549299 [14]

2) **User-Centred Approaches**.

> ✍ **Example:** Audrey Sanctorum and Beat Signer. 2019. A Unifying Reference Framework and Model for Adaptive Distributed Hybrid User Interfaces. In *Proceedings of the 13th International Conference on Research Challenges*

in Information Science (RCIS '19). IEEE Computer Society Press, USA.

✍ **Example:** Vivian Genaro Motti and Jean Vanderdonckt. 2013. A computational framework for context-aware adaptation of user interfaces. In *Proceedings of the 7th International Conference on Research Challenges in Information Science (RCIS '13)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2013.6577709 [7]

3) **Data and Information Management**.

✍ **Example:** Giancarlo Guizzardi, Guylerme Figueiredo, Maria Hedbloom and Geert Poels. 2019. Ontology-Based Model Abstraction. In *Proceedings of the 13th International Conference on Research Challenges in Information Science (RCIS '19)*. IEEE Computer Society Press, USA.

✍ **Example:** Bouchra El Idrissi, Salah Bana and Karim Bana. 2013. Automatic generation of ontology from data models: A practical evaluation of existing approaches. In *Proceedings of the 7th International Conference on Research Challenges in Information Science (RCIS '13)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2013.6577694 [3]

4) **Business Process Management**.

✍ **Example:** Tahir Ahmad and Amy Van Looy. 2019. Process mining in logistics: The need for rule-based data abstraction. In *Proceedings of the 13th International Conference on Research Challenges in Information Science (RCIS '19)*. IEEE Computer Society Press, USA.

✍ **Example:** R. M. E. Ruud van Cruchten and H. Hans Weigand. 2018. Process mining in logistics: The need for rule-based data abstraction. In *Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS '18)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2018.8406653 [13]

5) **Domain-specific Information Science Engineering**.

✍ **Example:** Jonathan Crusoe, Anthony Simonofski, Antoine Clarinval and Elisabeth Gebka. 2019. The Impact of Impediments on Open Government Data Use: Insights from Users. In *Proceedings of the 13th International Conference on Research Challenges in Information Science (RCIS '19)*. IEEE Computer Society Press, USA.

✍ **Example:** Fabiano Francesconi, Fabiano Dalpiaz and John Mylopoulos. 2015. Models for strategic planning: Applying TBIM to the Montreux Jazz Festival case study. In *Proceedings of the 9th International Conference on Research Challenges in Information Science (RCIS '15)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2015.7128884 [2]

6) **Data Science**.

✍ **Example:** Ana Len Palacio and Oscar Pastor Lpez. 2018. From Big Data to Smart Data: A Genomic Information Systems Perspective. In *Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS '18)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2018.8406658 [8]

✍ **Example:** Nicolas Kuchmann-Beauger, Falk Brauer and Marie-Aude Aufaure. 2013. QUASL: A framework for question answering and its Application to business intelligence. In *Proceedings of the 7th International Conference on Research Challenges in Information Science (RCIS '13)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2013.6577686 [5]

7) **Information Infrastructures**.

✍ **Example:** Monika Kaczmarek-Hess, Qin Ma and Iván S. Razo-Zapata. 2018. Modeling in support of multi-perspective valuation of smart grid initiatives. In *Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS '18)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2018.8406650 [4]

✍ **Example:** Jacques Simonin and Sbastien Bigaret. 2013. Business alignment-based data warehousing physical design driven by models. In *Proceedings of the 7th International Conference on Research Challenges in Information Science (RCIS '13)*. IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2013.6577688 [11]

8) **Reflective Research and Practice**.

✍ **Example:** Nadine Mandran, Sophie Dupuy-Chessa. 2018 Supporting experimental methods in information system research. In *Proceedings of the 12th International Confer-*

> *ence on Research Challenges in Information Science (RCIS '18).* IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2018.8406654 [6]

> ✍ **Example:** Milan Schramm, Maya Daneva. 2018 Implementations of service oriented architecture and agile software development: What works and what are the challenges? In *Proceedings of the 12th International Conference on Research Challenges in Information Science (RCIS '18).* IEEE Computer Society Press, USA. DOI: http://dx.doi.org/10.1109/RCIS.2016.7549345 [10]

Of course, these are only some examples among many other ones. It is also possible to submit a paper involving more than one area. For instance, [1] falls in the intersection of "user-centred approaches" and of "business process management" since it addresses the problem of mapping BPMN models to patterns for Graphical User Interfaces supporting these business processes while [14] concerns user experience and rationale for agile systems development or [10] deals with reflective aspects of infrastructure and information systems engineering.

To conclude

As the use of information systems is pervading an increasing number of aspects of our society, we are strongly convinced there are still a large number of interesting challenges that deserve our researcher's attention, especially relating technology to it's social and human aspects. We look forward to the next edition and encourage all researchers to submit their best papers to RCIS 2020 and to encourage their fellow researchers to do the same.

The fourteenth edition of the International Conference on Research Challenges in Information Science, RCIS 2020, will take place in Limassol, May 20 - 22. All information and deadlines are available from the RCIS website (see http://www.rcis-conf.com/rcis2020/). **See you all in Cyprus!**

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Keynotes

A Refinement Calculus for Requirements Engineering Based on Argumentation Semantics

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***Abstract*—The requirements problem consists of transforming stakeholder requirements - however informal, ambiguous, conflicting, unattainable, imprecise and incomplete – into a consistent, complete and realizable specification through a systematic process. We propose a refinement calculus for requirements engineering (CaRE) for solving this problem, which is inspired by the typically dialectical nature of requirements activities. The calculus casts the requirement problem as an iterative argument between stakeholders and requirements engineers, where posited requirements are attacked for being ambiguous, incomplete, etc. and refined into new requirements that address the defect pointed out by the attack. Refinements are carried out by operators provided by CaRE that refine (e.g., strengthen, weaken, decompose) existing requirements to eliminate the defect under attack, to build a refinement graph. The semantics of refinement graphs is based on the notion of acceptable argument in Dung's argumentation theory.**

***Index Terms*—RCIS 2019, Keynote, Refinement Calculus, Requirements Engineering, Theory of Argumentation, Argumentation Semantics.**

This is joint work with Yehia ElRakaiby, Alessio Ferrari and Alex Borgida.

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Towards a Digital Business Operating System

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***Abstract*—The digital transformation requires companies to change their operating system from a traditional to a digital one. This implies changes to business models, the business ecosystem, the architecture of products, the ways of working, the structure of the organization as well as the basic organizational culture. In this paper, we present our perspective on the operating system that digital companies employ consisting of five dimensions, i.e. speed, data, artificial intelligence, empowerment and ecosystems. For each of these dimension, we present the typical stages that companies evolve through while undergoing the transformation. The contribution of the paper is that it provides a holistic, integrated framework that allows companies to define desired state, assess current state and plan the necessary steps to transition.**

***Index Terms*—Research and development management, data systems, artificial intelligence, ecosystems**

I. Introduction

With the increasing prevalence of software, data and artificial intelligence (AI), the key elements of digitalization, companies are reaching an inflection point. Although the need for change in business model, management approach and technology strategy has been building slowly for decades, we now are reaching a point where transformation will be sudden and disruptive.

One of the more profound indicators of increasing industry disruption is the increasingly rapid turnover in the Fortune 500 list of companies. According to research [4], the average tenure of companies on the list is now down to 10 years from 35 years in the 1990s. This illustrates the difficulty that many companies experience when confronted with the digital transformation.

So, why is it so complex to address the digital transformation? One of the reasons is that it initially tends to hide as a new technology. Whether it is software, data or AI, from a general management perspective, it looks like yet another technology that R&D has to contest with but that does not affect the rest of the organization in any meaningful way.

Of course, today we know that the assumption that technology can be incorporated in isolation is entirely incorrect. Virtually all innovations start with the creation and broad availability of a new technology. Over time, this new technology then changes business models as well as business strategy, the architecture of products, systems and services, ways of working, processes and tools as well as the organizational structure of the company.

The point is not that digital technologies are so disruptive in nature. These technologies are, but there have been several disruptive technologies in the past that significantly affected industry and society. The key challenge today is that society as well as industry as a whole is able to absorb new, disruptive technologies at a significantly accelerated rate and traditional, typically hierarchically organized companies, are experiencing significant challenges in absorbing these changes and quickly before they are disrupted by competitors.

The key challenge of traditional companies is that these use an outdated business operating system. This is exacerbated by the fact that most research focuses on a specialized and narrow aspect of a technology or process. Although this is generally how research progresses, there is a need for a holistic perspective that brings together contributions from different sub-fields and integrates these into a holistic framework. We need a novel, digital business operating system for companies that seek to continue to be successful.

Digitalization is a topic that has received vast amounts of attention in industry, governments and society at large. Although one can naively view the adoption of and transition to the use of digital technologies as a purely technical issue, the reality is that the effects of digitalization are far-reaching and affect ways of working, organizational structures and the way the company interacts with others in its business ecosystem.

In this paper, we define digitalization as the implications of the adoption of digital technologies, specifically software, data and artificial intelligence (AI). These digital technologies allow for the emergence of a new business operating system. This digital business operating system has five dimensions, i.e. speed, data, AI, ecosystems and empowerment.

The contribution of this paper is that it provides a holistic framework combining the aforementioned five dimensions into a framework that companies can use to assess their current state and to decide on the next improvement steps. The framework is based on a decade of research in the context of Software Center, a collaboration between, at the time of writing, 13 companies and 5 universities focused on accelerating the pace of digitalization of the European software-intensive systems industry.

The remainder of the paper is organized as follows. In the

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next section, we discuss the main trends that are driving the adoption of digital technologies. In section III, we discuss digitalization and its primary implications. Then, in section IV, we present the five dimensions of the digital business operating system. Finally, we conclude the paper in section V.

II. Trends

When studying the Gartner technology hype cycle [7] for 2019, it is obvious that software is eating the world. Virtually every technology on the hype cycle, ranging from augmented reality to connected homes and from autonomous cars to deep neural nets, is driving by software. This is affecting every industry including automotive, defense, robotics and even construction. Whereas earlier the ability to build mechanical solutions was the key differentiator, these days it is the ability to use software effectively.

The consequence of software increasingly being the differentiator is that the size of software is going up with an order of magnitude every five to ten years [5]. The challenge that companies experience is that an order of magnitude in difference in software size requires fundamentally different software architectural approaches, different ways of working as well as different tool sets. The consequence is a tendency in companies to continuously reinvent their approach to R&D to meet the challenge.

A second major trend is the constant increase in the amount of data that is generated, stored and used in the world. According to a recent Forbes article, 2.5 quintillion (that's 18 zeros) bytes of data are created every day [6]. All this data, obviously, is created and stored for a reason: to derive information about users and systems in the field in order to make better decisions, optimize the performance of systems and to dynamically adjust behavior to the specific context in which the system is used.

The third major trend concerns artificial intelligence and specifically machine- and deep learning. The amount of data in the world combined with algorithmic improvements as well as novel hardware architectures such as GPUs and FPGA configurations for machine learning allow novel, real-time ways to classify, predict and generate information that is as good or even better than what humans are capable of.

The final trend is not necessarily novel, but it has a fundamental effect on industry and business: speed. Customer adoption of novel technologies, products and services is constantly accelerating. Whereas it took the world 12 years to reach 50 million mobile phone users, it took WeChat only a year and Pokemon Go reached this milestone in 19 days. This means that companies using a "fast follower" innovation strategy will have real difficulty keeping up. Even innovation leaders will long development cycles will be challenged by the fast evolution of customer interest, both in B2C and in B2B contexts.

Concluding, the trends of ever growing software size, ever increasing amounts of data, the fast adoption of machine- and deep learning and the constantly accelerating innovation adoption speed have a profound impact on society, industries and companies.

III. Digitalization

Digitalization is the use of digital technologies to change business models and to create new value producing opportunities, according to Gartner. In this paper, we define digitalization as software, data and AI, the key trends that we discussed in the previous section. Although this is easy to understand at a high level of abstraction, it often is difficult to concretize and apply to ones own business.

In our research into digitalization, we have identified three implications that companies transitioning from a traditional to a digital business tend to experience. As shown in figure 1, these are the transition from customers owning your product to accessing your product as a service, from selling physical products to monetizing through digital means and from a one-dimensional business model to a multi-dimensional business model. Below we discuss each of the transitions in more detail.

The first transition is concerned with the change in ownership model of products and systems. Traditionally, customers would buy a product, use it for the duration of its economic life and then buy the next instance of the product. This product was typically a bit better because of technological innovation and these improvements were used to convince the customer to switch to the new product and to keep competitors at bay. With the emergence of digitalization, the business model also changed to increasingly focus on access rather than ownership. So, customers want, through different models, have access to the system or product, but are less interested in actually owning it. The primary change in this context is that the customer relationship changes from a transactional one to a continuous one, i.e. rather than interacting with the customer every few years to convince the customer to upgrade to the newest system, the company now is in a continuous interaction with the customer.

The second change is concerned with the business model. Although one could assume a simple transition from an ownership to a leasing model, digital technologies allow for very different types of monetization. One example is the pay-for-use model where the customer only pays when using the system. Alternatively, quality-of-service contracts provide more of an outcome-oriented way of monetizing. Traditionally, service-level agreements were mostly used to instill fines on suppliers that did not deliver up to the necessary levels, but obviously the model can equally well be used to monetize for service delivery above the minimal level. Of course, quality-of-service contracts require the collection of data about the operations at the customer and this allows for additional business models where the company can offer its customers support for operational improvements based on the insights generated by the data.

The third transition is a complicated one that many companies struggle with. Traditionally, most companies used a one-dimensional business model where they would sell a product to a customer and this customer paid the company. Due to

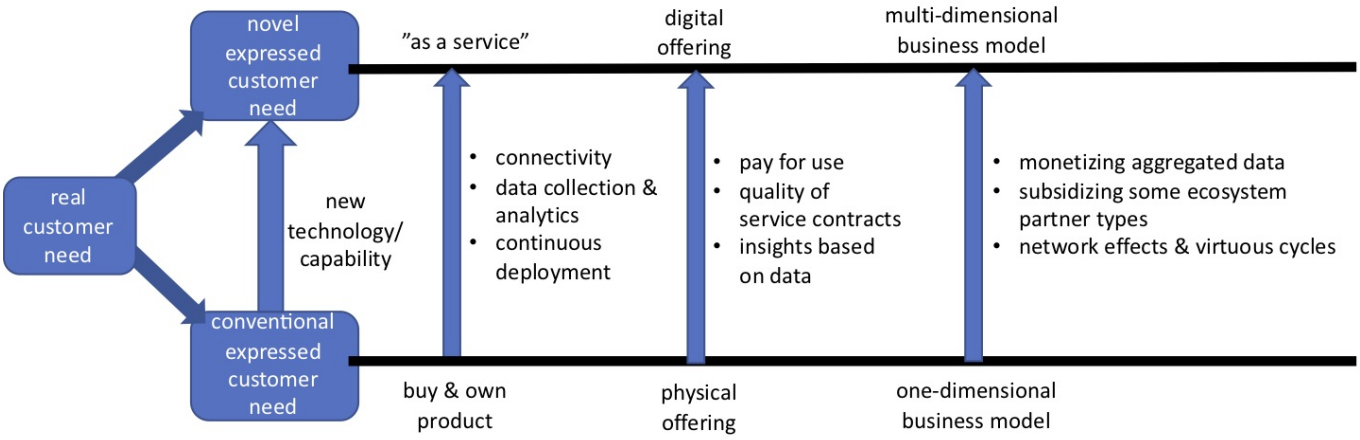


Fig. 1. Three implications of moving to a digital business

digitalization and the increasing availability of data, several companies are now able to collect data from their traditional customer base and monetize this data with a second customer base that is interested in acquiring the aggregated data. This can easily lead to a positive feedback cycle: a company that can monetize the data from its primary customer base can subsidize its offering to that customer base, which will lead to an increased market share. This will, in turn, lead to more data being available to the company which makes the data more valuable. This increases revenue from the second customer base which can then be used to further subsidize the offering to the primary customer base, leading to increased market share. And so on. It is clear that any company that figures out the transition from a one-dimensional to a multi-dimensional business model can easily out-compete its competitors in this way. This pattern explains why digital industries often experience a winner-takes-all situation where there is one company that enjoys massive market share.

The implications of digitalization discussed above cause a fundamental shift in the operations of digital companies as compared to traditional ones. Our research shows that digital companies are different in at least eight aspects:

- **Data driven decision making**: Although no company will claim to make decisions by the seat of their pants, in practice, in many companies, decisions are to a large extent driven by the opinions of senior leaders. Digital companies follow the principle defined by Edwards Deming - in God we trust; all others must bring data. Very few decisions in digital companies are taken without a validated empirical grounding. This results in a significantly higher quality of decisions as it functions as a natural antidote against the shadow beliefs that are prevalent in many organizations.
- **Relentless experimentation**: As in many cases, data for decision making is not available, digital companies employ rigorous experimentation. Examples include A/B testing, cross-over experiments and dark launches, but the fundamental principle is that in situations where data for decision making is lacking, rather than jumping to a decision based on experience and beliefs, digital companies plan and execute experiments to collect the necessary data.
- **Short feedback cycles**: Due to the long cycles that traditional companies experience when building mechanical products, the feedback cycles for decisions in these companies are often measured in years. Digital companies, in contrast, look to continuously accelerate and shorten the feedback cycle to the point that, ideally, one has feedback on ones decisions within hours, days or weeks.
- **Decision making pushed down in organization**: Traditional companies typically are highly hierarchical in their organization and most decisions affecting the business are pushed up the hierarchy. Digital companies use the opposite pattern and push decision making authority down in the organization. The underlying belief is that the team closest to the data is also optimally positioned to take the necessary decisions. Although there obviously are decisions that are still left to the senior management, the authority for the vast majority of decisions is pushed to teams.
- **Strategic data collection**: As digital companies seek to take data-driven decisions, these companies employ strategic collection of data. This requires key people in the company to predict which decisions will likely be necessary in the foreseeable future and to initiate the collection of data pertaining to those decisions already now. This is a powerful tool to accelerate decision making as it avoids the situation where the company has to wait with making a decision because the data is not yet available.
- **Unified data warehouse**: Traditional companies tend to spread their data across the organization and each team and department has its own data store. Digital companies, instead, collect all data in a single, unified data warehouse. Even if it doesn't address all challenges with respect to the semantics of the data, using data

collected by others in the organization is much simpler if all data is in a single location.

- **Pervasive automation**: Especially manufacturing companies tend to view humans as cogs in machines and love to employ repeatable processes for human work. Digital companies typically seek to automate all activities that are even remotely repetitive. Humans are used for what they are uniquely good at: creative problem solving in new situations. Machines are used for everything that is repeatable and can be described in a process.
- **New job descriptions**: Finally, even if traditional and digital companies often have the same job titles, the actual job description of especially new types of jobs such as data scientists is fundamentally different in digital companies. For instance, a data scientist in a traditional company often operates in a staff function advising key decision makers. In a digital company, a data scientist is part of a multi-disciplinary team, or may even lead a team, that has significant authority to operate independently. The data scientist can make decisions, together with the team.

IV. Digital Business Operating System

Digitalization and the technologies and trends that drive the digital transformation require companies to respond. One can take a victim role and let the wave of change crest over the company and hope for the best, but in practice it typically is preferable to take charge of ones destiny and to proactively implement the necessary changes.

In our research, we have, for the last decade, studied the necessary steps that companies should take in response to the digitalization of their respective industries. Based on this research, we have come to the realization that digital companies use a completely different operating system when compared to traditional companies. Companies, just like computers, execute an operating system in terms of the norms, values, expectations, ways of working, organizational architecture, etc. In table IV, we discuss the difference between these business operating systems.

The table indicates the key challenge that companies undergoing a digital transformation have to contend with: the change literally affects every aspect of the company. Every function, every department and every individual is affected by the shift from a traditional to a digitalized business. Not only that: it also requires that every part of the organization changes with a certain or significant level of alignment as otherwise the intended changes will be impossible to realize. A typical example in this context is that the R&D organization prepares a service offering to complement the product offerings that the sales organization is completely unprepared for and incapable of selling.

Based on our research, we have defined five dimensions of the digital business operating system (DBOS), i.e. speed, data, AI, empowerment and ecosystems. In the next sections, we first define each of these dimensions and then describe how companies typically evolve through for this dimension. Where relevant, we discuss the dependencies between the dimensions.

A. Speed

One of the key challenges of virtually any company and organization is responding sufficiently fast to requests from customers and changes in the market place. For software-intensive systems companies, this typically translates into developing approaches to release software more frequently. This allows the company to shorten the time from the identification of a customer need to the delivery of a solution meeting that need.

In our research, we have studied how companies evolve over time in response to the demands of accelerating their speed. As companies transition from traditional to digital, companies evolve through several stages. In [9], we captured this in a five step model that defined the speed dimension of the digital business operating system. This model is presented graphically in figure 2. Below, we discuss each of the steps in more detail:

- **Traditional Development**: While the company is in the traditional state, it will experience slow development cycles. Often, software is released yearly and in some cases even less frequently. The development cycle is driven by requirement specifications instead of through communicating with customers. Finally, most companies experience a difficult to plan release process as all testing is conducted at the end of the development cycle and many issues may surface without the awareness of the company.
- **Agile Development**: The first step that companies take when looking to accelerate is to adopt agile development practices. Agile has been a popular approach for many years now and it is broadly viewed as the state-of-the-art approach to software development. The key element of agile is the notion of a sprint. The length of a sprint is typically two or three weeks and the intent is that, at the end of every sprint, value adding functionality has been created that, in principle, is self-contained and could be delivered to customers.
- **Continuous Integration**: Whereas agile practices typically focus on the development process, the step after that is typically concerned with ensuring quality. Continuous integration is concerned with verifying every check-in of code and ensuring that the code base is at production quality at all times. This is different from traditional development where the quality of the software is ”tested back in” after a long period of development.
- **Continuous Deployment**: Once the R&D organization has its testing practices under control and has reached a state where the software is always at production quality, the next step is to embrace continuous deployment. In this case, the software is deployed in the field with customers at the end of every agile sprint (potentially after an additional testing period). Once this stage is reached, the system gets better ”every day”. The notion of

	Traditional	Digitalized
Business	Transactional model where customers buy products periodically (typically every couple of years).	Continuous value delivery model based on services; monetization through KPIs and expectation of continuous improvement.
Ecosystem	One dimensional value network from suppliers to product company to customer.	Multi-dimensional business network with multiple avenues for monetization using products, data and other assets.
Architecture	Deeply integrated architecture optimized for minimal bill of material cost. Focus is on freezing the architecture after design and a "big bang" release.	Modularized architecture separating parts that evolve at different frequencies through APIs (mechanics, electronics, software). Focus is on facilitating continuous evolution and release.
Process	Process dictated by mechanical design and manufacturing constraints. Focus on planning and prediction in order to minimize cost due to late changes and quality issues.	Process focused on fast feedback loops facilitated by continuous deployment and data streams. Focus on experimentation and continuous learning.
Organization	Hierarchical organization with functionally organized departments. HIPPO-based escalation paths to iron out conflicts due to local optimization.	Empowered, cross functional teams responsible for different aspects of value delivery. Cross-team coordination through architecture evolution.
Culture	Atoms-over-bits mindset; tendency for local over global optimization. "I'm responsible for doing my job well; nothing else".	Bits-over-atoms mindset. Deliver on the company mission and take on responsibilities based on what is needed rather than job description.

TABLE I
COMPARING TRADITIONAL AND DIGITALIZED ORGANIZATIONS

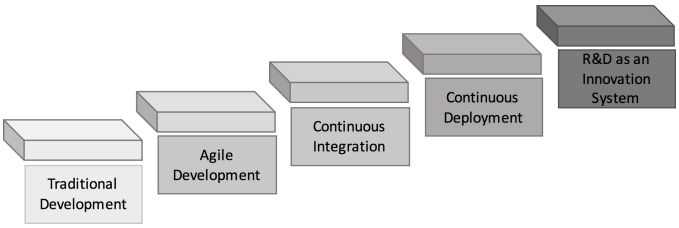


Fig. 2. The Speed dimension of DBOS

a continuously improving system is one of the hallmarks of a digital company.

- **R&D as Innovation System**: The final stage is where the company uses the ability to conduct continuous deployment as an enabler for a more experimental way of development. For new functionality, when it is not clear what is the right way of realizing this functionality is, the company can conduct A/B experiments or other forms of experimentation to validate which realization resonates best with customers, performs best in the systems in the field or yields the best business outcome for the organization.

B. Data

One of the key enablers of the digital transformation is the unprecedented availability of data as well as our constantly improving ability to process large amounts of data and use these for various purposes. These purposes are varied but are typically concerned with better decision making, either because of the higher information content available or by increasing the frequency of decision making in order to have a more optimal choice for each decision point.

Data is one of the most misunderstood commodities in the entire digital transformation. Especially leaders in traditional companies find it extremely difficult to even imagine a world where the data generated by physical products has value beyond, perhaps, quality control. Several "born digital" companies are currently selling hardware at or below cost because of the value of the data generated from the products or the ability to offer services that would otherwise not be available. This illustrates that these companies have found mechanisms to monetize their data to a point that it is subsidizing the physical products.

In practice, data is, among others, used to manage quality of deployed products, to improve decision making in R&D, to inform decision making at the general management level, to facilitate novel business models and to be monetized with the current or other customer bases. There are many other cases where data is used for the benefit of the company.

As part of our research [11], we have seen that companies evolve through several stages as they adopt data-driven practices. Below, we discuss these stages in more detail.

- **Ad-hoc**: The first stage is where any effort to adopt data-driven decision making is conducted in an ad-hoc fashion. This means that the collection of data, the analysis of it, reporting as well as the final decision making is all conducted manually. As one has to initiate an entire machinery whenever deciding to take a data-driven approach to a decision, the result is a significant amount of effort being expended. This requires the goal of the initiative to be quite significant in terms of revenue and importance for the company. This causes the use of data to be used only in exceptional cases and the remainder of the decisions are conducted as traditional, opinion-based decision processes.
- **Collection**: The second stage is where the company decides that it is worthwhile to at least collect the data automatically in order to have it available for any type of analysis and hypothesis testing that individuals in the organization can come up with. This means that although the collection of data is automated, analysis, reporting and decision making is still conducted manually. Even if

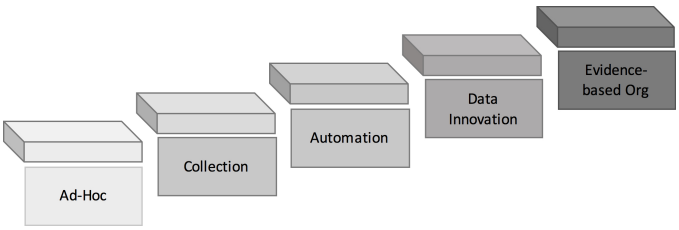


Fig. 3. The Data dimension of DBOS

this is a significant step forward, experience shows that the availability of data does not automatically cause an increase in the adoption of data-driven decision making. For many, the required effort is still considered to be too significant.

- **Automation**: The third stage is concerned with automation of the entire process of collection, analysis and reporting with the intent of supporting decision making with standard reporting activities. In many companies, this results in the presence of dashboards that are available to everyone in the company, such as the dashboards used by agile software development teams, or to key decision makers. In many companies, the definition and creation of dashboards is a one time effort.
- **Data innovation**: As dashboards showing live data are concerned with the real world, the challenge is that the real-world evolves and the dashboard does not. The consequence is that quite soon, the dashboard becomes less and less aligned with the real world and, as a result, the quality of decision making automatically starts to deteriorate. In addition, the company will constantly develop its understanding and insights of the market. Consequently, there is a desire to change the available dashboards to reflect the new insights. The fourth stage is concerned with establishing this process. In this stage, data scientists are continuously looking for novel relevant correlations in the data. Once a new correlation is found, it is presented to the relevant management or R&D team and if the team decides to adopt this new insight on its dashboard, an older, outdated view on the dashboard is removed. This leads to continuously evolving dashboards in the company that are aligned with the evolving real-world and the developing understanding and insight in the company.
- **Evidence-based organization**: The final stage is where every decision process in the company is data-driven, including performance reviews, sales processes, HR processes, etc. In this case everything in the company is data-driven and the culture is defined by Edwards Deming's motto: "In God we trust, all others must bring data."

C. Artificial Intelligence

Although artificial intelligence has been a subject of study for decades, it is during recent years that especially machine learning (ML) and deep learning (DL) have evolved to a state of maturity that allows for the techniques to be broadly deployed in industry. One reason for this rapid adoption of AI/ML/DL is the availability of data due to the "Big Data" era. Although initially intended for human data analytics, the data sets that are now available are often quite suitable for training ML/DL models as well.

The second reason is the availability of computation hardware, such as GPUs and FPGAs, that are uniquely suited for the type of computation required for large scale neural networks. These networks benefit from the massive parallelism provided by these computing architectures.

In our research [1], [8], we have identified that companies that start to employ artificial intelligence and specifically machine- and deep-learning evolve through several stages. In figure 4 and the text below, we describe these stages in more detail.

- **Experimentation and prototyping**: The first stage of adopting artificial intelligence typically is concerned with experimentation and prototyping. The company has data available, thinks that there might be value in the data and the associated ML/DL models and, to prove the point, experiments with ML/DL models with the intent of building a prototype. This prototype typically works on a static data set and is disconnected from the day-to-day operations of the system or systems that the ML/DL model could be deployed in.
- **Non-critical deployment of ML/DL components**: Once one or more promising prototypes have been developed, the next stage is to deploy a first ML/DL component in an operational system, but to do it in such a way that the ML/DL component can support but not break the system completely. This means that even if the ML/DL component is failing to deliver, the system is still operational and not critically dependent on any ML/DL functionality.
- **Critical deployment of ML/DL components**: Once the confidence in the organization grows, the next step is to deploy ML/DL components in critical deployments where the lack of performance of the component will also hurt the system performance overall. At this stage, the company can be said to truly have adopted artificial intelligence as part of its offering.
- **Cascading deployment of ML/DL components**: The next step for the company is to develop architectures where the output of one ML/DL component is the input for the next one. This is sometimes referred to as "ensembles". At this point, we reach the stage of cascading deployment of AI components and the complexity of logging, monitoring and troubleshooting goes up significantly. As a consequence, the AI maturity of the company needs to evolve as well.
- **Autonomous ML/DL components**: The final stage is where ML/DL components are designed to be autonomous, meaning that these components are able to monitor their own performance, retrain themselves based on new data as it becomes available and to alert the

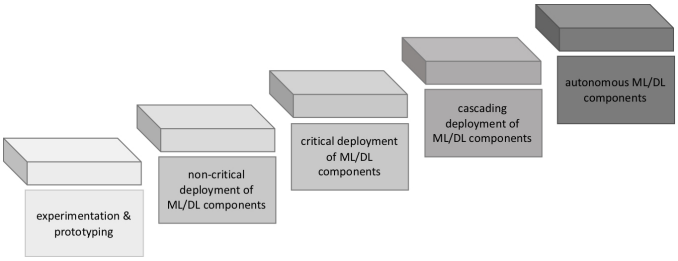


Fig. 4. The AI dimension of DBOS

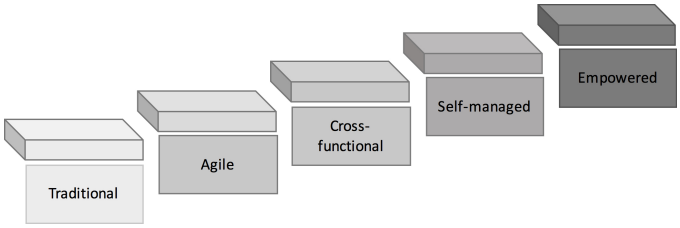


Fig. 5. The Empowerment dimension of DBOS

company when there is evidence that shows that the model is not longer performing as required.

D. Empowerment

As we indicated in the introduction of the paper, digital companies are different from traditional companies in several ways and one of the dimensions is the way teams work and are organized. The primary difference is that in digital companies teams are empowered to take decisions without the approval of senior managers as long as the decision is based on empirical data.

As a concept, the notion of empowered teams is broadly used and discussed, but the reality is that in traditional companies teams are about as empowered as the length of the leash that senior managers give the teams. This leash can easily be pulled back when management feels that teams are not delivering. Although this can be viewed as a normal way of operating, managers often operate on limited information and can easily make incorrect decisions.

In our research on empowerment [10], [13], we have identified several stages that companies evolve through as they seek to adopt higher degrees of empowerment. These stages are shown graphically in figure 5 and described in more detail below.

- **Traditional**: The starting point for most companies is the traditional, hierarchical organizational model. Here the hierarchy is used for decision making and information sharing. Every relevant decision is pushed up the hierarchy until it reaches a level where the manager is authorized to make the decision. Once the decision has been taken, it is communicated along the hierarchy downwards.
- **Agile**: The first step in the empowerment journey is the adoption of agile development practices. When adopting agile, teams obtain a significant level of empowerment within the boundary of the team. During sprint planning, agile teams commit to sprint content but can't be forced to accept whatever others feel is relevant. Similarly, the order in which things are build during the sprint is up to the team. Although other roles are involved during the planning activities, typically teams are highly autonomous and empowered during the sprint itself.
- **Cross-functional**: Once agile development teams are established, the next step is to include other functions in the same way of working. This may result in, for instance, product management to be empowered and working much closer with development teams and conducting A/B experiments rather than operating according to specifications defined by others.
- **Self-managed**: The fourth stage is where every function, role and team is self-managed, typically based on quantitative output targets. In this case, coordination of work occurs laterally rather than through hierarchies. Every individual and team is free to experiment with new ways of doing things as long as it coordinates with those affected.
- **Empowered**: In the fourth stage, everyone may be self-managed, but the culture in the company still makes people grasp for traditional, hierarchical decision mechanisms. Especially in organizations that originate from a hierarchical structure, the tendency to abdicate responsibility and to put it on someone else tends to be strong. In the final, fully empowered, stage, the culture of the company is such that everyone takes full responsibility for his or her role and acts with authority.

As we discuss in [13], the adoption of empowerment needs to be conducted carefully as offering empowerment without responsibility can easily lead to local optimization, lack of alignment and, in the worst case, chaos. Successful adoption of empowerment requires carefully defined, preferably quantitative output metrics for individuals and teams, so that it is clear what success at the company level entails and how team activities are expected to contribute.

E. Ecosystems

Although the term "ecosystem" is used extensively in academia and industry and consequently has become an overloaded term, the fact of the matter is that there is a fundamental shift ongoing in industry where most companies operate in an increasingly complex network of suppliers, partners, complementers, customers and users. Traditionally, a company would mostly focus on its customers and maintain a one-dimensional business model. Digital companies often maintain complex, multi-dimensional business models fuelled by data. These companies often have multiple customer groups and structures where the data generated by one customer group is aggregated, processed and monetized with other customer groups. In addition, digital companies are prone to focus their resources on the activities that are truly differentiating and to

rely on partners for all activities that are commodity. In earlier research, we have introduced the Three Layer Product Model (3LPM) [2] to describe this pattern.

In their engagement with the ecosystem around them, companies evolve through several stages that we have studied in our earlier research [3], [12]. In figure 6 as well as in the text below, we discuss these stages in more detail.

- **Internally focused**: Traditional companies tend to focus on conducting as much of the value adding process inside the walls of the company. The underlying idea is that it is difficult to rely on outside parties as these often have other incentives beyond serving their customer and hence there is high risk associated with relying on outsiders. In these companies, the goal is to keep every activity that isn't completely commoditized in-house and minimize dependencies on others.
- **Ad-hoc ecosystem engagement**: During the second stage, it is often individuals inside the company that get frustrated with slow moving internal processes and relying on departments that are optimized for scale and not responsiveness that decide to look outside the walls of the company to partner with other companies. This tends to happen in an ad-hoc and bottom-up fashion. The advantage is that, when these experiments are successful, the first positive experiences with collaborating with and relying on outside parties are accumulated.
- **Tactical ecosystem engagement**: Once some evidence is available that collaborating with partners can be a suitable engagement model for faster execution, access to competence or other reasons, the next step is that that the company adopts a tactical approach to engaging with ecosystem partners. Often related to a tactical goal and based on the desire to move quickly, the company selects to work with specific partners to capitalize on a specific opportunity.
- **Strategic single ecosystem engagement**: In the aforementioned 3LPM, we categorize all the activities in the company as resulting in commodity, differentiation or innovation. The company, in this stage, has selected often the commodity layer and strategically engages with one or more ecosystem partners to ensure that these partners provide the commodity functionality that the company needs. This allows the company to free up its own resources for differentiating work.
- **Strategic multi-ecosystem engagement**: Finally, in this stage, the company continuously evaluates from a strategic perspective what activities to conduct in-house, what activities to give to partners and what activities should be conducted in collaboration with others. Typically, the guideline is that differentiating functionality in products and services should be developed in-house as it allows to company to capitalize on its unique capabilities. Commodity work should be outsourced to the largest extent possible unless the cost of outsourcing outweighs the cost of performing these activities inside the company. Finally, innovation, being an expensive and risk-filled activity, should where possible be conducted in conjunction with others as it provides a mechanism to share costs and risks as well as to benefit from the creativity of others. The main challenge is that the company should be able to monetize successful innovations as part of its differentiation.

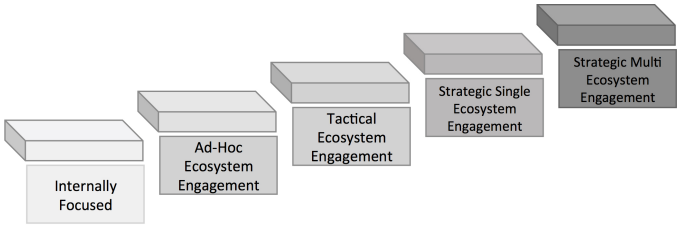


Fig. 6. The Ecosystem dimension of DBOS

V. Conclusions

With the increasing prevalence of software, data and artificial intelligence (AI), the key elements of digitalization, companies are an inflection point where transformation will be sudden and disruptive. Illustrated by the Fortune 500 list of companies where the average tenure of companies on the list is now down to 10 years from 35 years in the 1990s, it is clear that many companies struggle with the digital transformation of their industry.

One of the reasons that companies face difficulties in digitalizing their business is that it tends to hide as a new technology. Whether it is software, data or AI, from a general management perspective, it looks like yet another technology that R&D has to contest with but that does not affect the rest of the organization in any meaningful way. In practice, all innovation starts with the creation and broad availability of a new technology that then changes business models as well as business strategy, the architecture of products, systems and services, ways of working, processes and tools as well as the organizational structure of the company.

Digital technologies are not necessarily more disruptive than other technologies that in the past have affected industry and society. The key challenge today is that we absorb new, disruptive technologies at a significantly accelerated rate and traditional, typically hierarchically organized companies, are experiencing significant challenges in absorbing these changes proactively and before they are disrupted by competitors.

The premise of this paper is that traditional companies use an outdated business operating system that is due for replacement. Unfortunately, most research focuses on a specialized and narrow aspect of a technology or process and fails to provide a holistic perspective that brings together contributions from different sub-fields and integrates these into a holistic framework. In this paper, we have defined a digital business operating system for companies that is based on five dimensions of change, i.e. speed, data, artificial intelligence, empowerment and ecosystems.

The contribution of this paper is that we present a holistic model is based on more than a decade of research by dozens of researchers collaborating with more than ten international companies that are leading in their respective fields that companies can use to assess their current state and to decide on the next improvement steps. In that sense, the paper presents a map that allows companies to determine where they want to go and plan a path towards this desired state.

The digital transformation is a trend that invokes fear in the hearts of many business leaders, but our research shows that a conscious, systematic approach where companies build capabilities in a step-wise fashion can transform companies at a pace that is sustainable for those working in the company and that allows companies to avoid disruption.

ACKNOWLEDGMENT

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Towards Cross-Media Information Spaces and Architectures

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***Abstract*—The efficient management and retrieval of information via dedicated devices and data structures has been investigated since the early days of Vannevar Bush's seminal article *As We May Think* introducing the Memex. However, nowadays information is usually fragmented across different media types, devices as well as digital and physical environments, and we are often struggling to retrieve specific information. We discuss three main issues to be addressed when developing solutions for managing information in these co-called cross-media information spaces. First, we have a look at an extensible cross-media linking solution based on the resource-selector-link (RSL) hypermedia metamodel where information can be integrated across applications, devices as well as digital and physical information environments. We then outline some of the limitations of existing digital document formats which are often just a simulation of paper documents and their affordances on desktop computers, and discuss more flexible document representations for cross-media information spaces. Further, new forms of human-information interaction and cross-media user interfaces—including some recent work on dynamic data physicalisation—are discussed. A number of research artefacts are used to illustrate different aspects of the presented data-centric approach for cross-media information spaces and architectures. Last but not least, we provide an outlook on how the embedding of the presented concepts at the level of an operating system might ultimately lead to new possibilities for cross-media information management and innovative forms of human-information interaction.**

***Index Terms*—Cross-media technology, hypermedia, document engineering, human-information interaction, distributed user interfaces, personal information management, future file system**

I. Introduction

The efficient management and retrieval of information has been an issue since the early days of the printing press and the resulting increase of information in the form of paper documents. In his 1945 seminal article *As We May Think* [1], Vannevar Bush discussed the problem of managing and retrieving information from paper documents via hierarchical filing and classification techniques as used in offices and libraries at that time. The issue of getting lost in information space by the sheer amount of available information and the lack of tools for managing this information has later been coined as the problem of *information overload*.

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In his visionary article, Bush described the *mem*ory *ex*tender (Memex), a device that could be used to augment the human memory and intellect by storing and managing paper documents on microfilm. Rather than only using a hierarchical classification of information, he highlighted that the human mind works by association and proposed the use of *associative trails*, *"whereby any item may be caused at the will to select immediately and automatically another. This is the essential feature of the Memex. The process of tying two items together is the important thing."* [1] These associative trails (links) would be stored as separate metadata which could be as important as the information itself. Bush further proposed the new profession of *trail blazers* who would establish new useful trails to navigate through the massive amount of information.

Early hypertext pioneers such as Douglas Engelbart [2] or Ted Nelson [3] were inspired by Bush's vision and brought the idea of defining associations (links) between pieces of information to the digital age. Ultimately, also the World Wide Web, that most of us use for navigating information, is heavily based on the concept of hyperlinks between web pages. Note that hyperlinks as we know them from the Web show some limitations compared to the associative trails proposed by the Memex, given that they are embedded and form part of a document (web page). This implies that only the "owner" of a web page (a person with editing rights) can also add new links—it is not possible to have trail blazers who can add



Fig. 1: Cross-media information spaces

links between arbitrary web pages. Links can further not be easily shared in the form of separate metadata as envisioned in Bush's Memex.

While the Memex would help in managing and retrieving information from microfilm on a single device, today's information environments are more complex. Information is *fragmented across different media types, applications, devices as well as digital and physical environments* as illustrated in Figure 1. In these so-called *cross-media information spaces* we are facing three major challenges:

- *Cross-media linking*: How can we ensure that information that is managed by different applications or published to different devices can be linked in order that users can easily navigate across application and device boundaries? How can we further enable links between various media types, including digital as well as physical information? For example, if we print a web page, it should be possible to still follow any embedded links from the physical printout to the corresponding linked information.
- *Flexible document representation*: How can we represent documents in a flexible way in order that they can adapt to different media types, user needs or the devices they are accessed from? For example, a PDF document that is viewed on a desktop computer might change to an alternative graph visualisation of its text and images when moved to a tabletop computer. Note that different parts of a document may also be distributed over different devices and be concurrently accessed by multiple users.
- *Cross-media user interfaces*: How can we build more flexible user interfaces enabling richer interactions in cross-media information spaces? If we come back to our example of moving a document to a tabletop computer, parts of the cross-media interface to interact with the document might be offered by the tabletop while some user interface components could be provided by our smartphone that we have placed on the tabletop.

In order to address these challenges, we need a more *data-centric approach* where data is central and different metadata (e.g. navigational or structural metadata) can be defined on top of the underlying data. *Data as well as navigational and structural metadata should no longer be owned by individual applications* but be accessible to any application built on top of a cross-media information space. A simple example to illustrate the power of such a data-centric approach is the storage of an email attachment in our file system. While existing solutions do not keep track about the relationship between the stored attachment and the corresponding email, this metadata could be managed as an external link between the two resources and made available to any application. If we later access the stored attachment in our file system, we could easily get access to the original email content.

The ultimate goal when building architectures and solutions for cross-media information spaces is to provide the "glue" between different devices as shown in Figure 1, enabling the flow of flexible document structures between devices, the integration of documents across device boundaries via cross-media linking and the dynamic composition of distributed cross-media user interfaces for these documents. In the following sections we address each of the three major challenges mentioned above and discuss a data-centric approach for cross-media information solutions based on a hypermedia metamodel.

II. Cross-Media Linking

The resource-selector-link (RSL) hypermedia metamodel has been introduced by Signer and Norrie [4] for managing navigational as well as structural links across different media types. An overview of the main components of the RSL hypermedia metamodel is provided in Figure 2, but for the full metamodel the reader should refer to the original article on *As We May Link* [4].

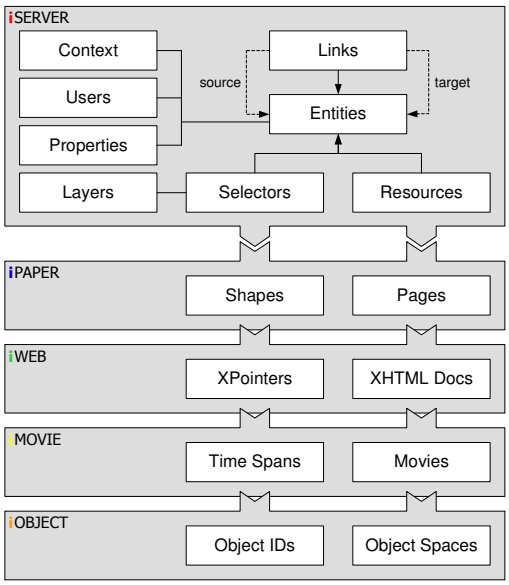


Fig. 2: RSL hypermedia metamodel overview

The three core RSL concepts are the `Resource`, the `Selector` and the `Link` which are all specialisations of an `Entity`. More general than in most existing hypermedia solutions, a link is treated as a first class object and can have multiple sources as well as multiple targets (entities). Further, links are always bidirectional which is different from what we, for example, know from the Web with its embedded unidirectional links. A `Resource` is an abstract representation of a piece of information and concrete implementations (plug-ins) have to be provided for different media types (e.g. HTML documents or movies). It is important to note that as soon as a media type is supported via a new plug-in, it can be linked with any of the already existing media types. Often we do not want to link an entire resource and therefore a `Selector` allows us to address parts of a resource. Each selector is further associated with a layer, which enables multiple overlapping selectors with some well-defined semantics. Given that links are entities, we can, for instance, also define a link that has one or multiple other links as source or target.

Another important feature of the RSL hypermedia metamodel is its integrated user management where each entity (i.e. resource, selector or link) has exactly one creator and where access rights can be defined for other users at the level of an entity. Not only these access rights might determine whether and entity is accessible or not, but the RSL metamodel also offers the concept of *context resolvers* which can be attached to entities in order to support context-dependent adaptation. Last but not least, properties represent some general metadata in the form of key/value pairs that can be attached to entities. While it is out of the scope of this paper to describe all the features of the RSL hypermedia model, more details can be found in [4].

Over the past 15 years, a number of plug-ins for different media types have been realised for the RSL hypermedia metamodel and the corresponding iServer link service implementation by Signer and Norrie [4]. This includes the iPaper plug-in [5], [6] for interactive paper solutions [7], the iWeb plug-in [4] for enhanced linking on the Web, the iMovie plug-in [5] for linking parts of movies or the iObject plug-in [8] for linking physical objects in Internet of Things (IoT) environments.

The tight integration of information across the digital and physical space via cross-media linking has been illustrated in various applications, in particular in the domain of interactive paper solutions and the mapping of paper and digital documents [9]. The EdFest paper-digital festival guide by Signer et al. [10], [11] highlights various aspects of cross-media publishing and linking. While the festival data is stored in a content management system, it can be published as a website, an automatically generated PDF booklet for later printing or as voice output. It is further not only possible to link from paper to digital information but also from paper to paper or from digital information to paper. In addition, information can flow between different media types. For example, a comment written in the paper booklet gets digitised via some handwriting recognition software and is stored in a database. Later, when another user is asking for comments about an event, text-to-speech technology is applied to the stored text in order to present the captured information via voice output.

Another domain where the RSL hypermedia metamodel has been applied is personal information management (PIM) and in particular cross-media personal information management [12], [13] where information is organised and retrieved in digital as well as physical space. While working on a desktop or tabletop computer, users can define explicit links between documents. However, documents can not only be associated via these explicit links but our cross-media PIM solution is also creating implicit links between documents that are used at the same time or in the same context, in order to improve the later retrieval process. Digital documents are further linked to their physical printouts which are tracked by an augmented filing cabinet. While working with a digital document, a user can ask for its digital counterpart and if it has been filed in the augmented filing cabinet, some LEDs will highlight its position. Note that, based on metadata managed by RSL, the filling cabinet can not only highlight a single document but also multiple folders containing documents that are relevant for a given context (e.g. a specific project). In the future some augmented reality solutions such as the Microsoft HoloLens might further be used for bridging the digital and physical space based on cross-media personal information management.

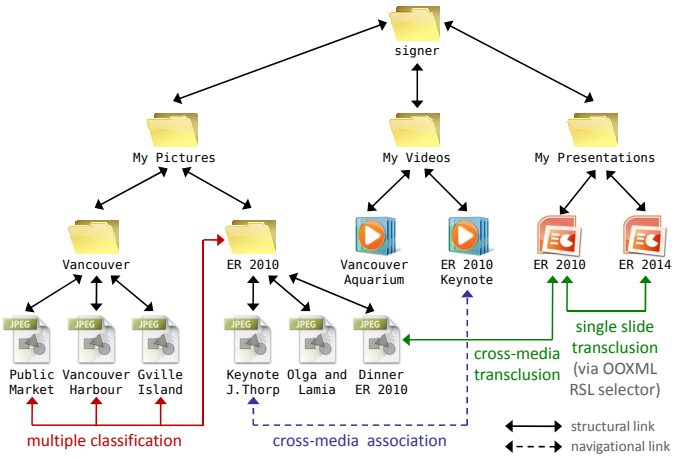


Fig. 3: RSL-based associative file system prototype

In the past, we have also investigated how the RSL hypermedia metamodel might be used for a file management solution that goes beyond the features offered by hierarchical file systems, and developed an RSL-based associative file system [14]. The idea is that we no longer use the folder structure offered by most file systems to organise our documents, but define some structural metadata on top of existing files as illustrated in the example shown in Figure 3. While the example looks like a classical hierarchical file system, the folders are no file system folders but rather just some RSL resources that can be associated with multiple files or other folders via structural links. This implies that the presented RSL-based associative file system allows *multiple classification* where a file can easily be added to multiple folders via different structural links. For example, the file `Vancouver Harbour` belongs to the folder `Vancouver` as well as to the folder `ER 2010`. Note that the same holds for a folder which can be a subfolder of multiple parent folders (not shown in the example). When storing a file, it is sometimes not easy to choose between different potential folders where a file might be put, in which case the later retrieval process may lead to the selection of the wrong path in a hierarchical structure. By using multiple classification, a user can add a single file—without making use of any copies—to multiple folders if they think it belongs to different folders, and thereby simplify the later retrieval process via alternative forms of file management [15]. A main feature of the RSL-based associative file system is that links can be defined between arbitrary files in order to simplify the retrieval and navigation of related files. For instance, in our example the jpeg file `Keynote J. Thorp` has been linked to the movie file `ER 2010 Keynote` of the very

same keynote which has been stored in another folder. Finally, we experimented with some forms of transclusion where a single PowerPoint slide can be used in multiple PowerPoint presentations without replication. In order to select a single slide of a PowerPoint presentation, we only had to define a new selector allowing us to address parts of a presentation stored in Office Open XML (OOXML) [16] format.

The extensibility of the RSL hypermedia metamodel via different media plug-ins makes it challenging to provide a general cross-media link browser and editor since for every newly supported media type, we also need the corresponding visualisation as well as the necessary functionality to define selectors. While the Memex vision only included a single media type (microfilm), we have to deal with a potentially unlimited number of media types. In order to support *open cross-media linking*, Signer and Norrie [17] proposed an architecture with visual media plug-ins and we have recently realised a solution for open cross-media linking in the form of an extensible cross-document link service [18]. For each document format or media type to be rendered in the link browser, a visual plug-in must be implemented. The visual plug-in has two main responsibilities. First it has to render a specific document format and visualise any selectors that have been defined. Second, it should provide the necessary functionality for the basic create, read, update and delete (CRUD) operations for a given media type. Note that our dynamically extensible cross-document link service can also be integrated with existing third-party applications and currently serves as a research platform for investigating different types of linking in cross-media information spaces.

III. Flexible Document Representation

Existing digital document formats are often based on monolithic containers of linear content and simply represent a *simulation of paper affordances* on desktop computers [14]. The *What You See Is What You Get* (WYSIWYG) document representation does not exploit the possibilities that digital document formats could offer as criticised by Ted Nelson: *"Most people don't understand the logic of the concept: "What You See Is What You Get" is based on printing the document out ("get" means "get WHEN YOU PRINT IT OUT"). And that means a metaphysical shift: a document can only consist of what can be printed! This re-froze the computer document into a closed rectangular object which cannot be penetrated by outside markings (curtailing what you could do with paper). No marginal notes, no sticky notes, no crossouts, no insertions, no overlays, no highlighting—PAPER UNDER GLASS."* [19]

A major problem is the fact that the *within document structure* describing different parts of a document (e.g. sections or images) is often fixed and only accessible to the application that was used to create the document. Signer and Norrie [4] describe how the RSL hypermedia metamodel can not only be used for defining navigational links between resources but also to define some structure over resources via structural links. Given that structural links are a specialisation of the more general RSL link concept, they offer the same features as a link (e.g. context awareness or access rights). This allows us define different *context-dependent adaptive overlay structures* on top of (parts of) content. The document structure might therefore change based on contextual information such as the device a document is accessed from. The clear *separation between content and structure* further enables cross-media content reuse via *transclusion* [20].

In the following, we would like to illustrate how the RSL hypermedia metamodel has been applied to achieve more flexible document representations in the domain of presentation software or slideware. Our research on next generation presentation solutions all started with the question *"What is wrong with slideware?"*. Many people do not know that the PowerPoint presentation software was originally used to create 35mm slides for slide projectors as well as transparencies for overhead projectors and that this is from where the term *slideware* comes from. It was only later that the output to physical media disappeared and was replaced by the use of digital projectors. Nevertheless, even the latest version of PowerPoint can be mainly seen as a *simulation of physical slides* with their *limited space*, provides mainly *linear navigation* and treats presentations as *monolithic documents*. It is further *difficult to reuse parts of content* (except for copying entire slides) and to embed rich media types.

In order to experiment with more flexible representations of presentations and innovative forms of presentation delivery, we developed the MindXpres[1] presentation platform [21]. MindXpres follows a *content-based approach* where a presenter focusses on creating the content, while the MindXpres platform offers some automatic presentation visualisation with a zoomable user interface. By making use of the RSL hypermedia metamodel and its structural links, MindXpres enables cross-media content reuse via transclusion and without the need to copy content between presentations. The use of RSL's navigational link further supports new forms of non-linear presentation navigation where a presenter can either predefine alternative paths through a presentation or the presentation tool might automatically propose some alternative paths based on the presented content. Note that the content of all MindXpres presentations is stored in a single data store managed by an RSL software library. This implies that presentations no longer have to be seen as monolithic containers but rather as alternative overlay structures on top of the shared underlying content, making it easy to navigate between the content of different presentations. It is also not necessary that the RSL-enabled data store deals with presentation content only, but it could also contain any other information as, for instance, managed by the cross-media personal information management solution presented earlier.

Last but not least, MindXpres blurs the boundaries between documents and applications by offering support for various rich media types via a plug-in mechanism. For example, by making use of our interactive source code visualisation MindXpres plug-in [22], a presenter can simply refer to some

[1] https://mindxpres.com

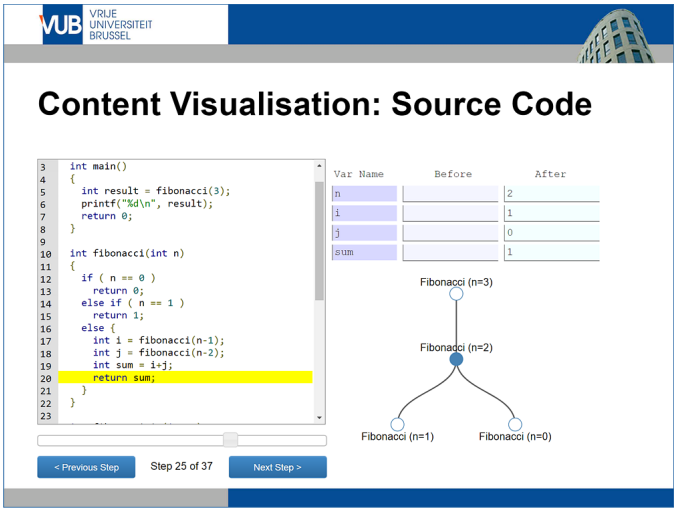


Fig. 4: Interactive source code visualisation in MindXpres

of their source code and the MindXpres plug-in will offer an interactive visualisation of the source code on a slide as shown in Figure 4. In this automatically generated visualisation, the presenter can then step through the code and see changes in the values of variables as well as other visualisations of the executed code such as the call stack. For more details about the flexible MindXpres presentation document format and some of its additional features we refer to [23]. While our work on the MindXpres presentation platform revealed various advantages of using RSL's structural links for realising more flexible document representations, these findings are of course not limited to presentations only and can be applied to other domains in order to address the problems of some existing document formats [14].

IV. Cross-Media User Interfaces

As mentioned earlier, nowadays information is often distributed across different devices as well as the digital and physical space. When interacting with information in these cross-media information spaces, we might therefore want to work with user interfaces that are distributed across different devices as well as the digital and physical space (hybrid user interfaces). We first provide some examples of our work on distributed and tangible user interfaces and then report on some of our more recent work on supporting the development of these kind of user interfaces.

A first cross-media user interface has been realised for our cross-media personal information management solution introduced earlier [13]. While users can interact with an RSL-enabled personal information store via their desktop computer, a tabletop interface or their smartphone, there is also the possibility to use a combination of physical and digital interface components. The augmented filing cabinet offers a number of physical sliders and other tangible interface elements for retrieving paper documents. If a paper document is placed on the tabletop computer, it is tracked by a camera and thereby forms part of the user interface. Our cross-media PIM system identifies the paper document and searches for digital documents that are linked to the physical document. These digital documents are then visualised around the physical document on the tabletop as part of a hybrid user interface.

Another form of hybrid user interface has been investigated in our ArtVis prototype for the exploration of artwork collections [24]. Various tangible objects (e.g. painting tubes) have been equipped with RFID tags and trigger some queries for retrieving specific types of artworks when they are placed close to a painters palette with an integrated RFID reader. While the ArtVis user interface offers some innovative forms of real-time cross-media data exploration, the interaction is unidirectional in the sense that the interaction with a tangible object might trigger some actions in digital space but not vice versa.

Recently some vision-driven research on radical atoms and programmable matter has been proposed by Ishii et al. [25] in order that interactions with tangible objects might not only lead to changes in digital space, but updates in digital space can result in a transformation of physical artefacts. They are currently investigating different shape changing physical interfaces in order to simulate interactions that might later be possible via programmable matter. We have chosen a different approach by physically augmenting the digital space based on our tangible hologram (TangHo) [26] platform in order to enable different forms of dynamic data physicalisation. We are further investigating a framework for dynamic data physicalisation [27] to support new forms of cross-media user interfaces where different physical variables and multiple modalities can be used for the exploration of multi-dimensional datasets.

In order to support the development of cross-media user interfaces and adaptive distributed hybrid user interfaces in particular, we are currently developing the eSPACE reference framework and conceptual model [28]. The conceptual model is again based on the RSL hypermedia metamodel, but this time the structural and navigational links are used to define the bindings between user interface components and the corresponding actions as well as to build more complex user interfaces out of simple UI elements. The adaptation of the resulting cross-media user interfaces is achieved via RSL's context resolvers and the loose coupling of UI elements and the corresponding actions supports reusability and extensibility. Further, the eSPACE conceptual model introduces a specialisation of RSL's structural links for realising distributed user interfaces. An advantage of the fine granularity of UI elements offered by eSPACE is that end users might reconfigure and adapt parts of their user interfaces to better fit their needs. The flexibility in defining cross-media user interfaces might ultimately lead to innovative forms of human-information interaction for cross-media information spaces.

V. Outlook

We have shown how to address the issues of *cross-media linking*, *flexible document representation* and *cross-media user interfaces* in cross-media information spaces, all based on the same RSL hypermedia metamodel. However, different cross-media applications such as the cross-media personal

information management framework or the MindXpres presentation platform are based on separate instances of RSL-enabled data stores. Further, these applications have been built on top of an existing file system that does not support any of the discussed hypermedia functionality, and therefore cannot offer access to the navigational and structural metadata to any third-party application. We have outlined how a file management system might profit from additional navigational and structural metadata when discussing the RSL-based associative file system prototype. In order to enable the integration of information across application boundaries and to support the sharing of navigational as well as structural metadata, we therefore propose the embedding of an RSL-based hypermedia engine at the level of an operating system as illustrated in Figure 5.

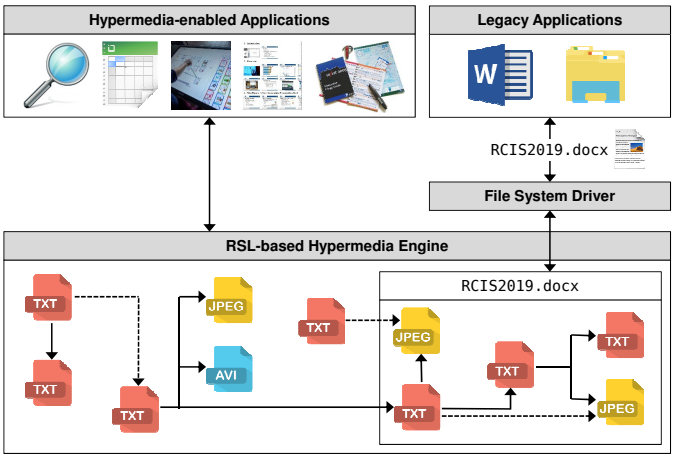


Fig. 5: Next generation cross-media storage platform

The proposed RSL-based hypermedia engine would treat documents or "files" as *placeless documents* [29] and organise them via navigational and structural metadata. Documents would further no longer have to be stored as monolithic containers but the hypermedia engine could provide access to the internal document structure as shown for the document `RCIS2019.docx` in Figure 5, consisting of multiple content fragments (RSL resources) such as text fragments or jpeg images that are combined via structural links (represented by solid arrows). Further, navigational links (represented by dashed arrows) could be used for navigating between documents as well as within documents. The same content fragment could not only be used in a single document but transcluded from other documents, as shown for a part of document `RCIS2019.docx` being integrated into another document via a structural link. Of course the RSL-based hypermedia engine might also support the multiple classification of documents via virtual folder structures as discussed earlier for the RSL-based associative file system prototype.

We cannot expect existing applications that are currently using a classical file system to be adapted in order to make use of the proposed RSL-based hypermedia engine. Therefore, in order to provide some compatibility with these "legacy" applications, a classical file system interface might be offered on top of the RSL-based hypermedia engine. In its simplest form, this file system interface would just store any file as a resource in the underlying cross-media information space managed by the hypermedia engine. However, for some existing document formats, such as the Office Open XML document format with the `docx` extension in our example, specific file system drivers might be deployed which no longer store a file as a single resource but rather as a composition of its content fragments, providing access to the internal document structure. This has the advantage that—without any modifications—legacy applications could store their content via the RSL-based hypermedia engine and make the content and structure of a document available to any newly developed hypermedia-enabled application. In addition, a classical hierarchical file browser could be provided to users who do not immediately want to switch to some next generation file browsers realised on top of the RSL-based hypermedia engine.

By offering an RSL-based hypermedia engine at the level of an operating system, future hypermedia-enabled applications may profit from any of the RSL features (e.g. context awareness or access rights) discussed earlier, and we enable a system-wide application interoperability via the shared content and RSL metadata. Note that content might not only be shared within a system but also between different systems with their own embedded RSL-based hypermedia engine.

Our envisioned cross-media storage platform represents an ideal environment for investigating innovative forms of cross-media information management and human-information interaction. Users gain a lot of freedom in organising their digital and physical content by making use of navigational and structural links or via simple tagging enabled by RSL properties. Further, the findings of different research domains (e.g. personal information management or information retrieval) can be applied on top of the RSL-based hypermedia engine in order to provide some advanced services for dealing with our daily digital as well physical information. By offering new tools for managing content in general cross-media information spaces, we might have to reflect on the role of a document which just becomes a specific view of parts of the underlying shared content fragments as well as to reconsider the file and folder paradigms. The proposal for a next generation cross-media storage platform and the rich features offered by the presented cross-media applications will hopefully stimulate some discussion on innovative solutions for managing and retrieving information in cross-media information environments.

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Papers

A Discussion of the Impact of Judgmental Heuristics on Elicitation during Requirements Engineering

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***Abstract*—A stakeholder decides which information to share during requirements elicitation. These decisions are made under uncertainty: stakeholders may not have precise, concrete, and complete information about their own expectations from, or about the environment of the system-to-be, they may misunderstand information which a requirements engineer gives them, and they may not have perfect knowledge about the various opportunities that the current technology may offer. Stakeholders' decision-making is therefore likely to involve the use of heuristics. Understanding if stakeholders do indeed use heuristics during requirements elicitation, and if so, then which ones, should help understand requirements elicitation better, and design methods which can stimulate positive heuristics (those which help elicit relevant requirements) and mitigate negative ones. This paper defines what an elicitation heuristic may be, and proposes a set of research questions under the form of a matrix for the theoretical and empirical study of elicitation heuristics.**

***Keywords*—Requirements, Elicitation, Judgmental Heuristics**

I. Introduction

Requirements elicitation (or simply *elicitation*) designates activities performed to collect information about the requirements of a system-to-be or the environment in which that system will run. Elicitation produces information that is used in other Requirements Engineering (RE) activities, the aim of which is to produce a requirements specification, which, in turn, will inform the engineering and development of the system. Elicitation typically involves two parties: the stakeholders and the requirements engineers. The latter elicit information from the former. This elicitation process involves decision-making; engineers decide what to ask or how to otherwise stimulate the stakeholders to provide information, stakeholders choose which information to provide to engineers. Many factors influence stakeholders' decisions to share or not information. Elsewhere, we studied how the elicitation context influences the information that a stakeholder chooses to provide [1]. The focus in this paper is on the role that *uncertainty may have on stakeholders' decision-making during elicitation*. Stakeholders may have various backgrounds, experience, expectations, and expertise. They may be concerned or focus only on some aspects of a system, and ignore others. They can thus hardly predict with certainty how the system will influence their environment and activities. That is, stakeholders make decisions under uncertainty, when choosing the information to give during elicitation.

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Decisions that people make under uncertainty are called judgments [2], i.e., stakeholders make judgments during elicitation. *Judgments are influenced by heuristics.* This is the case in general, regardless of what the decisions are about. In their seminal paper on choices under uncertainty, Tversky and Kahneman suggested that decision-makers use heuristics to formulate beliefs to support judgments [2]. Heuristics can be seen as strategies used by decision-makers to "reduce the complex tasks of assessing probabilities [of an event] and predicting values to simpler judgmental operations" [2]. There is considerable research on the identification of biases related to judgmental heuristics. It suggests that using heuristics may lead to non-optimal decisions [3]. Another line of work sees heuristics as mechanisms whose deficiencies are compensated by advantages. This is more recent research, which suggests that a heuristic is not good or bad in itself, but is more or less efficient depending on the context of the decision [4].

If heuristics influence judgments in general, then they also influence stakeholders' and engineers' judgments during elicitation. The premise of this paper is that if these impacts are understood better, then that understanding can help engineers during elicitation. For example, a heuristic might work as follows: a stakeholder will not, or is less likely to argue against a requirement which was given by an influential stakeholder. Another heuristic may be that the stakeholder will not argue against a requirement which was already approved by the majority of the stakeholders. Elicitation can be adjusted to minimise the influence of such heuristics, or to benefit from these heuristics. For the first heuristic, if the engineer's aim is to get a requirements approved quickly, she may inform other stakeholders about who gave it. If the aim is, instead, to find out if some stakeholders oppose the requirement, then it may be more appropriate to hide who gave that requirement. This gives the following central research question: *Do judgmental heuristics influence elicitation, and if yes, then how?*

The question above is hard. There is no known complete set of judgmental heuristics in existing research on decision-making in general. To the best of our knowledge, there is no research on the role of the known ones specifically in elicitation. There are no theoretical discussions which relate judgmental heuristics to elicitation, and there are no tested instruments for empirical research into the influence of judgmental heuristics on elicitation. The research question above sets a long term goal, and this paper suggests a list of research questions towards one aspect of that goal. Namely, this paper proposes a research question matrix towards the following

research question:

> *Is there a relationship between properties of elicited information and judgmental heuristics applied by stakeholders when giving that information?*

In other words, does the use of judgmental heuristics during elicitation influence the properties of the information obtained during elicitation? To clarify this research question, consider the following example. In elicitation, it is common to categorise some information that stakeholders gave as being about requirements, while other information is about the environment of the future system. One of the judgmental heuristics discussed in this paper says that, if one needs to give information, then among alternative information she can give, she is more likely to give that which is easier than others to recall from memory. In this specific case, the research question becomes: Is information about requirements easier to recall than information about domain knowledge? We identify many such specific research questions, and suggest how to obtain empirical data to answer them. The questions are based on two sets of classification dimensions: (i) one set is based on prior RE research, and gives rules for the classification of elicited information, called **statements** below. These dimensions are called **RE classification dimensions**, (ii) the other set of classification dimensions are called **Heuristics classification dimensions**. Each classification dimension is based on one or several judgmental heuristics identified in existing research.

II. Heuristics Classification Dimensions

We first identify existing judgmental heuristics and discuss their potential role in elicitation. We take judgmental heuristics which are likely to be used by managers and other corporate decision makers [4]. We then discuss if, why and how these judgmental heuristics might be used by stakeholders to decide which statements to share during elicitation. The elicitation heuristics suggest the Elicitation classification dimensions for statements. The classification dimensions are not exhaustive, as they are based on a subset of judgmental heuristics which are currently known in research, and research on judgmental heuristics is still ongoing, with potentially new heuristics to be formalized in the future.

A. Recognition Dimension: Accessible or Distant

This first classification dimension is suggested by the Recognition, Fluency and Take-the-first judgmental heuristics [4]. These heuristics are used in recognition-based decision-making. Namely, when a decision-maker has to select one among a set of alternative statements, she will pick the one she recalls the more easily and rapidly from memory. On the contrary, alternative statements which are difficult to access will tend to be overlooked, regardless of how relevant they may be in elicitation. This suggests two categories of statements. *Accessible statements*, which can be retrieved easily and/or rapidly from memory or which refer to something that is easily and/or rapidly retrievable from memory and *Distant statements*, which are distant and difficult to retrieve from memory, or which refer to something that is hardly accessible in memory. An illustration of these heuristics is the case of a stakeholder who has to select one refinement of a business goal, among two different ones. The stakeholder may pick the refinement of the goal that best fits with what comes the more rapidly to her mind. Typically, this will be the alternative she is more familiar with, that she encounters regularly, or that is not too complex and hence relatively easy to remember.

B. Rationale Dimension: Verified or Refuted

This classification dimension is inspired by the Take-the-best and One-clever-cue judgmental heuristics, and more generally by heuristics used in the case of one-reason decision making [4]. These heuristics work on the idea that an alternative statement is chosen as soon as it is observed that this statement satisfies one specific condition. This condition is used by the decision-maker either because it discriminates sufficiently among different possible alternatives (take-the-best heuristic) or because it is innate and the decision-maker does not want to use another (one-clever-cue heuristic). This suggests the following categories of statements. *Verified statements*, which are selected by stakeholders based on a single selection criterion, and *Denied statements*, which are rejected by stakeholders based on a single selection criterion. For illustration, take the case of a stakeholder who has to decide which of two conflicting requirements to keep. The stakeholder may decide to keep the requirement which requires less time to develop, and consider no other aspects of the two conflicting requirements such as the cost of development, the impact on other systems in the business, etc. This criterion is used by the stakeholder because, from the set of criteria she though of, time of development was the one that was the most discriminant one (take-the-best heuristic), or the one she always uses when she has to make such decision (one-clever-cue heuristic).

C. Tradeoff Dimension: Consensus or Disagreement

This classification dimension comes from the Tallying Heuristic, which implies to identify several criteria for comparison, and selecting the alternative which satisfies the best this set of criteria [4]. The decision maker will evaluate, for each possible alternative, the number of criteria that are met, and will select as a solution to her problem the alternative which scores best. This brings us to the definition of *Elected statements*, which are selected by stakeholders based on more than one selection criterion and *Dismissed statements*which are rejected by stakeholders based on more than one selection criterion. The illustration of this heuristic is similar to that for the Rationale dimension; to decide between two conflicting requirements, a stakeholder may consider three criteria - namely, development time and cost, and impact on the other systems - and select the alternative that matches most of these criteria. The difference here is that each statement is evaluated against each selection criterion, unlike in the Rationale dimension where only one selection criteria is used to evaluate the different alternatives. Although close in their way of working, the output may therefore significantly vary.

D. Resilience Dimension: Default or Exception

This classification dimension is derived from the so-called Default heuristic [4]. Roughly stated, this heuristic suggests that a decision-maker will typically select from a set of alternatives, the one that best reflects the standard way of doing something according to her experience. This brings us

to the definition of the following statements; *Default statements*, which a stakeholder selects because they reflect her understanding of the world and *Exception statements* that a stakeholder rejects because they clash with her understanding of the world. An illustration of this heuristic is the case of a stakeholder who has to decide if the business rule "backup business data every hour" is still applicable to the system-to-be. Perhaps the rule was initially adopted a decade ago, when there was no reliable cloud solution. It is unclear if this business rule is still relevant now. In order to decide about such problem, the stakeholder may resort to the default heuristic and consider that, by default of other indications that would contradict it, the business rule is still applicable. Doing so, the stakeholder decides to follow the standard procedure.

E. Imitation Dimension: Influencer, Majority, Minority

This last classification dimension is suggested by the Imitate-the-Successful and Imitate-the-majority heuristics [5]. With these heuristics, a decision-maker selects a solution from a set of alternatives if there are cues that others adopted that same solution. Successful or famous people will be considered in the case of Imitate-the-Successful heuristic. Large groups and majorities will be preferred when making use of the Imitate-the-Majority heuristic. This suggests the following statement categories. *Influencer statements* are statements which a stakeholder selects because they seem to convey the same information as statements given by individuals, who are perceived as influencers of widely-held opinions. *Majority statements* refers to statements which a stakeholder selects because they seem to reflect the opinions of the majority. *Minority statements* are statements which a stakeholder rejects because they seem to clash with statements of influencers and, or the majority. Say for instance that a stakeholder has to decide whether she will ask to have mobile access (on a smartphone or tablet) to the system-to-be. If the stakeholder is unsure about this decision, she may decide to look at the decision of other stakeholders. For example, she might follow her superior's choice, whichever it is. Alternatively, she might make the same decision as the majority of the stakeholders, even though she may not need mobile access. In both cases, she resorts to the so-called imitation heuristics.

III. RE Classification Dimensions

To identify RE classification dimensions, we review RE literature which suggested taxonomies of goals/requirements. We limit our review to dimensions which originate in some way from speech acts of stakeholders [6]. We do not take into account technical taxonomies which are specifically intended for engineers. The list of classification dimensions is not exhaustive, but provides ample material for the discussion. For illustration, consider the following statements. Assume that they are speech acts resulting from decisions made by stakeholders in a context of uncertainty and are therefore likely produced through judgmental heuristics. We want to discuss how these statements differ from each others.

- *S1*: Optical fiber cables are used to transfer data anywhere in the world in less than a second;
- *S2*: I wanted to access business data from my smartphone in no more than 10 seconds;
- *S3*: I'll use the app if it updates easily and no too slowly;
- *S4*: We used to know when our sales targets were achieved when the indicator turned blue or green;
- *S5*: I think it is critical to me that, in case of server breakdown, (i) a backup service is launched automatically or (ii) the IT service is immediately contacted and a warning email is sent to user.

A. Nature Dimension: Environment or System

This classification dimension is inspired by Zave and Jackson's distinction [7] between information related to the environment of a system (domain knowledge), information about what is expected from the system-to-be (requirements), and information about how the requirements will be satisfied by the system-to-be (specifications). This distinction leads us to distinguish between two kinds of elicitation statements. *Environment statements* focus on conditions and events in the environment which may influence the system-to-be, while *System statements* focus on conditions and events controlled by the system, and, or which the system may influence in the environment. In our running example, S1 is an environment statement, because it describes a condition of the environment in which the system will operate; the fact that optical fiber cables are used is not related to the system, but to the environment in which that system will operate. On the contrary, S2, S3, S4 and S5 are system statements, because they all somehow describe information about the system itself, and not about its context.

B. Type Dimension: Function or Quality

This classification dimension comes from the distinction made in RE literature between the so-called functional and non-functional requirements, or goals. The former type of requirements refer to a function, a service, that is expected from the system-to-be. The latter type of requirements are to be seen as constraints, or qualities, being set on how functions are delivered [8], [9]. The fact that a requirement is functional/nonfunctional has an important impact in terms of validation; functional requirements have clear-cut validation criteria, while conditions to validate the satisfaction of nonfunctional requirements are often hard to define. This validation distinction leads to a RE dimension of statements with two different level. *Functional statements* are about events and conditions whose occurrence and holding can be established without a doubt while *Quality statements* refer to events and conditions whose occurrence and holding can be evaluated in different ways, by different people. In our running example, S1, S2, S4 and S5 are functional statements: they describe things about the system or its environment which leave no room for interpretation; for example, it can be established without a doubt that there is optical fiber in the data center, or that an indicator is green or blue. On the contrary, statement S3 is typically a quality statement, since the adjectives easily and slow are likely to interpreted differently by different people.

C. Guidance Dimension: Problem or Solution

This classification dimension is due to the fact that stakeholders may guide the analyst in different ways during elicitation. Most of the time, we expect stakeholder to simply share things they expect from the system-to-be, and analysts to find the best way to satisfy that requirement. In other

words, the stakeholder shares the requirements, while the analysts identifies the specifications of the system so as to satisfy these requirements [7]. Sometimes however, it may also happen that stakeholders share requirements together with some indications about how they expect them to be satisfied. This distinction brings us to a guidance dimension, with two types of statements. *Problem statements* are conditions and events which are either undesirable, and need to be prevented, or are desirable, whereby the statements do not say how to, respectively, prevent or achieve these conditions and event. *Solution statements* are about how to prevent undesirable conditions and events and, or achieve desirable conditions and events. In our running example, S2 and S3 are problem statements because they describe behaviors with no indications about how it should be satisfied. On the other hand, S4 and S5 are solution statements, providing indications to engineers about how the requirement could be satisfied. S1 is a Problem statement about the environment: it describes a condition in the environment (i.e. information can be transferred anywhere in the world in less than a second) together with the way it is achieved (i.e. using optical fiber).

D. Structure Dimension: Atomic, OR, AND or Complex

This classification dimension is common sense and is inspired by the logical disjunction and conjunction mechanisms. More precisely, it starts from the observation that statements being shared by stakeholders are not always simple. Sometimes, requirements being shared may imply several clauses to be related to each other with some conjunctions and/or disjunctions. In RE, the structure of a requirements or a goal is usually handled through AND/OR relations [10]. This brings us to an RE dimension with four different types of statements. *Atomic statements* are about a single event or condition, *OR statements* combine two or more mutually exclusive events or conditions, *AND statements* combine two or more events or conditions, none of which are mutually exclusive and finally *Complex statements* where more than two events or conditions are combined, some of which are mutually exclusive. In our running example, S1 is an atomic statement because it describes one single condition. S3 is an AND statement because it involves two events which are not mutually exclusive. S4 is an OR statement because it refers to events which are mutually exclusive: the light bulb in a same lift cannot be blue and green at the same time. Finally, S5 is an example of complex statement, because it involves three events combined with both AND and OR.

E. Source Dimension: "I", "We" or Impersonal

This dimension is inspired by research on the impact of groups on the definition of requirements [11]. The underlying idea is that a requirement being suggested by a group is more likely to be of better quality and creativity than a requirement being suggested by some individuals alone [11]. This suggests that a statement can be shared either as the request of a single person, or as the result of some concertation between several individuals. As it may happen that a statement cannot be attributed to one person or group in particular (as the result of culture, popular knowledge, science, etc.), we also consider an impersonal source of statement. This leads us to a three-level RE dimension. *I statements* are statements which convey speaker's own beliefs, and with which the speaker does not convey that others hold these beliefs. *We statements* are statements which convey speaker's own beliefs, and with which the speaker conveys that these beliefs are held by others as well. Finally, *Impersonal statements* convey general knowledge, opinions or ideas which cannot be attached to one particular individual or group. In our running example, S2, S3 and S5 are examples of I statements; they are expressed as the result of an individual decision. S4 on the contrary is clearly expressed as the result of a mutual decision. Finally, S1 is about a condition that is not directly produced by the person who shares the statement, neither by a group of several stakeholders. It simply reflects a condition that is true and that cannot be associated with one person or group in particular, so that it is expressed in an impersonal way.

F. Time Dimension: Past, Present or Future

This dimension comes from the distinction that is sometimes made in RE between the requirements intended to maintain a condition and the requirements intended to achieve or cease to do something; for example, the patterns suggested in KAOS [12]. We believe this distinction also applies to statements, in a more generic form. We interpret "maintain" requirements as being statements about the present situation; something that is currently observed, and which may be expected to hold true in the future. On the contrary, we interpret "achieve" and "cease" requirements as statements about the future; that is, things that are not true in the present, but expected to be verified in the future. Although RE literature does not define a type of requirement about the past, we believe that some statements may be formulated about things that were true in the past, and that do not longer hold. This leads us to a three-level RE dimension. *Past statements* are about events and conditions which occurred/held in the past, and no longer do today. *Present statements* are about events and conditions occurring/holding at present. *Future statements* are about events and conditions expected to occur/hold in the future, and do not at present. In our running example, S2 and S4 are typical examples of statements formulated about the past, for which there is not certainty today. S1 and S5, on the other hand, are formulated to express current ideas or actions, which are happening nowadays. S3 is a statement about the future: it describes nothing about the present or past situation, but simply states something about what is expected to hold true in the future.

G. Mood Dimension: Descriptive or Prescriptive

This dimension is inspired by the distinction that is made in modeling between models that describe the state of a system or a domain, and the models that aim to describe what is expected from future system or domain. Such distinction is also common in RE; the i* modeling language for example can be used in a descriptive way, as a mean to describe an existing business, or in a prescriptive way, as a mean to describe what context should be achieved via the new system [13]. This brings us to the mood RE dimension, with *Descriptive statements* describing events and conditions independently of being desirable or not and *Prescriptive statements* describing desired events and conditions. In our running example, S3 and S5 are prescriptive statements because they clearly state

that there are some needs, and that actions are expected in order to fulfill the needs. On the contrary, S1, S2 and S4 are descriptive statements; they describe things, with no clear indications about whether these things are desired. The purpose of these sentences is simply to provide information about the situation, as-is.

H. Background Dimension: Experience or Speculation

This last dimension is based on the idea that, in a context of uncertainty, stakeholders may be willing to express a degree of certainty about the statements they mention. In some cases, stakeholders may state that they "think" or "believe" a statement, and that they are not "sure" or "convinced" of the latter. One way to explain such difference between statements is the background being used by the stakeholders to produce the statements. Stakeholders may either justify their statements with some of their past experience, in which case they will appear to be relatively certain of the statements they share. On the contrary, they may resort to speculation, and share statements they are not certain of. We have found no research in RE about that concept of statements background, yet we believe it might be an interesting property to account for in the rest of this paper. *Experience statements* are statements supported by own experience, that is, events and conditions experienced in the past. *Speculative statements*, or the other hand, are not supported by own experience. In our running example, S1, S3 and S5 are speculative statements. It means that it seems, based on the statements, that the stakeholder who shared the statement has never experienced it. This is clearly not the case of S2 and S4, where the stakeholder clearly refers to some past experience as a way to support the statement.

IV. A Matrix of Possible New Elicitation Filters

We see research areas at each intersection of a RE dimension with a Heuristic dimension. In each of these research areas, there are several research hypotheses, which always take the same form; there is a correlation between one level of a RE dimension, and one level of a Heuristic dimension.

A. Feeding the Research Question Matrix

These research hypotheses are the 220 empty cells in Figure 1, and suggest new empirical questions to be investigated. It is not feasible to write down all the hypotheses suggested by the Matrix, yet we believe it is useful to state at least one of them explicitly. Consider **research Area 10**: "does the imitation elicitation heuristic influence in some way the chances of a statement to be a functional requirement (as opposed to non-functional requirements, i.e. quality)?". More precisely, does the fact that a statement is a majority, minority or influencer statement correlate with that same statement being a quality or a requirement? Our intuition here is that qualities have a coarser granularity, so that the stakeholder will only communicate it to the engineer if she is certain a majority of stakeholders agrees on that quality, i.e., H_6 (sixth box in area 10): there is a significant correlation between majority and quality statements. A requirement on the other hand has a thinner granularity, which makes it easier for the stakeholder to communicate to the engineer despite the statement being a minority statement, i.e., H_2 (second box in area 10): there is a significant correlation between minority and requirement

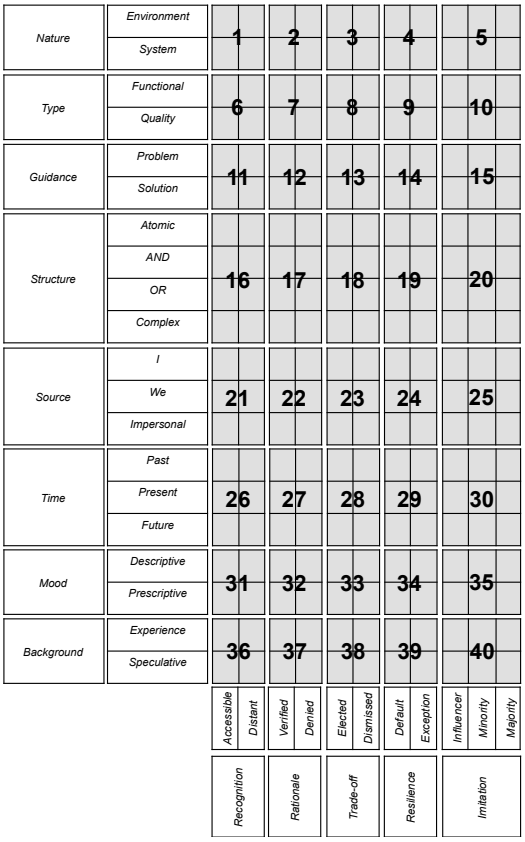


Fig. 1: Research Matrix of Potential Elicitation Filters Studies

statements. Our intuition about the other intersections (H_1, H_3, H_5 and H_6) is that there should not be any significant correlation, which are other relevant hypotheses to validate.

B. Empirical Evaluation of the Matrix

The matrix suggests empirical study of correlations and relationships between the different dimensions. More precisely, we suggest research which estimates the frequency in each cell, or the correlation between two levels from different dimensions. Ultimately, this would result in a map of the risks and benefits of using some heuristics rather than others. For example, looking in the first column, one could select the top five values and the top five worst values. Doing so, we would identify the statements that are the more likely to be shared or overlooked by a stakeholder, using the Recognition heuristic. Such a tool can be used during elicitation to help analysts elicit more information. To obtain these values, specific empirical tools must be designed, so as to capture statements and classify them according to at least one heuristic dimension, and one or more RE-dimensions. These statements, once collected, could be summarized under the form of a contingency table like in Table I, and reported in the matrix. The letter N refers to a number of occurrence, and the ratio in Table I represent the relative frequencies inside a research area. As a way to confirm or reject the existence of an actual relationship between two dimensions, statistical tests based on chi-square test can be computed for each contingency table appearing in the matrix

TABLE I: A contingency table for the Imitation-Nature Area

	Majority	Influencer	Minority
Environment	N_{EMaj}/N	N_{EInf}/N	N_{EMin}/N
System	N_{SMaj}/N	N_{SInf}/N	N_{SMin}/N

(research area), such as Table I. Additional statistical tools like the Pearson or Spearman correlation coefficient (depending on the type of data being collected) can be used to study the importance and direction of the effects.

C. Positioning the Matrix

Most of the questions suggested by the Matrix remain somehow unanswered in the context of information elicitation. Yet, the importance of adopting a cognitive or decision-making approach to elicitation and RE in general is often recognized. In [14], RE is presented as a decision-making intensive activity during which it is critical to better understand how engineers and stakeholders reason and decide to treat information. A similar view is adopted in [15], [16], where it is claimed that RE engineers make use of various heuristics or stopping rules to determine the sufficiency or priority of information gathered during the elicitation of requirements. In [17], a set of stakeholders enablers and inhibitors is defined, which paths the way for future research on how heuristics influence elicitation. In [18], it is clearly highlighted that cognitive sciences may help RE community in better dealing with main issues related to elicitation. None of the previous papers however conduct actual empirical study, nor do they address specifically one or more of the questions suggested by our Matrix. In [19], it is claimed that most problems related to elicitation can be traced to human cognitive limits, so that better understanding those constraints and the strategies used by human to overcome them turns out to be a worthy endeavor for RE researchers. We found few papers dealing explicitly with the use of judgmental heuristics by stakeholders, the biases such heuristics lead to during elicitation of requirements, and the techniques which could be used to deal with such biases.

V. Conclusions

This paper suggests a set of research questions for theoretical and empirical research on the role of judgmental heuristics in requirements elicitation. It starts from the observation that, during elicitation, stakeholders make decisions under uncertainty. As a consequence, they may resort to judgmental heuristics to make decisions about which information to share with the analyst. Our focus in the paper is to explore the usage of such heuristics and how it connects with the outcome of elicitation. As a first step to answer that question, we suggest a research question matrix, which defines a list of research questions about the potential impact of heuristics on the identification of elicitation statements. The matrix is obtained from a combination of two different classifications of statements that stakeholders can provide during elicitation. The first classification, RE-oriented, identifies a list of dimensions which can be used by analysts in order to characterize and distinguish different statements. The second classification, heuristic-oriented, identifies a list of dimensions which can be used to explain why some specific statement was given by a stakeholder. By combining these two classifications, we obtain a list of 220 research questions, that we argue can be addressed theoretically - through, for example, the study of ecological rationality or judgmental biases in elicitation - or empirically - through the study of correlation. The long term objective of the matrix is to lead to new research on requirements elicitation.

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Towards Detecting and Mitigating Conflicts for Privacy and Security Requirements

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***Abstract*—requirement engineering live in a world were contradiction is the norm. Hence, development of software engineering is usually an adjustable and upgrading cyclical process. We found in the literature that some requirements conflict with other requirements. We will focus in this study on identification and resolution of conflicts between security and privacy requirements. Although, most the recent studies focus on identifying conflicts without proposing a solution to resolve it. This paper presents an approach to identifying and resolving conflicting privacy and security requirements as patterns. By using patterns to describe the problem we can propose a solution for each conflict.**

Keywords*— *software engineering; security requirements; privacy requirements; conflict; strategy of resolution.

I. INTRODUCTION

Information systems are used everywhere and are becoming more complex. One aspect adding to that complexity is the growing number of security and privacy requirements that need to be built into the product. Moreover, with the new **GDPR** regulation (General Data Protection Regulation), agreed upon by the European Parliament and Council in April 2016, replacing the Data Protection Directive in spring 2018 as the primary law regulating how companies protect EU citizens' personal data needs a conclusion to this point [1] and regulation to protect privacy, since information system holds personal confidential information. Privacy is designed in software information systems. But this sometimes creates issues: on one hand we have security requirements and other hand we have privacy requirements, and these likely conflict.

The challenge is the literature doesn't appear to provide adequate methods to identify and mitigate conflicts between security and privacy requirements. However, identifying and mitigating such conflict is important to reduce risk on the software system, by having conflicts at least one of the security or privacy requirements will be vulnerable and easy to be target.

Conflicting requirements are identified as one of the three primary causes of additional effort or mistakes during software development [2]. Conflict can be defined as a clash of interest between two aspects of development: security and privacy. These conflicts may occur within a level of the project, such as among items at the goal level, requirements level, technical level, or implementation level.

II. Motivating

To represent the problem statement we can find that this issue are very common, almost in each sector, for instance, banking, education, and health care. All those sectors required to insure users' privacy, in the meantime to maintain system secure and invulnerable.

In order to have a better understanding of the problem, in case of having conflicts between requirements. We inspired by Q, Ramadan et al. [3] E-Health case study. Because it shown exactly how we identify conflicts between requirements. By represent the model. In the E-Health usually patients have strong privacy concerns about how and for what reason their health information is handled, which could cause an interfere with an organization's documentation responsibilities to certifying accountability.in other words patients priority to keep their information anonymity and undetectable, and that would conflict organisation goals such as accountability. Moreover, the model explain how a patient can use a telemedicine device in order to receive an over-distance healthcare service. Moreover a patient can also evaluate the service through an online evaluation portal. By having an example like E-Health system its appear to us many requirements could be conflicting, hence this paper focused on security and privacy requirements we will describe phase by phase how to Identify conflict between security and privacy requirements toward resolve or mitigate conflicting between requirements.

III. Related Work

Various studies have been conducted regarding the decision criteria to use in non-functional requirements conflicts. There is an interesting study that identifies conflicts between security and data-minimization requirements is a challenging task. Since such conflicts arise in the specific context of how the technical and

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organizational components of the target system interact with each other, their detection requires a thorough understanding of the underlying business processes. To address this challenge, Ramadan *et al.* [3] propose an extension of the business process modelling language (BPMN modeling language) to enable specification of process-oriented data-minimization and security requirements, also to detect conflicts between these requirements based on a catalogue of domain-independent anti-patterns. However this study is relevant to our work, it differs in the level of business process modelling, while our approach focused in a different SDLC stage (requirement engineering phase). In addition, Ramadan *et al.* do not consider resolving conflicts as part of their approach. Though Ramadan *et al* study is information rich that helps us in identifying conflicts and mapping the most requirements being conflicting.

In addition, Egyed and Grunbacher [4] used an automated traceability technique to eliminate false conflicts and cooperation. Analyzing the requirements is the first step and then an identification of the requirements is made based on their attributes which are cooperative or conflicting. Then, the trace analyzer automatically detects the trace dependencies among the requirements. The system aids in determining the extent requirements overlap by using trade dependencies knowledge. If two requirements overlap, then the two requirements are conflicts. Whereas, if there is no overlap between them, then conflicts cannot exist. Another technique used to identify the conflicts is known as the negotiation method. Here, the stakeholders and software engineers discuss the project orally and analyze the requirements as well as the conflicts that the project could be facing [5].

Mairiza and Zowghi [6] suggest that to manage the conflicts, some techniques can be used for viewing, interpreting and evaluating NFRs. It is important to assess NFRs while knowing their impact and importance to the system. Mairiza et al. [7] applied an experimental approach to design a framework that manages the relative conflicts among NFRs. As well, Santana and Liu [8] proposed a framework to analyze the conflicts among non-functional requirements using the integrated analysis of functional and non-functional requirements. The conflict detection is performed on high-level NFRs based on the relationship between quality attributes, constraints and functionality.

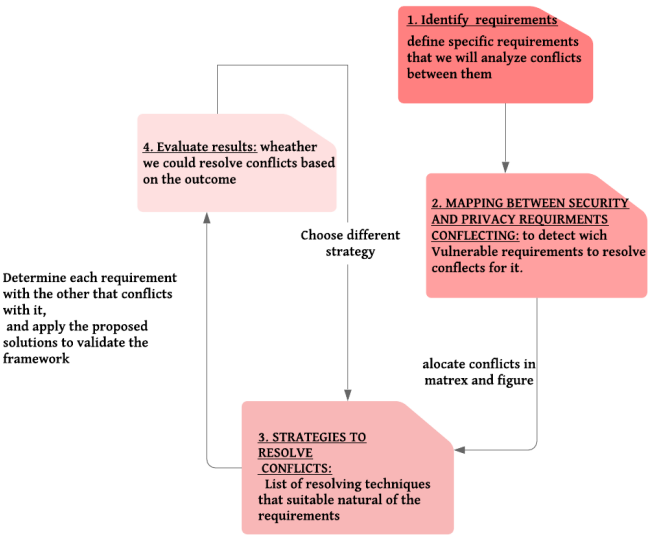
From the recent studies, we can identify that the following research gaps in the area of managing security and privacy requirements frameworks. That first of all, normally frameworks consider either security or privacy issues, we find very limited frameworks focused on both security and privacy. In addition, we find that most of approaches focused on identifying or analyzing conflicts as we found it's so infrequent to find a study consider resolving conflicts between the requirements.

In this research, we will present a way to enclose security and privacy requirements, after that will map between those conflicting requirements, to find which requirement is more vulnerable. We then apply the suitable resolution techniques being described in the third section of the paper.

IV. FRAMEWORK

The approach aims to achieve two goals: to identify a conflict between security and privacy requirements and to find a resolution technique to resolve or reduce different issues. The process begins with elicit requirements that we will apply it to the approach. Once the requirements are specified, the next step is listing conflicts between specific security and privacy items. Strategies to resolve the listed disputes must then be used. A common method is to describe a problem with an example, propose a solution that keeps the requirement in mind, and apply this solution to the case.

FIGURE1: FRAMEWORK PPROCESS



A. *IDENTIFY REQUIRMENTS*

The first step of detecting conflicts is to review the literature to find out more about conflicting issue provide it with some examples to detect how this conflict effect the system. Below are the most frequent requirements in the security and privacy aspects of software engineering [9].

1) Security Requirements:

Authentication is the task of determining whether an entity is what or who it is declared to be. This process involves the validation of identity. **Authorization** is the next logical step, wherein the identified entity is checked for the necessary permission or privileges to access data and resources. **Confidentiality** allows for the limitation of access to or exposure of a specific resource as dictated by policy [10].

SECURITY REQUIREMENTS	PRIVACY REQUIREMENTS
AVAILABILITY	Anonymity
NON REPUDIATION	Unlinkability
CONFIDENTIALITY	Pseudonymity
INTEGRITY	Unobservability
AUTHENTICATION	Unlinkability
AUTHORIZATION	Undetectability
SEPARATION OF DUTIES (SOD)	
BINDING OF DUTIES (BOD)	
ACCOUNTABILITY	
AUDITABILITY	

Table1: elicit most frequent the security and privacy requirements being conflict

Non-repudiation ensures that a user or entity provides an undeniable signature that accounts for their actions. **Integrity** is responsible for ensuring that all information is accurate and consistent during its use and has not been altered unknowingly or otherwise. **Availability** assures that data is always accessible and can easily be provided to an authorized entity. Denying information can cause both inconvenience and delays,which may prove to be critical. **Separation of Duties** acts as a restricting agent for any individual to have too much or inappropriate control over the system. **Binding of Duties** similarly ensures that two separate entities are needed to have sufficient control over the system. **Accountability** is the requirement that holds entities responsible for their actions or lack thereof. **Auditability** ensures that a trace can be done on an entity's activities within the system. [11].

2) Privacy Requirements:

Privacy requirements are often in compliance with existing data laws or rules within a country. For a project to be compliant, they must be able to ensure privacy within the system. [12].

First, **Anonymity** allows entities to use resources or services without having to reveal their identity. **Unlinkability** ensures that an entity can use a service without being associated with the service itself. **Pseudonymity** gives the users the freedom to work under an alias or aliases, without having to provide personal information sufficient to determine their identity. **Unobservability** denies any entity from knowing for sure that a user is accessing a service, as well as the inability to track a user's actions while using a service or resource. **Undetectability** ensures that an entity cannot identify which user among a user pool is accessing the service. [13] With this, it is apparent that some aspects of security and privacy requirements are already in conflict with each other. Security requirements, such as **Accountability**, **Authenticity**, **Auditability**, and **Non-repudiation**, require a log of movement and activity within the system. However, these are directly in conflict with the privacy requirements of **Anonymity** and **Unobservability**, which should conceal the user's actions. **Binding of duties** and **Separation of duties** could conflict with **Anonymity** and **Unlinkability** as well since the steps to be executed would have to verify their identity. Other aspects may have conflicts which are not apparent at the requirements stage. For example, the security requirements **Confidentiality**, **Integrity**, and **Availability** depend on having proper authorization to access or modify resources. Identification is not necessary to achieve these requirements, but it is a common approach which may be used by the system developers. As such, it opens a potential conflict between the security requirements mentioned above and data minimization privacy requirements. Conflicts can also occur within each aspect, whether of security or privacy. These conflicts arise when more concrete requirements are specified. For example, if a user should be required to access a service using their alias, then it conflicts with the general concept of **Anonymity**. However, if some aspects supplement or overlap concerning requirements, then they cannot be considered as conflicts [14]. **Confidentiality**, **Integrity**, and **Anonymity**, which are different aspects but ultimately strive towards the same goal of protecting data against unauthorized tampering, do not conflict with each other.

B. MAPPING BETWEEN SECURITY AND PRIVACY REQUIRMENTS CONFLECTING

The matrix maps conflicts between security requirements and privacy requirements. While there may indeed be conflicts among security requirements themselves, this will focus on conflicts that cross the two aspects. The matrix helps to visualize the requirements with the most conflicts, which aids in identifying which ones deserve focus. From this matrix, **Anonymity** and **Unobservability** conflict the most with other security requirements. In order to have more visual mapping to point on most frequent requirements having conflicts. Based on our previous studies we found that those five security requirements are luckily being conflict with more than one privacy requirements. As it shown below

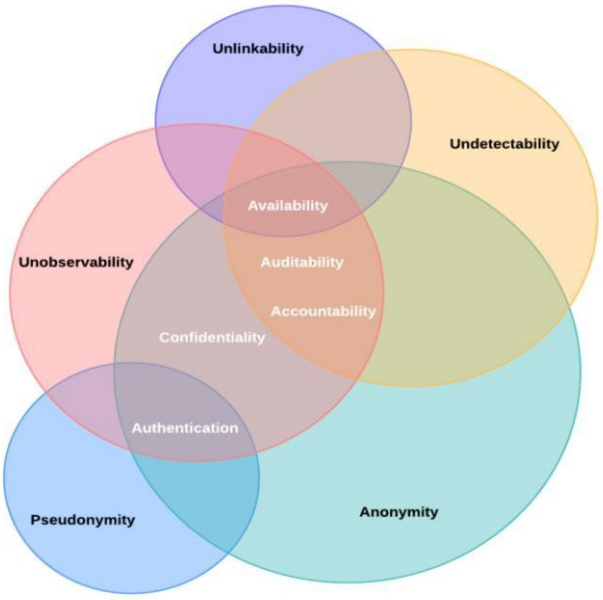


Figure2: detect conflicts between security and privacy requirements

		Security Requirements:										Privacy Requirements:				
		Availability	Non repudiation	Confidentiality	Integrity	Authentication	Authorization	SOD	BOD	Accountability	Auditability	Anonymity	Unlinkability	Pseudonymity	Unobservability	Undetectability
Security Requirements:	Availability							○				○	○		○	○
	Non repudiation											○			○	
	Confidentiality											○			○	
	Integrity											○	○		○	
	Authentication						○					○		○	○	
	Authorization					○		○							○	
	SOD	○					○									
	BOD												○	○		
	Accountability											○			○	○
	Auditability											○			○	○
Privacy Requirements	Anonymity	○	○	○	○	○				○	○	○	○	○	○	
	Unlinkability	○			○				○			○		○		○
	Pseudonymity					○			○			○	○			
	Unobservability	○	○	○	○	○	○			○	○	○				○
	Undetectability	○								○	○		○		○	

Table2: mapping conflicts between security and privacy requirements

As it appear to us at figure 2 that **Availability** as a security requirement is more complicated requirement while it involved with most privacy requirements therefore it apparently being conflicts with four privacy requirements: **Anonymity, Unlinkability**, **Unobservability** and **Undetectability.** Following we found that **Confidentiality, Accountability and Auditability** a security requirements could be conflict with three of privacy requirements. Finally **Authentication** security requirement always involved with two of privacy requirements (**Anonymity and Pseudonymity**) as we mentioned in the example in the introduction part.

C. *STRATEGIES TO RESOLVE CONFLICTS*

Conflict Resolution: is comprised of conflict management and negotiation. The former aspect is a process that after identifying conflicts between requirements, it could be a prioritization or negotiation. To have the right decision of which requirement the framework will support. We will describe further about those strategies and criteria to conceder to choose the suitable strategy in a next paper. In this part we enclose some common tools to support requirements, some tool can work with more than one requirement, while some tools conduct for a specific requirement. We will have a brief idea about each tool, after that we will classified them base on security, privacy requirements or maybe both!

Tools: The most requirement being conflict is Availability, therefore we could use Redundancy to the system to secure the information. Redundancy, or the duplication of critical points of the system, ensures that an application is reliable and available for its intended users. Should a function or component fail, another instance would be ready to take its place so that the system performs with little or no downtime [15].

However, a disadvantage is that redundancy increases both cost and complexity of the system. An architecture that correctly models the system is vital to the success of high availability. While redundancy is not necessary in many applications, it is a critical component if system failure or downtime has severe consequences.

Cryptography encryption of data is a common way of security of implementing confidentiality [16]. Standard examples include simple passwords, security tokens, and two-factor authentication. Both symmetric and asymmetric algorithms may be used to provide encryption. This kind of encryption works for security requirements (Confidentiality). For Integrity we have Message Authentication Codes (MAC): A fundamental technique to verify both the integrity and authenticity of transmitted data are Message Authentication Codes (MACs). Initially, the construction of most of these codes were based on pseudorandom functions which were either through fast block-cipher based algorithms or slower number-based theories.. Dummy Traffic occurs when a fake message is included in a mix network with the goal of confusing an attacker. With a dummy message, passive and active attacks on a network are more difficult, thus creating a more secure system [17]. Mixes usually generate these dummy messages, allowing for a higher level of anonymity and prevention of end-to-end intersection attacks. This method generally could apply on most privacy requirement except Pseudonymity. In the other hand we have some resolution techniques to protect privacy requirements: Third-party Conflict Resolution, is the most common method enlists the help of a neutral third party for management or resolution of a dispute. With the unbiased opinion of a third party [18].conflict resolution can be made in a calm and organized manner. This resolution also ensures that working relationships are somewhat preserved as a mediator is in place. This method is suitable for Anonymity, Unlinkability and Undetectability. Zero-knowledge Protocol allows a

party to prove that a statement is certainly true without revealing additional information [19]. This protocol must have the following properties: Completeness, that the honest verifier should be convinced by an equally honest prover; Soundness, which the probability of satisfying a verifier that a false statement is true is minimal; and Zero-knowledge, that a cheating verifier can learn nothing from the statement but the truth. Usually this method mechanism for Anonymity.

Trade-off Analysis is a simple give-and-take wherein one quality, quantity, or property is lost or diminished to increase these in another aspect. Trade-offs are usually obtained through discussions and sharing of insights. [20].Toward resolve conflicts for Pseudonymity requirements we should use Public key [21].

Pseudonymity provides a consistent identity without having to tie it to a specific physical person or organization. It allows for the advantages of having a known identity, such as accountability, while still maintaining anonymity. One way to implement pseudonymity is through a public key that verifies digital signatures anonymously made by the holder of the corresponding private key. Users can create their own public keys for digital pseudonyms. Each key pair may be bound to an email address, self-certified, and used thereafter. Moreover, Steganographic technologies to resolve conflicts in Unlinkability and Undetectability requirements. Stenography is the art of invisible communication, a technique where data is transmitted in a way that conceals the existence of another message. [22] Unlike cryptography, which only encrypts the message itself, stenography encrypts the message such that unauthorized parties would not be aware of a message at all, this method works well because a change in the least significant bit (0 to 1 or vice versa) does not drastically change the overall appearance of the image.

We categorize those tools base on:

1- Techniques are suitable for both security and privacy requirements, that's mean that one technique could support either security or privacy requirements.

2- Some techniques support as for privacy requirements only or security requirements. This decision based on a previous step (requirement prioritization) to know which requirements the analyst will choose to support.

1-Techniques suitable for either Security or Privacy requirements

SECURITY AND PRIVACY REQUIREMENTS	TOOL TO SUPPORT REQUIRMENT
Anonymity VS Confidentiality	Cryptographic, Steganographic technologies, Onion routing
Unlinkability VS Confidentiality	Cryptographic, Steganographic technologies, Homomorphic encryption, Onion routing
Unlinkability VS Integrity	Cryptographic
Pseudonymity VS Confidentiality	Searchable encryption
Undetectability VS Confidentiality	Steganographic technologies

2- Techniques suitable for Privacy requirements only, or Security requirements:

PRIVACY REQUIREMENTS	TOOL TO SUPPORT REQUIRMENT
Anonymity	Cryptographic, Steganographic technologies, Onion routing, trusted third parties, Dummy traffic, Zero-Knowledge Proofs of Knowledge (ZKPoKs), K-anonymity
Unobservability	Dummy traffic
Pseudonymity	Searchable encryption, Public key
Undetectability	Dummy traffic, Steganographic technologies
Unlinkability	Cryptographic, Steganographic technologies, Homomorphic encryption, Onion routing, K-anonymity, data hiding, trusted third parties, dummy traffic.

SECURITY REQUIREMENTS	TOOL TO SUPPORT REQUIRMENT
Confidentiality	Cryptographic, accesses control enforcement, Symmetric key and public key encryption, Steganographic technologies, Homomorphic encryption, Onion routing, Searchable encryption
Integrity	Cryptographic, accesses control enforcement, message authentication codes (MAC) redundancy and comparison
AVAILABILITY	Redundancy to the system

D. EVALUATE OUTCOME RESULTS:

Conflict outcomes depend on the method used to deal with the conflict. Each conflict has desired output and stakes in interpersonal relationships, so these factors help determine the issue as well [23].

The first possible outcome is a **Collaboration**, wherein all desired output is achieved. It is a win/win strategy because relationships between both parties are preserved or strengthened while reaching the goal of the project. Another possible outcome is a **Compromise**. This outcome provides partial satisfaction for both parties as a fraction of their desired result is achieved. A Compromise al so preserves the relationships between both parties but can also cause minor strain during negotiations. The third outcome occurs when one party yields to the other: **Accommodation**. The yielding party conforms to the demands of the other party to preserve o r strengthen their relationships. The opposite of this outcome is **controlling**, wherein a party forces the other to follow their desired outcome. This outcome often results in consequences to the losing party, placing a significant strain on the relationship between the parties. Finally, **Avoiding** is an outcome that happens when both parties quit and abandon their

desired results as well as their working relationship. In this case, both parties lose due to the withdrawal.

V. CONCLUSIONS AND FUTURE WORK

We proposed a framework to identify and mitigate conflicts between security and privacy requirements, being motivated by previous studies that illustrated the problem with a lack of solution. The framework have four sequence steps: The first step of identifying conflicts is to spot an attention to this problem from the literature to realize about conflicting issue. After that we focused on the most frequents requirements being conflicts to set our priority in order to resolve conflicts. In order to resolve conflicts we should follow some strategies that would be one of framework outcome. Therefore first we should give each requirement a value and do a prioritization for requirements in order to decide which requirement the framework should support. After that we present some tools to support requirements base on its natural. Final section we have the evaluation criteria to measure whether the resolution method solve the problem or at least reduce it? Or we have to reconsider using different resolving method. In the future, we will describe more about prioritization techniques and how to set a criteria to choose the appropriate technique. After that we will apply this framework on E-Health case study, to observe the problem and resolution techniques , in order to validate those solution we have to apply it in a real case study in order to validate effectiveness of the framework and whether it needs more improvements.

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Utilizing User Values to Generate System Requirements for a Geographically-dispersed Workforce

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***Abstract*—A geographically-dispersed user base presents challenges for requirements engineering in enterprise systems, with problems including limited access to end users, a lack of trust between users and developers, and poor informal communication. Not only must these standard organizational and personnel difficulties be taken into consideration, but geographic dispersal also complicates the steps of the requirements engineering process. This paper investigates whether a method can be created to develop requirements for just such geographically-distributed outposts within the same organization. A psychological instrument that measures basic values was coupled with individual interviews to collect the value profiles for frontline security guards throughout Sweden. The results were used to generate requirements for field equipment, with goal- and feature models generated as a final result.**

Keywords—values, feature modeling, goal modeling, requirements engineering

I. Introduction

A large proportion of projects in software development are only partially completed, and many resources are wasted not only in the actual work development but also to remedy problems that arise. For example, several factors such as the company's culture, past information systems, and communication between developers and users in the development process have been identified as critical for the successful implementation of ERP systems in enterprises [5].

Many aspects complicate the development and implementation of information systems in modern organizations, with the organization's specific context being a primary cause. Specifically cited as being particularly problematic are organizations with a geographical spread. Different priorities and individual values can lead to different needs, which in turn means that it is difficult to predict a uniform manner in which a system will be received [11]. A specific example are multinational companies that implement the same ERP system in different countries may encounter problems if business cultures of the various countries differ. [5] Since development and implementation are so closely coupled with business processes, to create problems in those processes significantly complicates the corporate environment where the system will be implemented [17], compounding the extant difficulties.

Changes often occur as a result of the organization's members continuously adapting to everyday unexpected challenges and opportunities [13]. External factors such as geographical position may represent different conditions for employees in the same profession, which in turn could lead to different requirements within a single system. So far, much of the research conducted around the challenges of distributed organizations occurred on an international level and the differences that occur within an organization as a result of national culture [3] [11] [17].

Thus, a geographically-dispersed user base presents challenges for requirements engineering. Not only must the various workplace needs be taken into consideration, but the geographic spread also hampers the requirements process. Problems identified with requirements for geographically-distributed organizations include limited access to end users, the lack of trust between users and developers and poor informal communication [3].

Several definitions of the concept of organizational culture include those of [4] [6] [14]. Differences in culture within an organization may also result from other factors. Change within organizations does not occur as a result of executive decisions, and it is not necessarily a conscious process. Common to these is that they mention, among other things, the shared values within an organization as one of the foundations of what constitutes the organization's culture. Some research has previously been done to examine how values affect system development [18], how they can be integrated into enterprise architectures [20], and how psychological methods to measure and quantify the values can be used in requirements engineering [25].

This paper intends to investigate whether a method that measures individual values can be used to develop requirements for outposts of a diverse organization. More specifically, an instrument from psychology was deployed to discover the value profiles of the employees of a large enterprise with a geographically-dispersed workforce, with the resulting data being used to develop system requirements.

II. Background

In this chapter, the underlying theories and existing research related to individual values are presented. Although the method intends to apply in this paper is a method for elicitation of user requirements, one of its primary resources comes from psychology, while the other concepts come from traditional software engineering.

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A. Users

It is important to see how organizational culture influences the system's user requirements for information system. Several approaches to this task have been made, and below is a summary of research done on how users are involved in the requirements process. Research on how values and preferences are used to adjust products is also presented to the reader.

The concept of stakeholder is used to designate the partners in the development process that can place demands on the eventual system. These are, at minimum, the originator of the system and the system's intended users, but the number of stakeholder groups can be much larger than that. Stakeholders all have needs and objectives which must be supported and met by the system.

Research has shown that there is a statistically significant correlation between successful systems development projects and projects involving users in requirements gathering. However, a lack of user involvement is often one of the major problems of the requirements process. Users who are, to some extent, involved in development can have a greater impact on system requirements.

Recently, Agile techniques as Scrum and extreme programming (XP) have become popular. Such development methods emphasize communication with stakeholders, along with end-user documentation, and specifications. This has led to the emergence of so-called Agile requirements. In Agile development methods often use so-called User Stories instead of requirements. User Stories are brief descriptions of predetermined syntax of what the user wants to do with the system that are discussed and validated by acceptance tests [2].

[1] presents the involvement of users in innovating products in eight companies, and created a framework for classifying user involvement to better understand how companies use the users to develop and innovate their products. They concluded that involvement of users falls into one of two categories. The first is when users are aware of their own input, for example by conducting surveys or allowing themselves to be interviewed or observed to give developers a better idea of how the system is used. But in recent years, the second type has become common: for users to be involved without being aware of it, and to have their behavior documented and analyzed to find patterns, in order to reach a deeper understanding of the user's habits, preferences, and behavior.

1) Segmentation of Users

Customer segmentation has been applied in requirements engineering by [25] as one of the fundamentals of their Consumer Preference Meta-Model (CPMM). This customer segmentation tool is used to identify the right customers for a product or service. By sharing all available potential customers into a homogeneous segment, subsequent efforts to focus are able to better focus on it. Whatever method used, at base it is the idea that unprofitable customers may be overlooked [10].

Of these, [22] notes that non-observable, product specific segmentation variables are often the most effective, although they are often also by far the most exhausting type of variable to segment. One way to segment the market in a non-observable, product-specific manner is benefit segmentation. One of the first proponents of this type of segmentation was Russell Haley [7] who experienced that the former, demographic methods of segmentation were inadequate since they are primarily based on descriptive, and not causal factors. He argued that consumer behavior was affected by the advantages and qualities they sought in a product, not demographic variables. Even if a single property might be found in the majority of the market (such as low price, high quality, etc.), one can see the clear market segments by looking at the combination of sought-after properties, and the relative importance ascribed to each property.

Since its introduction, benefit segmentation has been applied in a variety of areas and has been subject to both criticism and further development It has also been used to segment donors to charities and draw conclusions about which aspects of a charity attract different types of donors, and the characteristics of an organization that types of donors tend to give the most value [8]. The strength of this type of segmentation, as described above, is similar to the attributes identified as relevant for the requirements process where one of the main objectives is to create the right system for the customer.

2) Individual Values

Schwartz describes his Theory of Basic Human Values [15] as a set of ten values that are held in various degrees by all people, regardless of cultural affiliation. Values reflect what individuals deem important in life, and individuals will ascribe different values different weights. When values differ for specific goods, such as the taste of a type of alcohol, we have a positive attitude towards the thing that we experience which helps us fulfill our values.

The values are in order: Self-direction, describing an individual's tendency to think and act independently; Stimulation, the individual's search for excitement and challenges; Hedonism, the search for happiness and sensory satisfaction; Achievement, success in social context; Power, control and dominance in social contexts; Security, which includes both the stability in relationships and life, as well as physical protection from threats and damage; Tradition, respect for the customs and practices; Conformity, adaptation to social norms; Benevolence, the will to preserve and improve the well-being of those to whom the individual is close; and finally Universalism, the desire to understand, appreciate and respect nature and all people, not just those closest.

Of the different methods that have been proposed to measure how much weight a person puts on each value, this research employs two: Schwartz's Value Survey (SVS) and its related Portrait Value Questionnaire (PVQ). SVS is a questionnaire that measures how much weight each individual put on a value by asking them to evaluate the properties and principles related to the fundamental values of a nine-point scale. These can be, for example, loyalty and honesty for good will, ambition and influence for performance or freedom and curiosity for self-government. On the other hand, PVQ is a questionnaire that measures the importance each person puts on a value indirectly. The questionnaire consists of a number of statements about a hypothetical person, for example, "It's important for him to have fun. He likes to indulge things". The respondent answers on a six-point scale how similar they like to be to the described person. The responses then calculate how important each of the ten values are for the respondent.

Because individuals interpret the answers given different scales, there is no way to obtain an absolute value of how important each value is for the respondent. The result of both SVS and PVQ therefore intends to provide a value that indicates how much weight each respondent places on a value relative to other values, rather than an absolute value. This is achieved by taking the mean of all the respondent's answer from each response [16].

B. Goals

A concept that has emerged within requirements engineering are the goal orientation. Targets have been defined as anything a system intends to achieve. They can be formulated at various levels of abstraction and thus apply to both approaches and strategies at a high level, as well as the specific features of the system. Targets have been used in requirements methods, either as a core or as a supporting component [23]. They are an important aspect of requirements engineering, including the requirements' stakeholders, helping to detect redundant or irrelevant requirements and help provide a more complete overview [22]. In a compilation of studies, Yu [24] indicates that the goal can be used in requirements, among other things, to support the elicitation, anchor requirements for its environment and organization, and resolve conflicts among stakeholders. Goals can be produced in several different ways. Sometimes, given explicitly by stakeholders and sometimes they need be elicited, for example, by looking at the goals implied by the expressed requirements. The basic goal can be refined and abstracted to new goals. Goals can be further classified in various ways such as soft or hard, depending if the criteria for assessing whether or not they are satisfied is objective or not [22].

III. Case Summary

As this research deals with the differences in requirements based on the geographical area of operation, the population was sorted by the city they in which they were operating. The two segments selected were guards operating in offices in metropolitan area and guards working in offices outside cities. The division of offices took place according to a size classification of the places specified by the Swedish Agriculture Department. Table 1 shows which offices participated, along with the community size classification and the population.

TABLE I. Classification of Locale according to Swedish Agriculture Department

Office	*Size Classification*	*Population*
Arboga/Koping	Rural/Countryside	13 858/25 557
Gothenburg	Metropolitan Area	548 190
Kiruna	Sparse/Rural	23 178
Örebro	City	144 200
Stockholm	Metropolitan Area	923 516
Akalla/Kista	Stockholm (Suburb)	
Stockholm City		
Åhlens		
Söderhamn	Countryside	25 785
Södertalje	Metropolitan Area	93 202

In the selected offices all employees were asked to answer the questionnaire. All respondents were then asked to participate in interviews.

A. Quantitative Data Collection and Results

The first part of the data collection was to distribute a questionnaire containing the PVQ and a number of questions on demographic factors such as language, gender, age and the like. In addition, six issues relevant to the issue added.

The first question for the demographic questions concerned the services and equipment to which the respondent has access. The second concerned which operating system was preferred. As the survey was sent to both watchmen and security guards separated the third question out these two professions. The fourth question concerned how long the respondents worked in either profession. The fifth question was whether security guards are always positioned to a specific area and whether they primarily worked in place or on foot patrol. The last question was for their specific office.

To avoid losing potential interviewees there were alternative ways to report interest. When data collection started, it was made parallel inside and outside metropolitan areas. For the Stockholm area offices, it was possible within the time and resource constraints to visit the offices in person. This meant that the purpose of the survey could be explained, and thus increase the participation and the response rate. For offices in other locations in Sweden there was a collaboration with Securitas to get department heads who were interested in allowing their offices to participate. Data was collected at a distance from both urban and rural.

The total number of respondents was 72. The gender distribution of the respondents matches the distribution of Securitas as a whole, based on the figures given in the company's annual report for 2015. The test revealed significant differences between the rural and urban aggregate classes. In addition to the statistical significance between metropolitan and non-metropolitan additional statistical correlations in terms of number of years of service and gender were also found.

TABLE II. Summary of Survey Results

Position	***Number***	***Percentage***
Watchmen	57	79%
Guard	5	7%
Both	10	14%
Characteristic	***Number***	***Percentage***
Stationary	13	18%
Mobile (rounds)	57	79%
Indeterminate	2	3%
Gender	***Number***	***Percentage***
Male	52	72%
Female	20	28%
Age	***Number***	***Percentage***
21-25	5	7%
26-30	18	25%

Position	*Number*	*Percentage*
31-35	17	24%
36-40	12	17%
41+	19	26%
Indeterminate	1	1%
Years of Service	***Number***	***Percentage***
1-5	21	29%
6-10	21	29%
11-15	10	14%
16+	18	25%
Indeterminate	2	3%
City classification	***Number***	***Percentage***
Metropolitan area	47	65%
City	10	14%
Rural	12	17%
Rural/Countryside	3	4%

The average score for Securitas was compared with the average for the whole Sweden, based on data from ESS Round 5 [12]. Minor differences were found in the assessments of Universalism (0.32), Hedonism (0.36) and Stimulation (0.21). The main difference is in Universalism which differs by 0.64. In other respects, Securitas' values mirror average Swedish values.

TABLE III. ESS-VALUES FOR SWEDEN AND PVQ-VALUES FOR SECURITAS

Value	Sweden	Securitas	Difference
Self-Direction	0.57	0.51	0.06
Stimulation	-0.57	-0.36	0.21
Hedonism	0.13	0.50	0.36
Achievement	-0.85	-0.85	0.00
Power	-1.08	-1.34	0.26
Security	-0.12	-0.23	0.11
Tradition	-0.05	-0.15	0.10
Conformity	-0.31	0.02	0.32
Benevolence	0.97	0.91	0.06
Universalism	0.86	0.22	0.64

However, there were large differences in values which could be seen especially well between the urban and rural communities. Major differences could be measured in the Universalism (0.56), Stimulation (0.46) and Hedonism (0.46) and a t-test shows that all are statistically significant. Differences, though not statistically significant, were also measured in Safety (0.35), Self-direction (0.32) and Benevolence (0.30).

TABLE IV. METROPOLITAN VS. OTHER URBAN CLASSIFICATIONS

Value	Metro	Other	Difference
Self-Direction	0.62	0.30	0.32
Stimulation	-0.20	-0.66	0.46
Hedonism	0.64	0.22	0.42
Achievement	-0.78	-0.98	0.20
Power	-1.33	-1.36	-0.03
Security	-0.35	0.00	0.35
Tradition	-0.20	-0.06	0.14
Conformity	-0.18	0.38	0.56
Benevolence	0.80	1.10	0.30
Universalism	0.20	0.25	0.05

The valuations where a significant or statistically significant difference was measured higher for the guards employed in larger urban areas were Hedonism, Stimulation, and Self-direction while for guards in the smaller communities Security, Universalism, and Benevolence were higher.

A notable difference was observed in Universality between those who have worked one to ten years and those who have worked longer. Those who have worked in the profession for over ten years have an average of 0.4 which is about half the Swedish average. Those who had worked less than 10 years had an average of 0.06. Again, the results of a t-test show that the difference is statistically significant.

TABLE V. YEARS IN EMPLOYMENT

Value	1-5	6-10	11-15	16+
Self-Direction	0.57	0.35	0.49	0.69
Stimulation	-0.35	-0.41	-0.62	-0.19
Hedonism	0.81	0.47	0.44	0.31
Achievement	-0.55	-1.08	-0.97	-1.03
Power	-1.16	-1.22	-1.32	-1.72
Security	-0.26	-0.05	-0.62	-0.22
Tradition	-0.24	0.04	-0.07	-0.22
Conformity	-0.16	0.11	0.24	-0.03
Benevolence	0.76	1.00	1.09	0.86
Universalism	-0.01	0.11	0.45	0.46

A slight difference in basic values between men and women at Securitas compared to Swedish averages was discovered. When the respondents are divided by gender two statistically significant differences are observed. Hedonism is higher among women than among men, with the difference 0.57. Interestingly, in this value, both women and men express a higher value than their counterparts in Sweden. The other statistically significant value is Security, where women show a much lower value both to their colleagues (0.45) but also the

rest of the population (0.46). The men are closer to zero than the rest of the population. In this case, it is thus the segment of women that affect the entire enterprise security value.

B. Qualitative Data Collection and Results

The second part of the data collection was performed through interviews of guards who expressed an interest to further participate in the survey. The interview questions were based on Schwartz's basic values, which each had a score or several questions that were linked to the person's work and equipment. In addition to these, every interview ended with four self-assessment questions with the aim of highlighting how open to change those interviewed were. That self-image was then compared with the responses received in the survey and during the interview. The interviews took between 30 and 45 minutes per interview, each with a participant, an interviewer and an observer to take notes. The observer also recorded interviews. After all the interviews were conducted, recordings were transcribed, consolidated, and coded.

This second stage of data collection was an attempt to try to understand how the guards with different values differed in their system. The results of PVQ shows that the values Universalism, Safety, Stimulation and Hedonism differed in the highest degree between guards in and around large cities. During the interviews, the participants themselves decide what equipment they recommended for communication equipment.

Stimulation. Individuals who value high stimulation prefer variety, challenge, and excitement. The value of Stimulation was higher on average among the urban guards than the rest of Sweden. A clear sign of how the high values of the stimulation can be expressed was in how the guards talked about which aspects of their job they appreciated. All of them said they liked their work. Much frustration was expressed regarding the equipment by those who had high Stimulation values, this being because it restricted them from doing their job the way they wanted. They focused particularly on the strict manner in which their PDA demanded that tasks be performed, while the guards feel that there are many ways to solve problems in their work that are not possible because of limitations on the PDA. Even battery and software problems were also expressed to some degree as related to Stimulation. Software crashes and the need to charge the PDA at the station in the middle of rounds forced the employees to detour and prevented them from doing their job.

Safety was certainly one of the statistically higher values among the guards outside the major cities. Schwartz defines security both in terms of physical, personal safety, such as reluctance to put ones' self in danger. When respondents disagreed on Security it was often associated with radio and alarm equipment: the ability to summon reinforcement and help in vulnerable situations were of great importance for guards both in and outside the city. A rural guard remarked on how radios had fallen into disuse among colleagues, and thus no longer filled the function they were designed to fill. Guards in the city remarked on the poor radio coverage, and that extra security measures were often necessary to ensure that their colleagues were protected.

Conformity Schwartz characterizes Conformity as a deterrent from acts that could violate social norms and expectations. Loyalty and responsibility are important for those having high conformity. In interviews, guards seemed to express themselves in accordance with their respective groups' profiles. Many aspects of the work were linked to the group and group membership. One of those interviewed expressed that they learned how to work almost entirely by complying with what their fellow staff did. Guards who belonged to the metropolitan group also criticized some colleague's tendency to exceed the unwritten rules of work but also those which they felt impacted the group. However, it was difficult to find strong links to some articulated demands in this value. When those interviewed spoke of alarm functions, it was an important part in their ability to perform their data and there was a common belief in their colleagues' willingness to support them when they are alerted. However, they experienced all the coverage of these systems sometimes was lack of which limited them and their colleagues' ability to help each other. Mainly where the shortage was radio coverage but also the battery life was mentioned as a limiting factor. Correct use of radio was also important when communicating: operating error with the radio could bring strong criticism from others colleagues.

Hedonism The company's average is a bit over those of Sweden. The non-metropolitan value itself is slightly above Sweden's value while the metropolitan value is a bit higher than the rest of the company. Hedonism concerns an individual's satisfaction and search for pleasure. With this in mind, it is difficult to make clear links between this values and statements about the requirements: there was some frustration expressed around non-functioning equipment that hampered the experience of joy in their work, but it might well have been because it hindered them in their search of happiness by following their other values.

The two values where the statistically significant values were measured in large cities, Hedonism and Stimulation, can both be classified as calls for openness. Although Self-direction measured a comparatively high value in large cities also falls under openness. Likewise, the values measured higher values outside the big cities, Universalism and Safety, sorted under valuation conservation group. In the future, when the discussion is about how values reflect organization and culture requirements affect these valuation groups to be used instead of the individual values

The reason for this is that during the interviews it has been difficult to draw a clear line between what valuation is behind a specific statement. This is true to some extent consistent with the basic values which possess no strict boundaries between them, but rather should be understood as a spectrum. Because the values that differ in and outside the metropolitan is near another on the spectrum, it becomes natural to instead analyze the results by valuation groups.

IV. Requirements Engineering Results

A. Values and Requirements

Values have been described as fundamental beliefs about what is important in life (for such as freedom, power, pleasure, etc.). They are closely connected with the target (for example, show competence according to social standards, stability in relationships and society, entrustment to social and cultural practices and ideas, etc.) and have a major impact on how people are motivated.

It has been suggested that individual values can be a way to gain a deeper understanding of what users want out of a system. To see if it is possible to use individual values within requirements analysis, Sutcliffe [19] applied a value-based method for the development of a platform for e-health. During the study, they found, among other things, a strong relationship between values and non-functional requirements but mainly support their theories. From the outset there were two distinct user groupings close but not quite overlapping interests. Sutcliffe and Thew found that although the groups prioritized different things common interests could be identified, interests for which the platform could act as a venue for the two groups.

In a similar approach, Zdravkovic [25] proposed a method based on consumer values to develop requirements for different configurations of a Software Product Line (SPL). They used Schwartz's Theory of Basic Human Values, combined with Holbrook Theory of Consumer Values to identify consumer preferences of user groups. They then used these preferences as input to the requirements engineering process via a metamodel which is used to support the combination of functions suitable for and user segments. To test the model, they applied it to the development of a prospective platform for online education.

The Consumer Preference MetaModel (CPMM) presented in Figure 1 is used to house, classify, and categorize consumer preferences for products or services. It aims to accept the preferences from different sources of data, as well as to manage them according to different value.

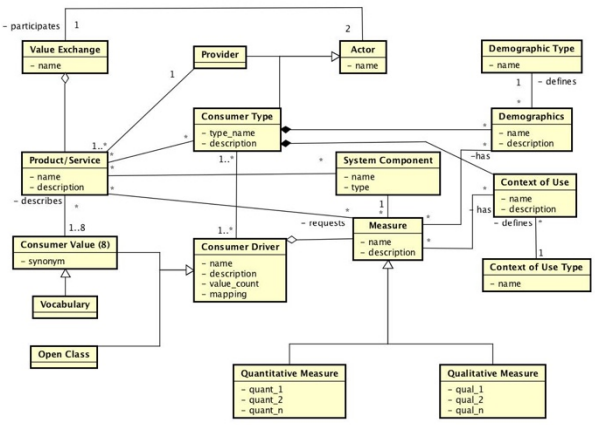


Fig. 1. Consumer Preference MetaModel

B. Method

The paper intends to utilize an update to the work of Zdravkovic, [25]. The approach uses the results from PVQ to identify differences between the values of the different user groups and then use requirements gathering interviews and other data points, such as from demographics, to identify requirements related to specific values.

As a first step, the users were placed into appropriate segments, in this case based on geographic location. Then to gather the user requirements for the system, their basic values were measured according to the PVQ. This quantitative method provided us with the ability to see which values were more or less important both to individuals and to different aggregations that could be created, based on the collected demographic data. .

As the second step, qualitative data was collected method to discover what features the user base expected to get out of the system. This was accomplished through semi-structured interviews. These features could then be given an approximate "weight" or priority, based on the importance of a particular value. The mapping between these various data points is accomplished via the metamodel found in Zdrav.

In the final stage, models are drawn up to illustrate how the system functions are intended to support users' goals and values. iStar was used to generate SRM and SDM model that expressed goals as supported by resources and their relationship to soft goals. Feature models were created to display how specific features supported specific system features. The models are also able to illustrate the differences in values and corporate culture between user segments.

C. Goal Derivation

Two overall values are identified which are then matched against a valuation group. Personal Safety is supported by the qualities that Security has, this group supports in turn the satisfaction of valuation group Conservation. Effective work performed, supported or hindered by qualities of the equipment affects the guards' ability to do their work, and these qualities affect the satisfaction of those who value Openness to change. Two qualities support both *Preservation* and *Openness*: *Minimal Equipment* and *Support Cooperation*. These affect the perceptions of guards as well as how effectively they feel they are carrying out their work. In the model, there is a certain overlapping of the links between different data and the various resources. This illustrates a redundancy in the equipment that can be used to perform a task. This redundancy has effects on both quality groups. This means an ability to adapt to the equipment to be most suitable for a given time and the circumstances at the time, which can increase both personal safety as well as the ability to perform work. However, this also means a disadvantage when the redundancy created by a larger variety of tools carried than necessary. The amount of equipment can be connected to the idea that equipment should not be in the way (soft goal *Minimal Equipment*), seen in Figure 2. Additionally, the effectiveness (in the sense of Efficiency) is damaged by the amount of gear thus preventing this quality from being achieved.

1) Proposed Future View of the Company

The interviews identified a number of functional and non-functional requirements by coding any statements which could be linked to some sort of requirement based on needs, wants or desires connected to one or more values with more or less strong connections. The requirements taken from of the different interviews were compared to reduce the number of duplicates and where it was possible to give greater weight to the individual requirements.

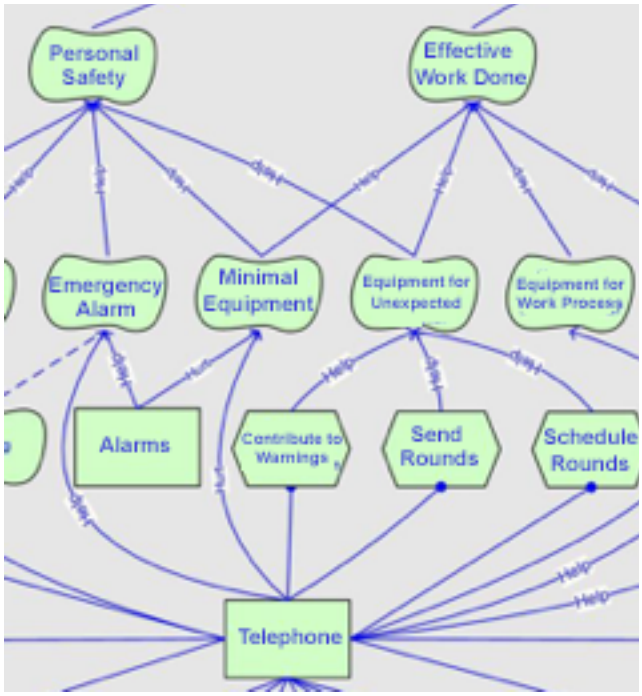


Fig. 2. Partial view of SRM

Two resources from the present state have been removed and the functions linked to them have been transferred to the remaining resource phone. Likewise, the new features that respond to the needs identified were also added to it. Broadly speaking the model contains some of the same functions as at present but with less redundancy. To some extent, a device with several systems alarms was retained because it has a strong link to personal safety while its awkwardness of use as judged to be moderate.

D. Development of the Feature Model

The feature model (Figures 3 and 4) illustrates the proposed IT solution for the company and how the new functions support the guards' goals and values.

The features added in future system were grouped under two value groups Preservation (Personal Security, see Figure 3) and Openness (Work done Efficiently, see Figure 4).

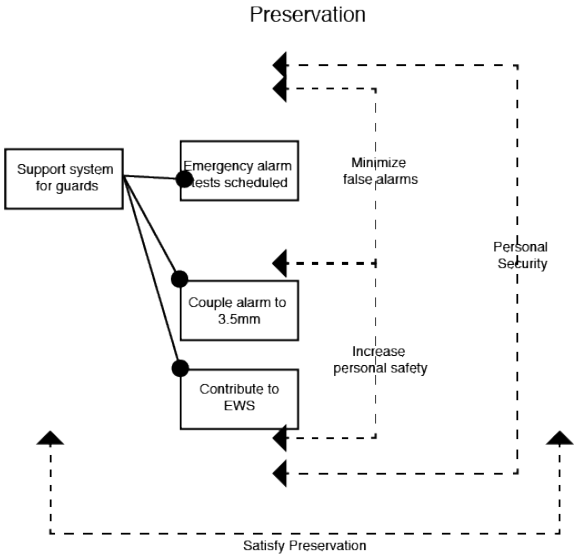


Fig. 3. Highlight of Feature Model of showing Preservation

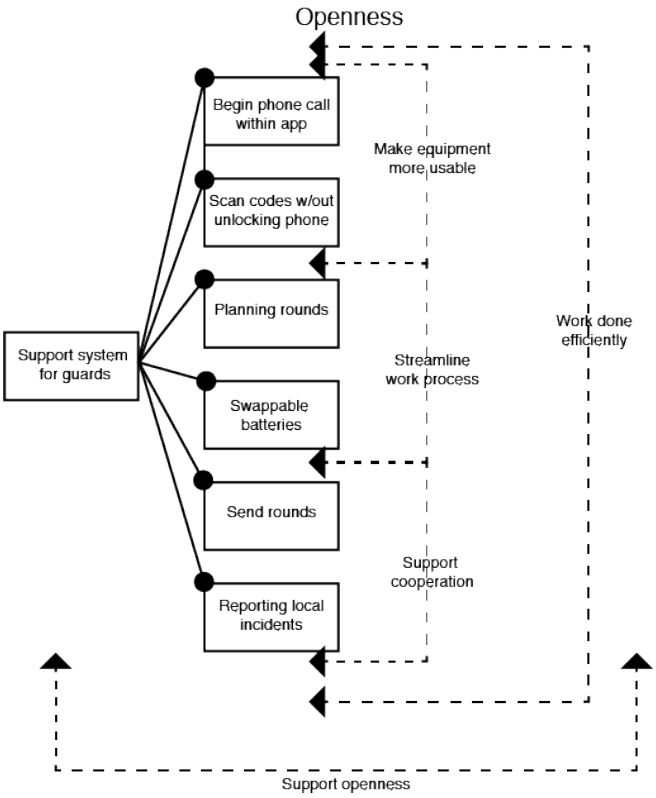


Fig. 4. Highlight of Feature Model showing Openness

Two of the new features are intended to increase personal safety while a third is intended to change the perception of the emergency alarm. The first feature seen in Figure 4., called *Couple alarm to 3.5mm* contributes to increased safety by giving the phone a physical alarm function while also makes the equipment easier to use. This assumes that the user has enabled the feature when disconnecting the 3.5mm jack sets of a panic alarm. It also further develops the idea that buttons should provide the same result when activated. This is represented by a feature contribution link between the telephone and emergency alarm as seen in Figure 2. The function can be used for a wide variety of messages, including temporary instructions, it is, however, primarily intended to be a tool to get information that helps users to more proactively respond to changing circumstances. Examples would be an unplanned bridge opening, policing in a specific area or information about extreme weather. The operation is also intended to facilitate collaboration between users, then these are supposed to be able to contribute information.

Figure 3 represents the feature task *Contribute to Early warning system (EWS)*. Scheduled function tests for the emergency alarm intend to remedy the stigma that exist around the use of emergency alarm and to increase confidence in it. Regular invitations to test a function can make the user more inclined to use this function when the user is experiencing a need for it. The frequency of how often a single user to be scheduled to perform functional test of the emergency alert can be based on how often it performs tests without prompts from the system.

Figure 3 also represents the task *Emergency Alarm Tests Scheduled.* Efficient work performed falls three subgroups, the first of these is make the equipment easier to use. Moving the PDA and radio functionality to the phone, minimizing the amount of equipment sets challenges in the implementation of

the functions in that phone is not built specifically to support guard work. The phone must be used to run the app, making calls more difficult, although function *Begin call within the app* is supposed to fix this, as seen in Figure 4. This feature means that users of the application can start a phone call, for example, with a contact or a customer. This is to allow a user to use the phone for normal phone calls without having to change the app already running. This also means that the calls are automatically connected via the monitoring center, something which is prescribed but rarely obeyed because the process is tedious. For these two reasons the phone in the diagram is linked with positive contributions link to the qualities of equipment adapted to both the work processes and also to secure communications.

In a similar way, *Scan codes without unlocking the phone* is meant to help to make the phone easier to use as a tool in the work as a security guard. The function means that codes can be scanned directly, not having to unlock the phone, either by a button on the lock screen or by using a hardware button. In addition to making it easier to use the equipment's help function, it also reduces battery consumption which is cited as an obstacle in the work. The second subgroup, *Streamline work process* consists of planning of the rounds. This makes it easier for users to adapt to new circumstances, the can move on to the data originated, the user is unfamiliar with the data and how they are geographical or similar. A side effect of this feature is that it is easier for the user to vary the order the tasks are performed from pass to pass, making it harder for outsiders to predict guard's movements.

As seen in Figure 4., the group's second function is *Swappable batteries*. The ability to replace the batteries will mean that user-replaceable battery on the user's data prevents it from charging the battery during work. It also implies that used batteries can be recycled and new ones acquired without the system needing to be decommissioned or it loses charge faster than it can be charged and thus the system is unusable. The ability to implement this feature, however, is dependent on the hardware platform which are selected so permits. In Figure 2 this state is represented through the contribution link between the phone and adequate battery life.

The third and last in the group's operations that are intended to support cooperation. One of its features include *Send rounds*. It is designed to make users more responsive to changes that occurs during a session by a user can take over the rounds from another having difficulty in performing their duties. If desired, this function is implemented limitations on how often or how many rounds can be sent between users, alternatively, function require approval from the supervision of a high frequency of switching is not desirable.

The last feature in the group, reporting of local events is a function that provides function *Take note of key information on hazards, incidents and warnings* with local information users believe that their colleagues should be aware of. Some information is intended to be fed out of line as described above, and the opportunity to contribute to this system is intended to users to feel more connected with each other. To increase system reliability for individual users, the GPS in the platform should always be enabled. This could be accomplished by rooting the hardware. This means that users cannot accidentally turn off positioning but also that the device can be tracked even if it could be restored to factory settings. A rooted unit would also cause unwanted features to be removed completely.

E. Feedback from the company

The results from the application of the method was presented to two company representatives who provided a number of comments. Why the device does not allow the acknowledgment of the distress alert is unclear, as is whether the proposed configuration of the devices could achieve this requirement. Although a minimum amount of equipment is desirable, partly for the reasons indicated in the study, but also for economic reasons, a certain level of redundancy in the devices that support two-way communication was necessary.

Remarks were also made that the features of the imagined future state supported by the device phone do not necessarily need to be carried out by a smartphone, as the model assumes, but can carried out by an arbitrary handheld. In the selection of the hardware used to perform the necessary functions can its features withstand the all-important economic factor? All units currently used meet the requirements of resistance and can handle the wear and tear of the job. A smartphone is cheaper to buy than a specially developed PDA device, but is not specifically designed to withstand the guards working conditions. This can result in the devices breaking and wearing out more frequently, which would increase costs in the long run. The cost for the purchase of smart phones that meet the requirement level would reach such levels that it becomes more reasonable to develop the handheld device with the features and physical buttons as needed. Extensive use of networks operated by other companies also brings security to be explored: it means a dependence on other companies deliver their services even under extreme conditions. This then led to concerns about the interception of telephone traffic. However, these concerns were dismissed by the admission that these problems also existed in the current radio system and was beyond the company's own control.

1) Observations on the work done

The current study is intended to examine how well psychological methods to measure individuals' fundamental values to support requirements engineering processes, especially in cases where the external factors have led to differences in corporate culture between different groups within the company. PVQ has been used to identify groups and semi-structured interviews were used to understand whether and, if so, how differences in values has led to different requirements on the same system. The study original purpose was to identify differences in requirements between the guards of employees in areas of varying size. This is because the assessment was made that the external factors that could affect the corporate culture, and thus the requirements, place of employment would be most evident. A prerequisite for the applied method at all to be of use is to the result of PVQ can be used to identify ways in which the corporate culture is different in different resorts. In this aspect, the method has proved useful. Statistically significant differences in values have been observed between guards inside and outside the city. These constitute a good basis for understand the business culture differs. The question remains, however, whether, and if so how, the differences leads different requirements for employees of the various user groups. In the tests done with the help of demands interviews trying to understand the connection between values and system identified a number of shortcomings with the method. It has proved difficult to measure able to say how the fundamental values affect the guards in their work. An example in this context is difficult to interpret conformity. People with high conformity tend to follow social norms and fall into group behavior patterns. To

seriously understand how conformity effects requirements requires a more in-depth understanding of the current workplace norms. The interviews indicate among other things that there is a tendency among guards to question procedures and instructions, and there is a shred of distrust of management's review the practical work situations. This is a setting that could be linked to Self-direction, with the desire to make their own decisions, but, in that it seems to be an established perception among guards, it can also be interpreted as an expression of conformity. To be able to approach an idea of how values affect attitudes to work would be more comprehensive, more profound and potentially more intimate interviews need to be conducted in the workplace where the method is supposed to be applied, which would be costly. Another example of a difficult to interpret measurement is security. All the guards reported that they were keen towards safety. It was difficult to assess how much of this approach to security that was due to they are employed in a risky profession and how much was due to their fundamental values. For example, it is possible that even guards with low levels of security are highly committed to equipment contributes to their safety, as their profession exposes them to more risk than average person.

Zdravkovic et al. [25] use an additional step where Schwartz's basic values are mapped to Holbrook's consumer values framework [9]. Holbrook's framework is more directly related to consumer attitudes to products than Schwartz's basic values, and had thus been able to facilitate the search for a direct link between them and setting the interviewees for their equipment.

V. Conclusions

The current study is intended to examine how well psychological methods to measure individuals' fundamental values to support requirements management processes, especially in cases where the external factors have led to differences in corporate culture between different groups within the company. PVQ has been used to identify population cohorts through their value profiles, and semi-structured interviews were used to understand whether and, if so, how differences in values led to different requirements on the same system. The study's original purpose was to identify differences in requirements between the guards of employees in areas of varying size. This is because the assessment was made that the external factors that could affect the corporate culture, and thus the requirements, place of employment would be most evident.

A prerequisite for the applied method to be of use is that the result of PVQ can be used to identify ways in which the corporate culture is different in different locations. In this aspect, the method has proved useful. Statistically significant differences in values have been observed between guards inside and outside the cities. These constitute a good basis for understand how business culture differs. The question remains, however, whether, and if so how, the differences leads different requirements for employees of the various user groups. In the tests done with the help of demands interviews trying to understand the connection between values and systems identified a number of shortcomings with the method. It has proved difficult to measure how the fundamental values affect the guards in their work. The approach to work is most likely the result of various factors, and the reality is rarely so simple as that people with high values of, for example, Universalism, want their equipment to show them how to assist strangers.

An example in this context is difficult to interpret measurement Conformity. People with high conformity tend to follow social norms and fall into group behavior patterns. To seriously understand how Conformity would affect requirements requires a more in-depth understanding of the current workplace norms. The interviews indicate among other things that there is a tendency among guards to question procedures and instructions, there is a shred of distrust towards management's review of the many practical work situations. This is a setting that could linked to Self-direction, the desire to make their own decisions, but, in that it seems to be an established perception among guards, it can also be interpreted as an expression of Conformity. To be able to approach an idea of how values affect attitudes to work would be more comprehensive, more profound and potentially more intimate interviews need to be conducted in the workplace where the method is supposed to be applied, which would be costly. Another example of a difficult to interpret measurement is Security. All the guards reported that they were keen about safety. It was difficult to assess how much of this approach to security that was due to they are employed in a risky profession and how much was due to their fundamental values. For example, it is possible that even guards with low levels of security are highly committed to equipment contributes to their safety, as their profession exposes them to more risk than average person.

Based on the observations made during the study, a number of alternative approaches to conduct future research were identified. An alternative way to understand the impact of values on the requirements had been taking a more quantitative approach. With a greater amount of more structured interviews, attempts could be made to correlate certain types of statements with high or low values in certain values.

During the analysis of PVQ also showed that there were other segmentation variables for the user base, in addition to employment, which led to significant differences in values between user groups, especially the number of years of employment. Instead of pre-defining user groups based on employment survey had been able to fill a more exploratory purpose. In such an approach, a survey could be used to identify the user groups where the values differ the most, and then examine the differences in more detail with the help of demands interviews.

The differences in results as the PVQ-based survey conducted among the guards at Securitas show that PVQ can be an interesting tool to apply to understand the differences in corporate culture, not just between the place of employment, but also, for example, between new employees and those who have been employed for a longer time. Much work remains, however, to take a systematic approach to applying PVQ to understand the link between values and system requirements. It is our hope that this study will help to clarify some of the difficulties and challenges that exist in the area and that it can facilitate with continued research.

VI. Future Work

The intended purpose of the study was to examine how well a method based on a survey of the basic values combined with semi-structured interviews requirements can support

requirements engineering processes by identifying and defining the differences in corporate culture and how these affect users' system. For the method to be able to answer this question, there must be clear links between the results of PVQ and expressed requirements. Although the results from PVQ indicate that the method can be used to observe the differences between user groups must also be clear links between the results of PVQ and expressed requirements are observed. Although some shortcomings with the method were identified and assessed in previous section, the results suffer from the part of the study with lean data, so a more complete evaluation should be implemented. A larger and more representative number of respondents could be interviewed to reach insights into how the fundamental values affect the user's system. Although the division metropolitan respectively non-metropolitan significantly had guards from sparsely populated rural probably been contrasted with stronger guards in the city and thus more easily led to insights on both the differences in organizational culture and the relationship between requirements and values. The interviewees were also too few in number, and the questions had needed refined to more effectively been interviewed to begin reasoning about the work according to their values, especially for the interviews conducted over the telephone. More respondents and more time to develop Questions had thus been able to lead to a better basis for analysis.

A. Suggestions for future research

Based on the observations made during the study, a number of alternative approaches to conduct research in identified. Building on these can then suggestions for further research proposed.

An alternative way to understand the impact of values on the requirements had been taking a more quantitative approach. With a greater amount of more structured interviews were attempts could be made to correlate certain types of statements with high or low values in certain values. Although this would require a greater extent on the work. It has previously been suggested that Schwartz's basic values should not be understood as isolated values, but in interaction with each other. Studies have been done where clustering algorithms have been applied to find and interpret common patterns in the combination of measurement values. With a larger amount of data had this has been an interesting method to apply to the quantitative analysis of survey data. In that it had sorted out the respondents in one of only a few categories had been able to help further reducing the number of necessary interviews.

During the analysis of PVQ also showed that there were other segmentation variables for the user base, in addition to employment, which led to significant differences in values between user groups, especially the number of years of employment. Instead of pre-define user groups based on employment type had been able to fill a more exploratory purpose. In such an approach, had a survey been employed, it could be used to identify the user groups where the values differ the most, and then examine the differences in more detail with the help of demands interviews. The differences in results as the PVQ-based survey conducted among the guards at Securitas show that PVQ can be an interesting tool to apply to understand the differences in corporate culture, not just between the place of employment, but also, for example, between new employees and those who have been employed for a longer time. Much work remains, however, to take a systematic approach to applying PVQ to understand the link between values and system requirements. It is our hope that this study will help to clarify some of the difficulties and challenges that exist in the area and that it can facilitate with continued research.

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The Effects of Consumer Interests in Top Box Office Movies in Thailand: *evidence from the pre-during-post-peak periods*

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***Abstract*— This paper examined the information searches by consumers for movies from one-year Google Trends data and their relationship with the top box-office movies' performance. Top five box-office movie data over a 53-week period were collected from boxofficemojo.com and Google Trends. Both Web search and YouTube search in the Arts & Entertainment category and the Online Communities category were explored. Two hundred sixty-five movies, listed in Thailand box office in 2017, were gathered for the analysis phase. Interest over time scores, showing relative search volume from Google Trends, represented the level of consumers' interests in the movies over time. This study tried to investigate the impacts of consumer interests before, during, and after the peak period on the rank of the movie. Results partially supported the correlations between consumer interests in the pre-peak period and the movie rank, fully supported the correlations between consumer interests in the during-peak period and the movie rank, and supported the correlations between consumer interests in the post-peak period and the movie rank. Findings also indicated higher consumer interests in the during-peak period than the pre-peak period and higher consumer interests in the during-peak period than the post-peak period. In addition, there were an association between two movie ranks in consecutive week and a positive correlation between the latest movie rank and the time to be on the top box office chart.**

Keywords—Google Trends, box office, consumer interests, information search, movie rank, Thailand

I. INTRODUCTION

The movie industry is a massive worldwide industry worth hundreds of billions of dollars [1]. Filmmaking also has been indicated as one of the most valuable economic resources for some countries [2]. For example, in 2012, global film market has a market size of $34.7 billion and Korean film market size is $1.3 billion (3.8 percent of worldwide market) [3]. However, the movie industry is a high-risk cultural industry, which faces many challenges [4, 5]. The vast amount of films released each year fail to make the theatrical-run profits. Many of them lose millions of dollars [5]. For example, there were only 10 movies in China that obtained a profit among 103 movies released in the first and second quarters of 2012 [4]. In addition, movie revenues are becoming a smaller proportion of worldwide revenues because of the growth of online streaming services such as Netflix. Therefore, it is necessary to enhance overall understanding of the movie market [6]. The non-US movie markets have become increasingly important. The theatrical movie market in Thailand is also interesting because of the competition between Thai movies and imported foreign movies [6].

The most basic process in analyzing the movie industry is exploring factors that affect the movie success [7]. For example, a higher revenue growth can be expected when the cinema specifying the ideal number or screens through a precise prediction of ticket sales in the near future [3]. The questions such as "what kind of film product is most likely to bring high returns?", "how should the completed product be best distributed?", or "how should the film be promoted for best effect?" should be answered to promote cinematic success [5]. The box office presents important indicators for evaluating the movie success, such as revenues and movie ranks [4]. The rank of a movie determines its expected box-office revenue and characterizes a movie's performance [8]. Box-office rankings also reduce uncertainty about the quality and popularity of a movie for consumers in their information seeking and processing behaviors [9]. However, a movie's rank in the film competition is ephemeral and unpredictable [10]. The accurate prediction of these success factors is significant to decrease movie market risks, improve the management of the movie industry, and support the development of movie-related products [4]. Nevertheless, it is difficult to specify the real reasons for the box-office revenue volatility [4]. Moreover, the literature studies on this subject have been quite scant [1]. Existing literature on the movie success has been mainly concentrated on either predicting box-office revenues or its first week/ weekend [4, 11, 12]. The high total gross in the opening weekend does not always indicate the theatrical movie success [11].

With the proliferation of the Internet, more people turn to the Internet for news and information. According to the consumer behavior theory, the stages of need recognition, information search, and decision-making are a consumer purchase process [13]. What consumers are searching for today predicts what they will do in the near future; for instance, moviegoers may search for a new movie's opening date. Information searches thus reflect the collective behavior

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of consumers' collective interests [13, 14]. Internet users get product information from various sources such as websites and online communities before the product is launched [3]. Search engines show the collective demands for a product in the current or the next period [13]. The demand in the movie industry could be largely driven by information search and online word of mouth as well [15]. There are relations between Web search queries and offline outcomes in the near future, such as stock returns [13]. Social media such as Facebook and YouTube have become essential internet-mediated communication tools for millions of people. Consumers thus use social media to search for information relating to their purchase decision [16]. Collective opinions in online communities can also have greater impact on the other consumers' choices [17]. Thus, web and social media searches are interesting to be explored since it could improve the prediction accuracy for product (movie) sales and pursue a better operation plan for a company (film maker) [3, 13].

The objectives of this research are: (1) to examine the connections between movie ranks and consumer interests (movie information searches through Web and YouTube) before, during, and after movies ranked in the top five, (2) to compare consumer interests before, during, and after the peak period, (3) to explore the association between two consecutive movie ranks and the correlation between the movie ranks and theatrical weeks, and (4) to guide film makers the effective time and sources to promote movies online. Google Trends are applied because they are based on Google Search, the most widely adopted Internet search engines [18]. The Google Trends' relative search index for search terms could also be obtained by country [15, 19], enabling this study to extend the understanding of the movie industry to new areas such as the Southeast Asian region rather than only in the Western countries [20]. Search query volume is an external factor reflects the sales performance [3]. This research fulfills the gap that there are limited studies on how Web search queries affect the product performance not only in the present phase, but throughout the whole product life cycle, [13, 14]. There is a wide variaty in the predictive power of search among the various domains [14]. Communication, advertisement, and distribution channels are crucial for movie success, but studies regarding their impacts on movie performance are still limited [1]. Moreover, previous works have not considered the information acquiring from distinct information sources and online platforms, which could diversely influence product sales [9]. Thus, different search categories (the Arts & Entertainment category and the Online Communities category) are also examined. This study collects one-year movie data because a longitudinal study may add more understanding to the temporal relationships of factors [16]. Achieving these research aims will provide new insights into the online promotion strategy for movies. This allows filmmakers to present movie information through the efficient marketing channels at the right time.

II. Related Work

Simonton reviewed factors relating to a film's success. The author examined three main criteria representing a film's success: critical evaluations before and after the theatrical run, financial performance, and movie awards [5]. Walls examined the movie market in Thailand using a sample of movies showed in 2004-2008. The author found the consistent distribution of winners' film revenues. Many top-earning movies in Thailand were in-house produced [6]. Goel et al. demonstrated that the volume of Web search could predict outcomes accurately by applying search query volume to forecast film revenues, video game sales, and song rankings. Search counts strongly predicted future outcomes in all cases, including flu trends [14]. Sangkil Moon et al. explored the influence of movie ratings by professionals, amateur communities, and viewers on movie performance. The authors found that the early-earned movie revenues increased subsequent movie ratings. High advertising costs that were invested in high-rated movies could maximize movie revenues. Sequel movies received low ratings, but gained more revenues. Movie experiences of viewers shaped their critical ratings over time [17]. Wen and Yang examined the drivers of box-office revenues in China. Films released during 2005-2010 were explored. Findings indicated three significant determinants i.e. the promotion cost, ticket price and the copies [21].

Demir, Kapralova, and Lai predicted IMDB movie ratings with Google search volume for movie-related information. The set of movie features was explored by Google search frequencies to forecast the popularity of movies [22]. Hand and Judge investigated whether Google Trends search data could improve the prediction of cinema admission, using various forecasting models. Results supported that Google Trends search information related to cinema visits [15]. Chen, Liu, and Zhang studied third-party product reviews (TPRs). Findings showed that TPRs played important roles because investors were interested in the potential of new product sales. Advertising spending also increased the positive influence and decreased the negative influence of TPRs on firms' values [23]. McKenzie and Walls tried to understand why Australian movies failed to draw the people's attention at the Australian box office. Results showed that although Australian films highly advertised, they earned less at the box office. Government subsidies did not affect a film's financial success as well [20]. Seonghoon Moon et al. developed a prediction model to forecast movie ticket sales in the near future using box-office data and external factors such as online reviews, movie ratings and search volume [3]. Baek, Ahn, and Oh explored the influence of tweets on the box-office revenues, based on the Expectation Confirmation Theory. One-hundred movies released in the US between February and August 2012 were targeted. The findings supported the disconfirmation that the total pre-consumption tweets negatively affected box-office revenues [24]. Miao and Ma examined how Web search volume affected product sales, using econometric models. Pre-launched Web search volume was a positive determinant

of product sales in the initial stage. Web search volume also had a significant impact on product sales throughout the whole product life cycle [13]. Ciciretti et al. explored the role of distribution strategy influencing the movie success in the Italian movie industry. The study confirmed the importance of star artists, famous directors and their experiences, critics, financing strategies, and stock market reactions. They also added the power of distribution, such as the foreign distributor alliance, the selection of cinema location on movie revenues and market endurance [1].

Liu et al. employed linear and non-linear regression models, based on social media data such as users' posts to assess box-office revenues. Large-scale social media data significantly correlated with movie revenues. Purchase intention of users also gave more accuracy of box-office revenue predications [4]. Oh et al. examined how consumer engagement behavior (CEB) in terms of social media activities affected economic performance in terms of the US box-office gross revenues. Consumer engagement behavior on Facebook and YouTube positively associated with movie revenues [16]. Hwang et al. collected text data about Korean movies to find factors contributing to successful commercialization of Korean movies. Results showed that a film's release date, rating, and genre were the most influential drivers of movie successes [7]. Hofmann et al. analyzed the relationship between star powers (commercial success and artistic success) and movie successes. Findings indicated that the influence of star power on movie revenue was upwards biased. The artistic star power significantly associated with lower box-office revenues than the commercial star power [12]. Huang et al. examined when and why online opinions on different platforms affected box-office revenues. Reviews of online experts and consumers were collected. Results confirmed that expert reviews and peer comments were significant determinants in the early stages when a movie was released, but their effects decreased over time. The comment volumes also had a significant impact on later movie receipts [9]. Bioglio and Pensa measured a movie's success by exploring how much it influenced other movies after it launched both in the views of artistic and economic. Their findings mainly reflected the movie industry for Western culture because the IMDB dataset heavily relied on European and North American movies [2].

III. The Development of Hypotheses

A. Movie Search in the Pre-Peak Period and the Movie Rank in This Week

A consumer's interest level correlates with his/ her viewing time. The most interested consumer tends to see the new movie first, whereas the less interested consumer will see the movie later [17]. When a consumer faces choice uncertainty, which means a consumer's uncertainty as to which alternative out of a considered set to choose, they will conduct an information search. The more alternatives (movies) lead to the greater degree of uncertainty. The relationship between choice uncertainty and external information search is extensively acknowledged [9]. Uncertainty is quite high before the release of product such as a movie, but decreases when the product is launched and on sale [23]. Search can predict a wide range of consumer behaviors such as airline travel and economic factors such as real-estate prices. Search counts could predict consumer activities in the near future, such as going to cinema, buying music or video games [14]. There is a positive correlation between search volume and movie ticket sales [3]. Search data from Google Trends relates to cinema visits. People may conduct the Internet search activity regarding movie titles. General searches that are relevant to cinema or movies rather than movie titles could be used to forecast cinema admissions as well [15]. Searches about a movie's title, director, and the main actor also have discriminative values on the prediction accuracy [22]. The prediction of sales performance could be drawn from mining consumers' online activities. Search patterns and online reviews closely relate to sales performance of a product [3]. Online third-party product reviews are available over time, so the potential of product sales has changed continuously [23]. Online review volumes could effectively explain the increase of box-office revenues [24]. In terms of social media, the negative tweets have a negative impact on box-office revenues. The number of tweets also has a positive impact on box-office revenues. The differences in pre- and post-consumption tweets also significantly generate a negative impact on movie revenues [24].

Web search volume before a product released has a positive impact on its sales in the initial period [13]. A number of people search for movies around their release dates. Interestingly, search peaks appear on or slightly after the release dates, but signals to the peaks emerge several days or weeks in advance. For example, four weeks before a movie's release, search volume is highly correlated with its first weekend revenue [14]. The second peak time of a movie after its first peak could be speculated by its pre-watch (whether a movie is first released to a limited number of screens before its actual release date) and the invested budget [11]. Pre-consumption electronic word of mouth significantly drives box-office revenues in the opening week. Online reviews could foretell opening-week movie revenues. The pre-release Internet buzz such as trailer views, message board comments, and votes of desire significantly influences movie revenues in the first week. Twitter rate or the number of tweets relating to a movie per hour could significantly influence the opening-week box office revenue. The volume of pre-consumption tweets significantly also positively affect movie revenues in the opening week [24]. Prerelease critics' ratings could increase the cinema revenues during the opening week [17]. Comment volume of the previous weekend positively correlates with movie ticket sales of each weekend [3]. Third-party product reviews published in the pre-release period significantly affect a firm's value [23].

During the early period (around weeks 1-4), valence of expert reviews, the volume of pull-based comments in forums, the valence and volume of push-based comments in microblogs generally positively drive box-office receipts [9]. Therefore, hypotheses are formulated as follows.

H1a: There will be a negative correlation between consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.

H1b: There will be a negative correlation between consumer interests to conduct Web searches about a movie in the Online Communities category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.

H1c: There will be a negative correlation between consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.

B. Movie Rank in This Week and Movie Search in the During-Peak Period

Release date significantly affects the success of motion pictures [25]. Interests in the movies drive movie demands on their release dates. [15]. Web search volume on the current period significantly increases a product's sales in the current and the next period [13]. Search-based indicators strongly correlate with the outcomes of movies if their revenues or ranks are predicted immediately after the event of interest occurs [14]. Movie-related attributes such as budget, review, star, and sequel positively correlate with movie revenues, both in the opening week and following weeks. Revenues and budgets of movies in the opening week also highly relate to opening week screens and advertising [20]. The potential of a new movie's sales is revealed after the opening weekend [23]. First-week revenues of movies are highly relevant to the their total box office revenues [12]. Personal and interactive consumer engagement behaviors on social media (Facebook, YouTube, and Twitter) significantly positively correlate with movie revenues in the opening weekend [16]. External factors such as distribution, reviews from the media and critics, advertisement, word-of mouth, and the social ambience at the time of release are expected to impact the number of viewers and box-office incomes [7]. Third-party reviews published on a product's release date have possibly received greater attention from investors [23]. Hence, the following hypotheses are proposed.

H2a: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period.

H2b: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period.

H2c: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period.

C. Movie Rank in This Week and Movie Search in the Post-Peak Period

In general, a movie's sales performance decreases rapidly after the movie is released [3]. The movie ratings of sample movies before release are higher than the ratings after the release. The comment volumes of sample movies after release are larger than the comments before the release. The search volumes after release of sample movies are also greater than the searches before release [3]. The volume of post-consumption tweets positively affect box-office revenues after the opening week [24]. Videos released on holidays shortly after the movies are theater release receive higher ratings [17]. To obtain more sustained incomes, marketers should maintain their ad spending on high-rating movies in not only in the early weeks, but also the later weeks [17]. Thus, this research posits the following hypotheses.

H3a: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the post-peak period.

H3b: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Online Communities category in the post-peak period.

H3c: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the post-peak period.

D. The Comparison of Movie Search in Pre-, During-, and Post-Peak Periods

Each product has its own life cycle, i.e. introduction, growth, maturity, and decline stages. Before a new product is presented to the market, search engine is important because consumers find information about the new product online. Information search behaviors, thus reflect the consumers' collective concerns, which could be turned into demands and sales after the new product is launched. After the introduction of a new product, consumers may apply more channels such as acquaintance referrals or online product reviews to retrieve the product's information. The effects of additional information channels in the late stage will decrease the influence of Web search volume in the early stage [13]. Consumer interests in a new product intensify on its release date. Third-party reviews published on the product release date draw more attention from investors and significantly increase firm value that those published before the release date [23]. Therefore, hypotheses are presented as follows.

H4a: There is a significant difference for consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period and the during-peak period.

H4b: There is a significant difference for consumer interests to conduct Web searches about a movie in the Online Communities category in the pre-peak period and the during-peak period.

H4c: There is a significant difference of consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period and the during-peak period.

H4d: There is a significant difference of consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period and the post-peak period.

H4e: There is a significant difference of consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period and the post-peak period.

H4f: There is a significant difference of consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period and the post-peak period.

E. Movie Rank in This Week and Last Week

A movie moves up or down in movie rankings in each week of its run. Over its lifetime, a movie's rank eventually goes down [10]. Ticket sales of the previous weekend positively correlates with ticket sales of this weekend [3]. The exhibitor could know an already released movie's rank from its attendance pattern in the previous week [8]. At the box-office tournament, movie viewers rank contending movies. The movies with high ranks survive and pass to the next week, the movies with low ranks fail and are replaced by newly released movies [10]. The enhanced revenues in the current week could increase movie ratings in the subsequent weeks. Positive movie ratings significantly increase the effectiveness of ads spending to boost movie revenues [17]. Thus, the following hypothesis will be examined.

H5: There will be a positive correlation between the movie rank (Rank 1 – 5) in this week and the movie rank (Rank 1 – 5) in the last week.

F. Movie Rank in This Week and the Number of Week Showing

The movie market is weekly changed with newcomers and old survival movies [6, 10]. Movies are different from other consumer products due to their extremely short life cycle [17]. Over a movie's lifetime, a movie's rank must finally decline, according to its age. A movie has to achieve high rank and keep staying in several ranks before death or it must be longer at low ranks to have a long life in the box office [10]. The expected net revenue of a movie is up to its ranks and its number of weeks playing time [8]. The highest-ranked movies live longer, but the lowest-ranked movies die faster [10]. There is the negative correlation between the week number of movies and their ticket sales each weekend [3]. Fewer ticket sales mean lower ranks in the box office, indicating that the longer total weeks, the lower movie ranks (numerically higher) will be achieved. These supports yield the following hypothesis.

H6: There will be a positive correlation between the movie rank (Rank 1 – 5) in this week and the number of week showing in this week.

IV. Research Methodology

All of the data for this study were secondary data collecting from two sources: box-office data from BoxOfficeMojo.com and movie search data from Google Trends. Non-probability samples were chosen as sampling method. Top five box-office movies from December 2016 to December 2017 were selected. There were two hundred sixty-five movies exhibited in Thailand cinemas from BoxOfficeMojo.com in total. BoxOfficeMojo.com was one of information aggregators monitoring box-office receipts. It enabled researchers to practically collect data that represented the movie industry [9]. Google Trends offered search volume data for search terms completed by Google over time. They could also show how often each search term was entered in Google relative to a given country and the date range. The relative search volume from Google Trends allowed the direct comparison of search volumes across search terms [15, 18, 19]. Not only the data from Google search engine, Google Trends covered social media search data i.e. YouTube as well. YouTube was the world's largest video-sharing community that allowed users to upload, view, and comment on videos. It changed the way consumers respond to brands, so movie marketers set up YouTube channels to share movie trailers and other related videos to their subscribers [16]. Search data from Google Trends, both Web search and YouTube search, were also aggregated with movie data according to movie names as search terms. Three types of searches covered 1) Web search in the Arts & Entertainment category, 2) Web search in the Online Communities category, and 3) YouTube search in the Arts & Entertainment category.

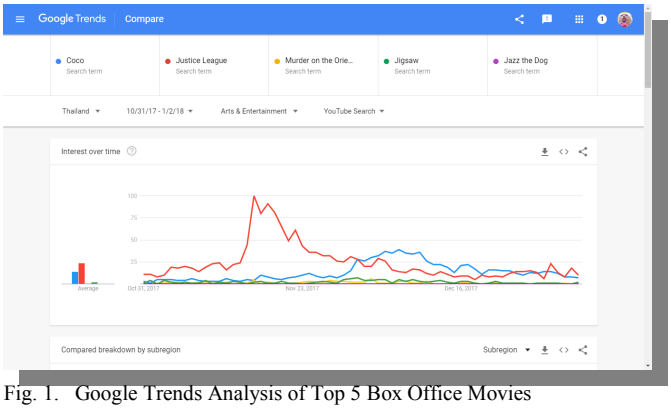


Fig. 1. Google Trends Analysis of Top 5 Box Office Movies

TABLE I. Description of Variables Used

Variable	Description
Movie Search in the Pre-Peak Period (from Google Trends)	Interest over time scores on the 0-4 days before the period that a movie was on the top five of box-office chart
	Interest over time scores on the 5-8 days before the period that a movie was on the top five of box-office chart
	Interest over time scores on the 9-12 days before the period that a movie was on the top five of box-office chart
Movie Search in the During-Peak Period (from Google Trends)	Interest over time scores on the 0-4 days during the period that a movie was on the top five of box-office chart
Movie Search in the Post-Peak Period (from Google Trends)	Interest over time scores on the 0-4 days after the period that a movie was on the top five of box-office chart
	Interest over time scores on the 5-8 days after the period that a movie was on the top five of box-office chart
	Interest over time scores on the 9-12 days after the period that a movie was on the top five of box-office chart
Movie Rank in This Week (from boxofficemojo.com)	The rank of a movie (1-5) in this week which was on the top five of box-office chart this week
Movie Rank in Last Week (from boxofficemojo.com)	The rank of a movie (1-5) in the last week which was on the top five of box-office chart this week
The Number of Week Showing (from boxofficemojo.com)	The total week showing of a movie that was on the top five of box-office chart

Consumer interests referred as the movie title searches in each period. They could be represented by interest over time score in Google Trends. Interest over time scores were defined as "search interest relative to the highest point on the chart for the given region and time. A value of 100 is the peak popularity of the term. A value of 50 means that the term is half as popular. A score of 0 means there was not enough data for this term". Figure 1 showed a screenshot of the search results of the top five movies obtained from Google Trends. Table 1 showed overall variables used in this study. Consumer interests or Web/ YouTube search volume data of each movie before, during, and after the week that the movie was in the top 5 were collected, from both the Arts & Entertainment category and the Online Communities category. Movie searches/ interest over time scores were measured in interval scale. Movie ranks were collected in ordinal scale. Weeks of theatrical run were measured in ratio scale.

This study applied both parametric (the paired sample t-test) and nonparametric tests (the Spearman's rank correlation coefficient) to test the proposed hypotheses, in accordance with each measurement type. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS). At first, the correlations between consumer interests in different periods and movie ranks were empirically investigated. Paired sample t-tests were also applied to compare consumer interests at different times. The correlation between current movie ranks and previous movie ranks and the association between current movie ranks and the total weeks showing were also examined using Spearman's rho.

V. Results

A. Descriptive Statistics of Movie Dataset

TABLE II. The Average Weekend Gross Revenue and Gross-to-Date Revenue for each Movie Rank

Movie Rank (This Week)	Average of Weekend Gross Revenue	Average of Gross-to-Date Revenue
1	$ 1,101,411.43	$ 1,905,188.30
2	$ 294,963.47	$ 1,779,354.91
3	$ 141,934.13	$ 1,173,762.21
4	$ 80,885.38	$ 773,881.60
5	$ 51,779.87	$ 1,077,890.40

TABLE III. Top 5 Movie Count and Average Gross-to-Date Revenue by Studio

Studio	Movie Count (n = 265)	Average of Gross-to-Date Revenue	Average No. of Week Showing
Sony	31 (11.7%)	$ 1,311,111.32	1.8
MongkFilms	29 (10.9%)	$ 342,393.93	2.1
WB	28 (10.6%)	$ 1,725,417.57	2.3
Disney	27 (10.2%)	$ 3,730,640.93	2.4
UPI	25 (9.4%)	$ 2,609,990.64	2.2
Fox	23 (8.7%)	$ 1,156,351.09	2.0
M	22 (8.3%)	$ 450,984.09	1.5
PPI	15 (5.7%)	$ 1,602,489.07	1.9
UIP	7 (2.6%)	$ 180,389.00	1.7
MongkolMaj	6 (2.3%)	$ 923,712.33	2.0
M39	4 (1.5%)	$ 366,231.00	1.5
Sahamongko	3 (1.1%)	$ 400,012.00	1.3
Mono	3 (1.1%)	$ 168,807.00	1.3
Joyncont	2 (0.8%)	$ 473,119.50	1.5
Logistic	2 (0.8%)	$ 144,441.00	1.0
MultPTL	2 (0.8%)	$ 31,840.50	1.0
No Studio Information (n/a)	36 (13.6%)	$ 526,145.11	1.5

TABLE IV. Top 5 Movie Rank by Studio

Studio	Movie Rank (This Week) (n = 265)				
	1	2	3	4	5
WB	10 (3.8%)	8 (3.0%)	6 (2.3%)	3 (1.1%)	1 (0.4%)
Disney	10 (3.8%)	5 (1.9%)	4 (1.5%)	3 (1.1%)	5 (1.9%)
Fox	7 (2.6%)	7 (2.6%)	4 (1.5%)	4 (1.5%)	1 (0.4%)
UPI	7 (2.6%)	4 (1.5%)	7 (2.6%)	2 (0.8%)	5 (1.9%)
Sony	5 (1.9%)	8 (3.0%)	6 (2.3%)	3 (1.1%)	9 (3.4%)
PPI	4 (1.5%)	3 (1.1%)	2 (0.8%)	3 (1.1%)	3 (1.1%)
MongkFilms	3 (1.1%)	6 (2.3%)	9 (3.4%)	8 (3.0%)	3 (1.1%)
M	3 (1.1%)	2 (0.8%)	5 (1.9%)	5 (1.9%)	7 (2.6%)
MongkolMaj	2 (0.8%)	1 (0.4%)	0 (0.0%)	2 (0.8%)	1 (0.4%)
No Studio Information (n/a)	1 (0.4%)	6 (2.3%)	6 (2.3%)	10 (3.8%)	13 (4.9%)
Joyncont	1 (0.4%)	0 (0.0%)	0 (0.0%)	1 (0.4%)	0 (0.0%)
Sahamongko	0 (0.0%)	1 (0.4%)	1 (0.4%)	1 (0.4%)	0 (0.0%)
Mono	0 (0.0%)	1 (0.4%)	1 (0.4%)	1 (0.4%)	0 (0.0%)
Logistic	0 (0.0%)	1 (0.4%)	0 (0.0%)	1 (0.4%)	0 (0.0%)
M39	0 (0.0%)	0 (0.0%)	2 (0.8%)	0 (0.0%)	2 (0.8%)
UIP	0 (0.0%)	0 (0.0%)	0 (0.0%)	5 (1.9%)	2 (0.8%)
MultPTL	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.4%)	1 (0.4%)

TABLE V. MOVIE RANK IN LAST WEEK AND MOVIE RANK IN THIS WEEK

Movie Rank (Last Week)	Movie Rank (This Week) (n = 265)				
	1	2	3	4	5
Unranked (N)	32 (12.1%)	17 (6.4%)	26 (9.8%)	24 (9.1%)	18 (6.8%)
1	15 (5.7%)	27 (10.2%)	7 (2.6%)	3 (2.6%)	1 (0.4%)
2	2 (0.8%)	5 (1.9%)	14 (5.3%)	10 (5.3%)	9 (3.4%)
6	2 (0.8%)	0 (0.0%)	1 (0.4%)	1 (0.4%)	3 (1.1%)
9	1 (0.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
3	1 (0.4%)	2 (0.8%)	3 (1.1%)	9 (3.4%)	12 (4.5%)
11	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.4%)
10	0 (0.0%)	0 (0.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)
4	0 (0.0%)	1 (0.4%)	1 (0.4%)	5 (1.9%)	9 (3.4%)
8	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.4%)	0 (0.0%)
7	0 (0.0%)	1 (0.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

Summary statistics of samples were described in Table 2 – 5. There was an extensive gap between the average of weekend gross revenues of top-ranked movies and second-ranked movies, but this gap declined in terms of average of gross-to-date revenues. Some lower-ranked movies performed better than higher-ranked movies in the aspect of average of gross-to-date revenues, as shown in Table 2. Of 265 movies in the 2017 top-five lists, the majority of movies released in Thailand belonged to international movie conglomerates excepts Mongkol Cinema (MongkFilms). However, the large number of movies that was pushed forward into the top five box-office charts did not always guarantee the success of distribution companies, as indicated by average of gross-to-date revenues of each studio in Table 3. The average number of weeks showing for all top-five films was ranging from 1.0 – 2.4 weeks. This supported the short life cycle of movies specified by Sangkil Moon et al. [17], the average of two weeks that movies ran in the top five [10], and the rare events of movies' long lifetimes [6]. Although Sony Pictures Entertainment (Sony) and MongkFilms exhibited more movies than Warner Bros. Studio (WB), WB maintained the higher rankings more than these studios. WB, the Walt Disney Pictures (Disney), Twentieth Century Fox Film Corporation (Fox), Universal Pictures International (UPI), and Sony had the highest number of top five movies respectively, as presented in Table 4. MongkFilms (Thai theatrical distributor) did not perform badly in the movie market competition. The study of Walls supported that domestically-produced Thai films were remarkably competitive with Hollywood films [6]. Table 5 compares the movie ranks in this week and last week. Surprisingly, many unranked movies in the last week could climb up to the highest rank in the current week. The result was contrasted to the study of Vany and Walls (1997), emphasizing that most movies would not achieve high ranks in their first week [10]. Fifteen percent of first-ranked movies could maintain their position in the highest ranks. Some first-ranked movies (27 percentage) climbed down to the second ranks at the same time. In contrast to the study of Vany and Walls [10], the ranks generally went down rather than raised up. In addition, it was noticeable that none of five-ranked movies could change their ranks upward. However, the majority of top-five movies in the last week, excluding unranked movies, were still listed on the top-five movies of this week.

B. Hypotheses Testing Results

The results of hypothesis testing are presented in Table 6. In sum, there was sufficient evidence to support all hypotheses in this study.

TABLE VI. THE SUMMARY OF HYPOTHESES TESTING

Hypothesis	Result
H1a: There will be a negative correlation between consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.	partially supported
H1b: There will be a negative correlation between consumer interests to conduct Web searches about a movie in the	partially supported

Hypothesis	Result
Online Communities category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.	
H1c: There will be a negative correlation between consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period and the movie rank (Rank 1 – 5) in this week.	partially supported
H2a: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period.	fully supported
H2b: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period.	fully supported
H2c: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period.	fully supported
H3a: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the post-peak period.	fully supported
H3b: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct Web searches about a movie in the Online Communities category in the post-peak period.	partially supported
H3c: There will be a negative correlation between the movie rank (Rank 1 – 5) in this week and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the post-peak period.	fully supported
H4a: There is a significant difference of consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period and the during-peak period.	fully supported
H4b: There is a significant difference of consumer interests to conduct Web searches about a movie in the Online Communities category in the pre-peak period and the during-peak period.	fully supported
H4c: There is a significant difference of consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period and the during-peak period.	fully supported
H4d: There is a significant difference of consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period and the post-peak period.	fully supported
H4e: There is a significant difference of consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period and the post-peak period.	fully supported
H4f: There is a significant difference of consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period and the post-peak period.	fully supported
H5: There will be a positive correlation between the movie rank (Rank 1 – 5) in this week and the movie rank (Rank 1 – 5) in the last week.	fully supported
H6: There will be a positive correlation between the movie rank (Rank 1 – 5) in this week and the number of week showing in this week.	fully supported

1) Movie Search in the Pre-Peak Period and the Movie Rank in This Week

Results of the Spearman correlation indicated that there was a significant negative association between consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period (0-4 days before), ($r_s(264) = -.213$, $p < .01$) and in the pre-peak period (5-8 days before), ($r_s(264) = -.154$, $p < .01$), and the movie rank (Rank 1 – 5), but there was an insignificant negative correlation between consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the pre-peak period (9-12 days before), ($r_s(264) = -.208$, $p = .170$) and the movie rank.

Results of the Spearman correlation indicated that there was a significant negative association between consumer interests to conduct Web searches about a movie in the Online Communities category in the pre-peak period (0-4 days before), ($r_s(264) = -.173$, $p < .01$) and in the pre-peak period (5-8 days before), ($r_s(264) = -.112$, $p < .05$), and the movie rank (Rank 1 – 5), but there was an insignificant negative correlation between consumer interests to conduct Web searches about a movie in the Online Communities category in the pre-peak period (9-12 days before), ($r_s(264) = -.022$, $p = .363$) and the movie rank.

Results of the Spearman correlation indicated that there was a significant negative association between consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period (0-4 days before), ($r_s(264) = -.222$, $p < .01$) and in the pre-peak period (5-8 days before), ($r_s(264) = -.114$, $p < .05$), and the movie rank (Rank 1 – 5), but there was an insignificant negative correlation between consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the pre-peak period (9-12 days before), ($r_s(264) = -.100$, $p = .053$) and the movie rank.

2) Movie Rank in This Week and Movie Search in the During-Peak Period

There was a negative correlation between the movie rank (Rank 1 – 5) and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period (4 days), which was statistically significant ($r_s(264) = -.325$, $p < .01$).

There was a negative correlation between the movie rank (Rank 1 – 5) and consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period (4 days), which was statistically significant ($r_s(264) = -.204$, $p < .01$).

There was a negative correlation between the movie rank (Rank 1 – 5) and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period (4 days), which was statistically significant ($r_s(264) = -.262$, $p < .01$).

3) Movie Rank in This Week and Movie Search in the Post-Peak Period

The movie rank (Rank 1 – 5) and consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the post-peak period (0-4 days after) ($r_s(264) = -.350$, $p < .01$), in the post-peak period (5-8 days after) ($r_s(264) = -.289$, $p < .01$), and in the post-peak period (9-12 days after) ($r_s(264) = -.272$, $p < .01$) were negatively correlated.

The movie rank (Rank 1 – 5) and consumer interests to conduct Web searches about a movie in the Online Communities category in the post-peak period (0-4 days after) (r_s (264) = -.165, p < .01) and in the post-peak period (5-8 days after) (r_s (264) = -.213, p < .01) were negatively correlated, but and in the post-peak period (9-12 days after) (r_s (264) = -.056, p = .182) were not negatively correlated.

The movie rank (Rank 1 – 5) and consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the post-peak period (0-4 days after) (r_s (264) = -.350, p < .01), in the post-peak period (5-8 days after) (r_s (264) = -.295, p < .01), and in the post-peak period (9-12 days after) (r_s (264) = -.328, p < .01) were negatively correlated.

4) The Comparison of Movie Search in Pre-, During-, and Post-Peak Periods

A paired-samples t-test indicated that consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period (4 days) (M = 18.5, SD = 22.82) were significantly higher than in the pre-peak period (0-4 days before) (M = 13.3, SD = 17.64), t(264) = -4.350, p < .001.

A paired-samples t-test indicated that consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period (4 days) (M = 6.8, SD = 11.78) were significantly higher than in the pre-peak period (0-4 days before) (M = 4.7, SD = 9.41), t(264) = -2.582, p < .05.

A paired-samples t-test indicated that consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period (4 days) (M = 14.8, SD = 19.80) were significantly higher than in the pre-peak period (0-4 days before) (M = 12.5, SD = 16.78), t(264) = -2.496, p < .05.

A paired-samples t-test indicated that consumer interests to conduct Web searches about a movie in the Arts & Entertainment category in the during-peak period (4 days) (M = 18.5, SD = 22.82) were significantly higher than in the post-peak period (0-4 days after) (M = 12.5, SD = 15.38), t(264) = 8.904, p < .01.

A paired-samples t-test indicated that consumer interests to conduct Web searches about a movie in the Online Communities category in the during-peak period (4 days) (M = 6.8, SD = 11.78) were significantly higher than in the post-peak period (0-4 days after) (M = 4.9, SD = 10.11), t(264) = 2.573, p < .05.

A paired-samples t-test indicated that consumer interests to conduct YouTube searches about a movie in the Arts & Entertainment category in the during-peak period (4 days) (M = 14.8, SD = 19.80) were significantly higher than in the post-peak period (0-4 days after) (M = 11.7, SD = 16.43), t(264) = 4.429, p < .01.

5) Movie Rank in This Week and Last Week

There was a positive association between the movie rank (Rank 1 – 5) in this week and the movie rank (Rank 1 – 5) in last week, which was statistically significant (r_s(147) = .572, p < .01).

6) Movie Rank in This Week and the Number of Week Showing

There was a positive association between the movie rank (Rank 1 – 5) in this week and the number of week showing in this week, which was statistically significant (r_s(264) = .210, p < .01).

C. Discussion

In terms of consumer interests before the peak period and movie ranks, consumers' Web searches and YouTube searches in both the Arts & Entertainment category and the Online Communities category in the period before peak: 0-4 days and 5-8 days before, significantly correlate with movie ranks respectively, but not information searches in 9-12 days before. The result conforms to the literature review of Huang et al., pointing that the volume of pull-based comments in forums positively affected the box office receipts in the early weeks [9], the study of Sangkil Moon et al., specifying that movie reviews easily captured the attention of movie goers in the early periods [17], and the study of Miao and Ma, indicating that Web search volume over the week before the release of a movie positively influenced the opening day revenues [13].

In terms of consumer interests during the peak period and movie ranks, consumers' Web search about a movie in the Arts & Entertainment category, their YouTube search about a movie in the Arts & Entertainment category, and their Web search about a movie in the Online Communities category in during peak period significantly correlate with movie ranks respectively. The result gives the contrast viewpoint to the study of Huang et al., emphasizing that the volume of pull-based comments in forums insignificantly aggregated with the box office receipts during the transition period [9].

In terms of consumer interests after the peak period and movie ranks, consumers' Web searches in the Arts & Entertainment category in post-peak period: 0-4, 5-8, 9-12 days after, significantly correlate with movie ranks respectively. Consumers' Web searches in the Online Communities category in post-peak period: 5-8 days and 0-4 days after, significantly associate with movie ranks respectively, but not Web searches in 9-12 days after. Consumers' YouTube searches in the Arts & Entertainment category in post-peak period: 0-4, 9-12, 5-8 days after, significantly correlate with movie ranks orderly.

Considering consumers' Web searches in the Arts & Entertainment category, consumers' interests negatively correlate with movie ranks (Rank 1-5), from highest to lowest, in 0-4 days after, 4 days, 4-8 days after, 8-12 days after, 0-4 days before, and 4-8 days before orderly. Considering consumers' Web searches in the Online Communities category, consumers' interests negatively

correlate with movie ranks (Rank 1-5), from highest to lowest, in 4-8 days after, 4 days, 0-4 days before, 0-4 days after, and 4-8 days before respectively. Considering consumers' YouTube searches in the Arts & Entertainment category, consumers' interests negatively correlate with movie ranks (Rank 1-5), from highest to lowest, in 0-4 days after, 8-12 days after, 4-8 days after, 4 days, 0-4 days before, and 4-8 days before orderly.

These findings yield the contrary results from the study of Miao and Ma indicating that the impact of Web search volume was decreased gradually by time. It was larger in the early stage, but smaller in the later stage. One-period lagged Web search volume also had less impact on a movie's current revenues than the Web search volume in the current time [13]. The results also differ from the study of Huang et al., specifying that consumers tended to conduct more active searches in the early stage because of the greater choice uncertainty [9], the study of Demir et al., pointing that short-term post-release search queries had a smaller predictive power than those of pre-release and long-term post –release search activities [22], and the study of Vany and Walls, mentioning that only the number of first runs was economically significant [10]. However, the result supports the study of Huang et al., emphasizing that the comment volume of push-based microblog platforms significantly affected later box-office receipts [9], the study of Seonghoon Moon et al., revealing that negative viral was proceeded actively with the large amount of online comments after a movie is released [3], and the study of Miao and Ma, showing that the movie revenues were higher when the Web searches about a movie were greater before and after the movie was launched [13].

In terms of the comparison of consumer interests in the pre-during-post-peak periods, consumers' Web searches and YouTube searches in both the Arts & Entertainment category and the Online Communities category in during-peak period are significantly greater than both the pre-peak period and the post-peak period.

In terms of movie ranks in consecutive weeks, the movie ranks (Rank 1-5) in this week significantly positively correlate with movie ranks in the last week. The result harmonizes with the study of Sangkil Moon et al., indicating that ticket sales of the previous weekend correlated with ticket sales of each weekend [3], but gives the different result from the study of Swami et al., pointing that after a movie was released, it did not make the transition to a higher rank [8]. In terms of movie ranks and theatrical weeks, the movie ranks in this week also positively associate with the showing weeks. The result accords with the study of Sangkil Moon et al., emphasizing that week number negatively correlated with ticket sales of each weekend [3] and the study of Yahav, specifying that movies peaked and dropped steeply after a few days at cinemas [11].

VI. Implications for Theory and Practice

This paper provides several theoretical contributions. First, it enhances overall understanding of the movie market in the aspect of consumer interests and their impacts on box-office movie performances. Second, the paper extends the literature to different information channels (from only Web search to social media search such as YouTube search) and digs deeper into various categories i.e. the Arts & Entertainment category and the Online Communities category. Third, the study analyzes one-year data, which could be a good representative of the movie market covering all seasons of 2017. Last, this study could be an example for studying the impact of information searches in the IS fields, for instance, the effect of information search volume on the performance of other products such as music or the relationship between the ads investment and information searches.

In terms of suggestions for practitioners, Wen and Yang highly recommended that movie marketers should focus on a movies' promotion such as advertising. The more budget movie makers and investors pay for ads, the more they gain from the box office [21]. Topf also pointed that advertising could inform the public about a movie's release and build hype around the movie. More high quality advertisements lead to more chance of the public's attention relative to the movie [25]. Web and YouTube searches affect movies' performance in the box office during their whole life cycle. Findings suggest movie marketers to promote through both Web and YouTube in 0-8 days before the movie seems to reach their highest position (Rank 1-5). A movie general reaches top-five ranks within 1.0 – 2.4 weeks. Chen et al. also specified that some movie distributors do not show weak movies to critics before their releases, to control the access and timing of negative criticisms [23].

When a movie is in the top five, people conduct the greatest search for movie information, more than the pre- and post-peak period. Therefore, movie marketers should heavily invest in Google Web search in the Arts & Entertainment category, YouTube search in the Arts & Entertainment category, and Google Web search in the Online Communities category respectively. Online communities such as webboard could be applied to raise the movie to a higher position as well. The movie searching of consumers decreases over time, but its association with the movie performance does not decrease. Promoting a movie after its peak period is also important because when a movie is listed as one of the top five movies, it becomes on the spot. Consumers pay so much attention to the top-five movies, particularly Web search and YouTube search in the Arts & Entertainment category within 12 days after the peak, and Web search in the Online Communities category within 8 days after the peak. This study thus highlights the promotion after the peak period since it could bring more consumer interests. Consequently, the interests of consumers in terms of their information searches could generate more revenues. If a movie could be listed in the top five movies today, it possibly maintains its position in the top five movies next week. A movie has to reach the highest position as fast as it

can too. The longer weeks that a movie exhibits, the lower rank that it will receive.

VII. Conclusion

A. Conclusion

This study is expected to give suggestions on the management of consumer interests through advertising through various channels over time (before, during, and after the movies are in the spotlight) and to examine how long will a movie be on the top lists and its relation to the movie's rank. This work also provides insights of consumer interests along a movie' product life cycle regarding when consumers are likely to show their interests in movies in which channels and in what time.

This research presents an empirical analysis of the movie market in Thailand. Data of two hundred sixty-five movies are collected from both BoxOfficeMojo.com and Google Trends for further analysis. The study finds strong evidence to support the importance of information search on box-office returns. A part of findings is consistent with previous finding in the literature, but this study shows some contrary results and add interesting insights, especially when and how a movie should be promoted online for the best impact?, to the movie market.

B. Limitations and Future Work

Limitations of this study are focusing on the movie product in Thailand and the demand side's factors (consumer interests) of the motion picture industry and using information search data from only one tool (Google Trends), which represents only searches done using Google and its related products. Future studies should be extended to other countries in Southeast Asia and other search tools such as Facebook or Twitter searches. The comparisons between consumer interests in Thailand and other Southeast Asian countries or other Western countries with the similar economic environments should be conducted. Movie-related factors such as genre, release date, and movie rating relating to consumer interests should be explored. Supply side factors; for instance, famous actors and production costs, should be examined. Other dependent variables of consumer interests such as the persistence of movies in online streaming movie services afterwards.

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Fault Detection of Elevator Systems Using Deep Autoencoder Feature Extraction

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***Abstract*—In this research, we propose a generic deep autoencoder model for automated feature extraction from the raw sensor data. Extracted deep features are classified with random forest algorithm for fault detection. Sensor data are labelled as healthy and faulty based on the maintenance actions recorded. The remaining healthy data is used for validation of the model to prove its efficacy in terms of avoiding false positives. We have achieved 100% accuracy in fault detection along with avoiding false positives based on new extracted deep features, which outperform the results using existing features. Existing features are also classified with random forest to compare results. Deep autoencoder random forest provides better results due to the new deep features extracted from the dataset when compared to existing features. Our model provides good classification and is robust against overfitting characteristics. This research will help various predictive maintenance systems to detect false alarms, which will reduce unnecessary visits of service technicians to installation sites.**

***Index Terms*—Elevator System, Deep Autoencoder, Fault Detection, Feature Extraction, Random Forest**

I. Introduction

In recent years, elevator systems have been used more and more extensively in apartments, commercial facilities and office buildings. Nowadays 54% of the worlds population lives in urban areas [1]. Elevators transport 325 million passengers every day in the United States and Canada alone [2]. Therefore, elevator systems need proper maintenance and safety. The next step for improving the safety of elevator systems is the development of predictive and pre-emptive maintenance strategies, which will also reduce repair costs and increase the lifetime whilst maximizing the uptime of the system [3], [4]. Elevator production and service companies are now opting for a predictive maintenance policy to provide better service to customers. They are remotely monitoring faults in elevators and estimating the remaining lifetime of the components responsible for faults. Elevator systems require fault detection and diagnosis for healthy operation [5].

Fault diagnosis methods based on deep neural networks [6], [7], [8] and convolutional neural networks [9], [10] feature extraction methodology are presented as state of the art for rotatory machines similar to elevator systems. Linear discriminant analysis [11], [12], artificial neural networks [13] and kalman filter [14] are also used as fault detection methods for rotatory machines. However, we have developed an intelligent deep autoencoder random forest based feature extraction methodology for fault detection in elevator systems to improve the performance of traditional fault diagnosis methods.

In the last decade, neural networks [15] have extracted highly meaningful statistical patterns from large-scale and high-dimensional datasets. A deep learning network can self-learn the relevant features from multiple signals [16]. Deep learning algorithms [17] are frequently used in areas such as natural language processing, signal processing, speech recognition, computer vision and image classication. Deep learning algorithms have also been used in various applications e.g. biotechnology [18], sentiment analysis [19], survival analysis [20] and information systems [21]. Autoencoding is a process for nonlinear dimension reduction with natural transformation architecture using feedforward neural network [22]. Autoencoders have proven powerful as nonlinear feature extractors [23]. Autoencoders can increase the generalization ability of machine learning models by extracting features of high interest as well as making possible its application to sensor data [24]. Autoencoders were first introduced by LeCun [25], and have been studied for decades. Traditionally, feature learning and dimensionality reduction are the two main features of autoencoders. Recently, autoencoders have been considered one of the most compelling subspace analysis techniques because of the existing theoretical relations between autoencoders and latent variable models [26]. Autoencoders have been used for feature extraction from the data in systems like industrial processes [27], induction motor [28] and wind turbines [29], different from elevator systems as in our research.

In our previous research, raw sensor data, mainly acceleration signals, were used to calculate elevator key performance and ride quality features, which we call here existing features. Random forest was used for fault detection based on these existing features. Existing domain specific features were calculated from raw sensor data, but that requires expert knowledge of the domain and results in a loss of information to some extent. To avoid these implications, we have developed a deep autoencoder random forest approach for automated feature extraction from raw sensor data, and based on these

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deep features, faults are detected. The rest of this paper is organized as follows. Section II presents the methodology of the paper including deep autoencoder and random forest algorithms. Then, section III includes the details of experiments performed, results and discussion. Finally, section IV concludes the paper and presents the future work.

II. Methodology

We have developed an automatic feature extraction technique in this research as an extension to the work of our previous research [30] to compare the results using new extracted deep features. Fig. 1 shows the fault detection approach used in this paper, which includes raw sensor data extracted based on time periods provided by the maintenance data. Data collected from an elevator system is fed to the deep autoencoder model for feature extraction and then random forest performs the fault detection task based on extracted deep features.

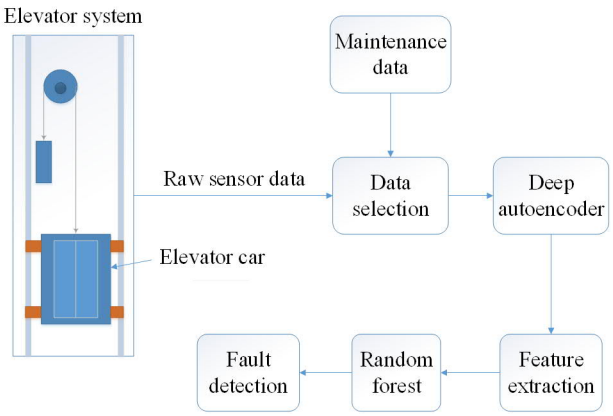


Fig. 1. Fault detection approach

A. Deep Autoencoder

The deep autoencoder model is based on deep learning autoencoder feature extraction methodology. A basic autoencoder is a fully connected three-layer feedforward neural network with one hidden layer. Typically, the autoencoder has the same number of neurons in the input and output layer and reproduces its inputs as its output. We are using a five layer deep autoencoder (see Fig. 2) including input, output, encoder, decoder and representation layers, which is a different approach than in [29], [31]. In our approach, we first analyze the data to find the most frequent floor pattern and then feed the segmented raw sensor data windows in up and down directions separately to the deep autoencoder model to extract new deep features from the raw data. Lastly, we apply random forest as a classifier for fault detection based on new deep features extracted from the data.

The encoder transforms the input x into corrupted input data $x^{'}$ using hidden representation h through nonlinear mapping

$$h = f(W_1 x^{'} + b) \tag{1}$$

where $f(.)$ is a nonlinear activation function as the sigmoid function, $W_1 \in \mathbb{R}^{k*m}$ is the weight matrix and $b \in \mathbb{R}^k$ the

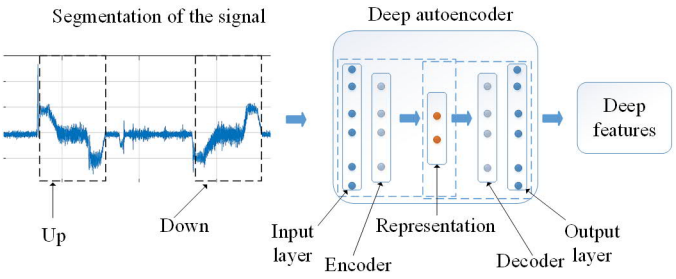


Fig. 2. Deep autoencoder feature extraction approach

bias vector to be optimized in encoding with k nodes in the hidden layer [31]. Then, with parameters $W_2 \in \mathbb{R}^{m*k}$ and $c \in \mathbb{R}^m$, the decoder uses nonlinear transformation to map hidden representation h to a reconstructed vector $x^{"}$ at the output layer

$$x^{"} = g(W_2 h + c) \tag{2}$$

where $g(.)$ is again nonlinear function (sigmoid function). In this study, the weight matrix is $W_2 = W_1^T$, which is tied weights for better learning performance [32].

B. Random Forest

Random forest includes an additional layer of randomness to bagging. It uses different bootstrap samples of the data for constructing each tree [33]. The best subset of predictors is used to split each node in random forest. This counterintuitive strategy is the best feature of random forest, which makes it different from other classifiers as well as robust against overfitting. It is one of the most user-friendly classifiers because it consists of only two parameters: the number of variables and number of trees. However, it is not usually very sensitive to their values [34]. The final classification accuracy of random forest is calculated by averaging, i.e. arithmetic mean of the probabilities of assigning classes related to all the produced trees (t). Testing data (d) that is unknown to all the decision trees is used for evaluation by the voting method (see Fig. 3).

Specifically, let sensor data value v_l^t have training sample l^{th} in the arrived leaf node of the decision tree $t \in T$, where $l \in [1, ..., L_t]$ and the number of training samples is L_t in the current arrived leaf node of decision tree t. The final prediction result is given by [35]:

$$\mu = \frac{\sum_{t \in T} \sum_{l \in [1,...,L_t]} v_l^t}{\sum_{t \in T} L_t} \tag{3}$$

All classification trees providing a final decision by voting method are given by [36]:

$$H(a) = \arg\max_{y_j} \sum_{i \in [1,2,...,Z]} I(h_i(a) = y_j) \tag{4}$$

where $j = 1,2,...,C$ and the combination model is $H(a)$, the number of training subsets are Z depending on which decision tree model is $h_i(a)$, $i \in [1, 2, ..., Z]$ while output or labels of

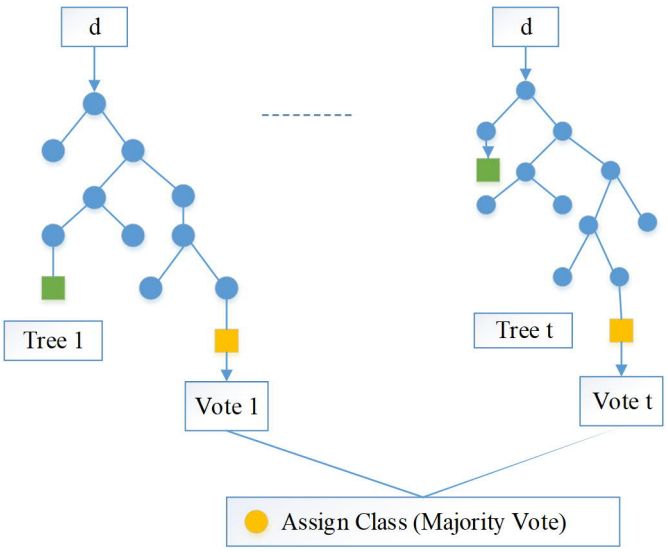


Fig. 3. Classification phase of random forest classifier

the P classes are y_j , $j= 1,2,...,P$ and combined strategy is $I(.)$ defined as:

$$I(x) = \begin{cases} 1, & h_i(a) = y_j \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

where output of the decision tree is $h_i(a)$ and i^{th} class label of the P classes is y_j, $j= 1,2,...,P$.

C. Evaluation Parameters

Evaluation parameters used in this research are defined with the confusion matrix in Table I.

TABLE I
CONFUSION MATRIX

	Predicted (P)	**(N)**
Actual (P)	True positive (TP)	False negative (FN)
(N)	False positive (FP)	True negative (TN)

The rate of positive test result is sensitivity,

$$Sensitivity = \frac{TP}{TP + FN} * 100\% \quad (6)$$

The ratio of a negative test result is specificity,

$$Specificity = \frac{TN}{TN + FP} * 100\% \quad (7)$$

The overall measure is accuracy,

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN} * 100\% \quad (8)$$

III. RESULTS AND DISCUSSION

In this research, first, we selected the most frequent floor patterns from the data, i.e. floor patterns which consist of the maximum number of rides between specific floor combinations. The next step includes the selection of faulty data from the most frequent floor patterns based on time periods provided by the maintenance data. An equal amount of healthy data is also selected and labelled as class 0 for healthy, with class 1 for faulty data. Only the vertical component of acceleration data is selected in this research because it is the most informative aspect consisting of significant changes in vibration levels as compared to other components. A combined version of healthy and faulty data is used for feature extraction with the deep autoencoder model.

A. Up Movement

We have analyzed up and down movements separately because the traction based elevator usually produces slightly different levels of vibration in each direction. First, we have selected the floor patterns 0 to 6 and faulty data based on time periods provided by the maintenance data as shown in Fig. 4. Each ride used in analysis contains around 5000 rows of the data, which proves robustness of the algorithm over large dataset.

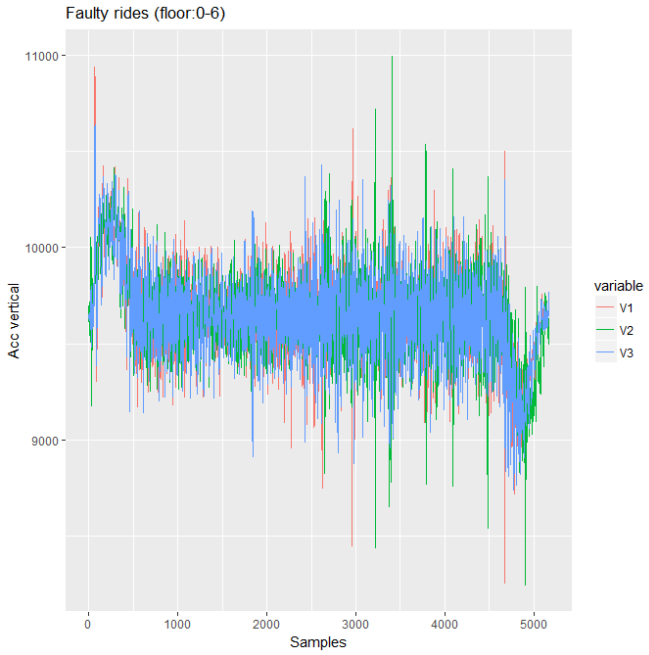


Fig. 4. Rides from faulty data

Then, we have selected an equal number of rides for healthy data, as shown in Fig. 5. The next step is to label both the healthy and faulty data with class labels 0 and 1 respectively. Healthy and faulty data with class labels are fed to the deep autoencoder model and the generated deep features are shown in Fig. 6. These are called as deep features or latent features in deep autoencoder terminology, which shows hidden representations of the data.

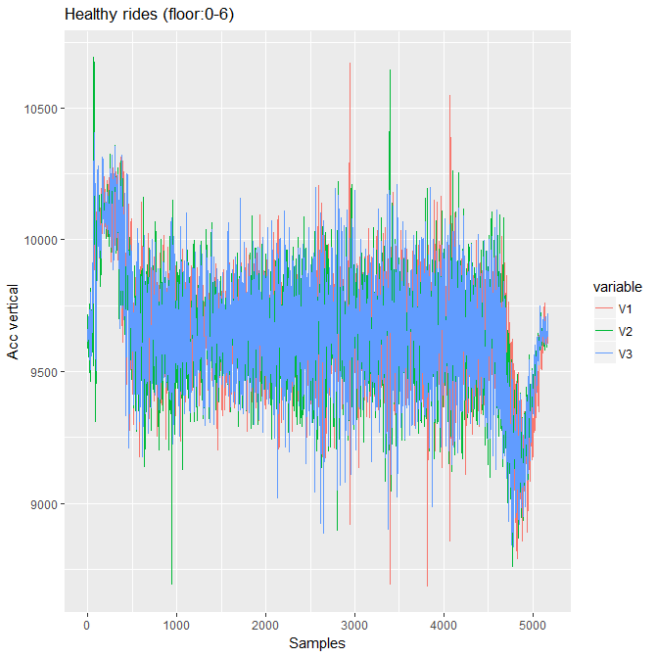


Fig. 5. Rides from healthy data

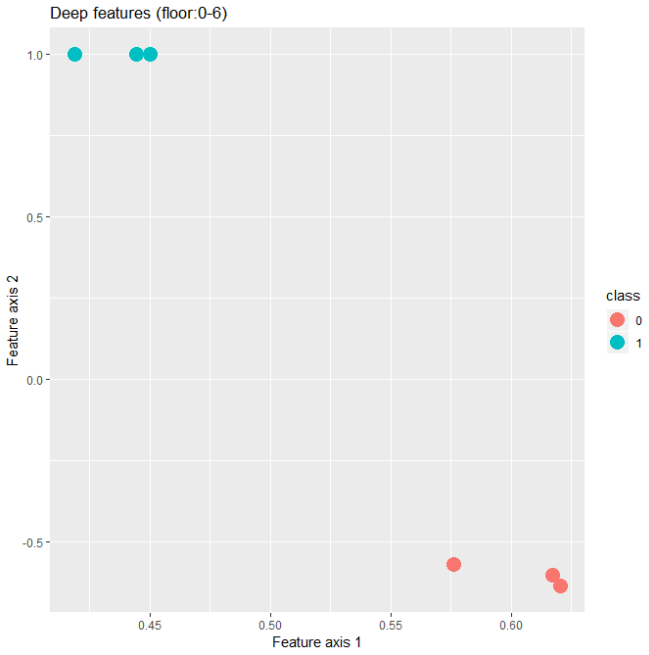


Fig. 6. Extracted deep autoencoder features. (Visualization of the features w.r.t class variable)

The extracted deep features are fed to the random forest algorithm for classification and the results provide 100% accuracy in fault detection, as shown in Table II. We have also calculated accuracy in terms of avoiding false positives from both features and found that the new deep features generated in this research outperform the existing features. We have used the rest of the healthy data similar as Fig. 5 to analyze the number of false positives. This healthy data is labelled as class 0 and fed to the deep autoencoder to extract new deep features from the data, as presented in Fig. 7. These new deep features are then classified with the pre-trained deep autoencoder random forest model to test the efficacy of the model in terms of false positives.

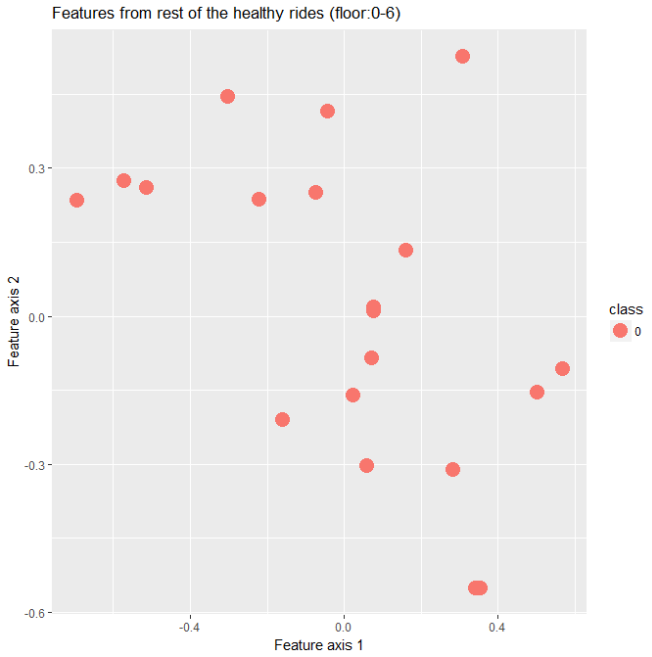


Fig. 7. Extracted deep features (only healthy rides)

Table II presents the results for upward movement of the elevator in terms of accuracy, sensitivity and specificity. We have also included the accuracy of avoiding false positives as evaluation parameters for this research. The results show that the new deep features provide better accuracy in terms of avoiding false positives from the data, which is helpful in detecting false alarms for elevator predictive maintenance strategies. It is extremely helpful in reducing the unnecessary visits of maintenance personnel to installation sites.

TABLE II
FAULT DETECTION ANALYSIS (FALSE POSITIVES FIELD RELATED TO ANALYZING REST OF THE HEALTHY DATA AFTER THE TRAINING AND TESTING PHASE)

	Deep features	**Existing features**
Accuracy	1	1
Sensitivity	1	1
Specificity	1	1
False positives	1	0.90

B. Down Movement

For downward motion, we have repeated the same analysis procedure as in the case of upward motion. We feed both healthy and faulty data with class labels to the deep autoen-

coder model for the extraction of new deep features, as shown in Fig. 8.

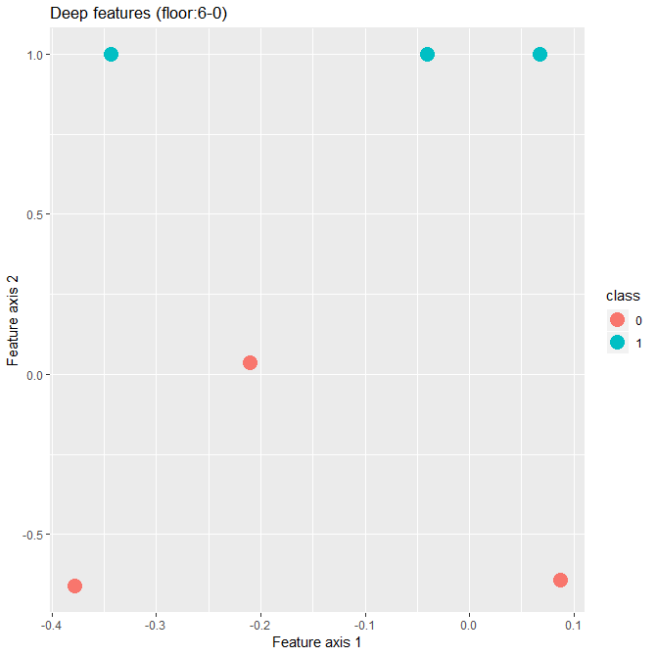


Fig. 8. Extracted deep features. (Visualization of the features w.r.t class variable).

Finally, the new extracted deep features are classified with random forest model, and the results are shown in Table III. After this, the rest of the healthy data with class label 0 is used to analyze the number of false positives. The extracted deep features are presented in Fig. 9. Table III presents the results for fault detection with deep autoencoder random forest model in the downward direction. The results are similar to the upward direction, but we can see significant change in terms of accuracy when analyzing the number of false positives with new deep features.

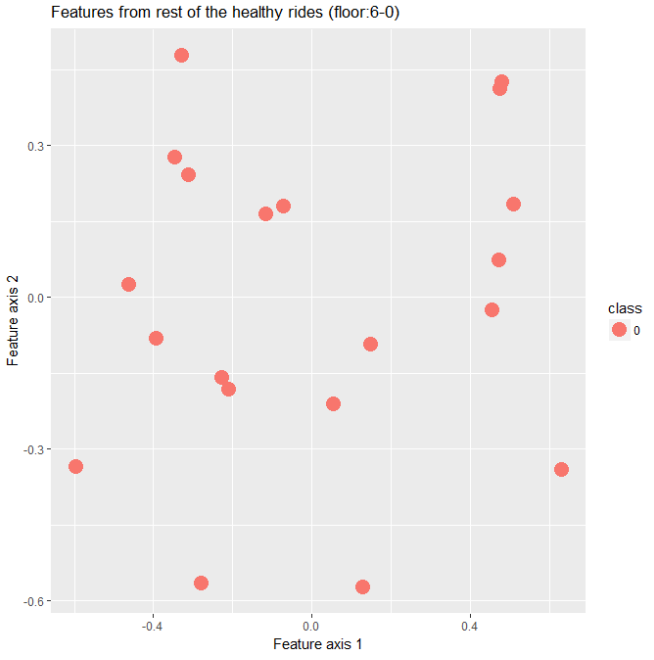


Fig. 9. Extracted deep features (only healthy rides)

TABLE III
FAULT DETECTION ANALYSIS

	Deep features	Existing features
Accuracy	1	1
Sensitivity	1	1
Specificity	1	1
False positives	1	0.55

IV. CONCLUSIONS AND FUTURE WORK

This research focuses on the health monitoring of elevator systems using a novel fault detection technique. The goal of the research was to develop a generic model for automated feature extraction and fault detection in the health state monitoring of elevator systems. Our approach provided 100% accuracy in the fault detection and in analyzing false positives for new extracted deep features. The results support our goal in this research of developing a generic model which can be used to other machine systems for automated feature extraction and fault detection. The results are useful in terms of detecting false alarms in elevator predictive maintenance. The approach will also reduce unnecessary visits of maintenance personnel to installation sites if the analysis results are utilized to allocate maintenance resources. Our developed model can also be used for different predictive maintenance solutions to automatically generate highly informative deep features for solving diagnostics problems. Our model outperforms because of new deep features extracted from the dataset as compared to existing features calculated from the raw sensor dataset of the same elevator. The automated feature extraction approach does not require any prior domain knowledge. It also provides dimensionality reduction and is robust against overfitting characteristics. The experimental results show the feasibility of our generic model, which will increase the safety of passengers as well as serve the public interest. We have tested the robustness of our model in the case of a large dataset, which proves the efficacy of our model.

In future work, we will extend our approach on more elevators including multiple floor patterns and real-world big data cases to validate its potential for other applications and improve its efficacy.

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Design for Efficient Production, a Model-Based Approach

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***Abstract*—The concept of simultaneous engineering has been used for several years in the industry. However, it rarely aims to think the design of the product and the design of its industrial system (the factory) together. In this paper, we address the need to have a global view of architectural design and manufacturing throughout the entire design process. More precisely, we define a model-based approach which makes it possible to evaluate the impact of a product design on its manufacturability. This approach constitutes a first step, in a long-term perspective, to consider several high-level industrial systems and product designs together and choose the one that gives the best performances.**

***Index Terms*—Conceptual Modelling, Model-Driven Engineering, Design for Manufacturability, Enterprise Modelling, Industry 4.0, Aeronautics.**

I. Introduction

For complex products, such as an aircraft, a satellite, or also some car models, it is necessary to have an industrial system (i.e. all the material and non-material means used to manufacture parts and assemble a product: workers, machines, factories, logistics and tools) specifically designed and dedicated to the manufacturing of the product. In this case, the industrial system is built for a single purpose, that is the construction of the specific product. In the cycle of development of such a complex product, the associated industrial system is usually specified only after the product is completely designed. Such a sequential process leads to a very poor consideration of the interactions between the product and its manufacturing. This is generally leading to severe constraints imposed to the manufacturing, which must be ableto assemble the product at any price.

In this paper, we show how a model-based approach can support simultaneous engineering and, more precisely, design for manufacturability (design a product in such a way that it is easy to manufacture).

In simultaneous engineering, the product and its industrial system are designed in the same time and not sequentially. All the actors of a project are involved from the beginning in order to have a global understanding of the objectives and the interactions between all the activities that will have to be performed. Simultaneous engineering is an old concept [1], but it is mainly applied to the optimization of parts, especially in the automotive industry [2], and not to a global optimization of the product and its production system in the context of complex objects such as an aircraft or a boat.

The first advantage of simultaneous engineering is by considering the problem of the design as a whole instead of two sequential sub-problems, the final global solution can be optimized according to many criteria. Among those criteria, a major one is the global cost. In fact, constraints on the industrial system could sometimes be easily lifted by modifying the product design. However, these product modifications can be extremely costly, and sometime impossible, due to sequential aspect of the standard approach. Considering both designs together allows the product design choices to be driven not only by the product but also by the different possible ways of manufacturing it. It provides a global view on the cost at early stages and therefore potential cost-savings.

The second advantage of simultaneous engineering is the agility that such an approach offers. Indeed, having a single framework for design and production allows to assess the impact of a product design on a given industrial system at an early stage and to compare, for a same design, different industrial systems against each other. As a result, the design of product/production couples that are impossible in a traditional sequential approach can here be considered. It should be noted that having a common model also makes it possible, in the case of an already existing product, to study changes in the product design and in the organization of the industrial system in order to be more efficient and reduce the manufacturing process duration.

Today, manufacturing processes already make good use of models as in blueprints, concrete diagrams, Computer-Aided Design (CAD) models, etc. In addition, different tools, and data, are used to define manufacturing tasks and to evaluate industrial performance. On the design side, we also have a set of tools that manage data such as 3D models. Our long-term goal is to use a model-based approach to structure all this information and to support the construction of a complete chain of methods and tools, for assessing the performance of the global solution design during the whole cycle of development. In other words, based on existing data and information, we seek to use conceptual models to propose an approach for thinking together the design of a product and its production.

In this direction, we proposed in [3] a model-based approach to switch from the sequential development to a simultaneous development of the product and its industrial system. Based

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on Airbus A320 aircraft production data, we identified the key elements of an assembly line and then abstracted these elements into a generic pattern. This generic pattern allows to unify the product design office view and the manufacturing department view, within the context of the A320. In addition, we proposed to use abstraction models of both the aircraft and its industrial system.

In this article, we take one more step towards the previously described global approach by proposing a methodology of models refinement starting at a high-level of abstraction and ending at complete detailed design description level. The idea is to support a simultaneous engineering activity between design and production by allowing to reason both about product design and assembly line at each level of abstraction. Thus, the high level of abstraction corresponds to the early stage of the development cycle and already takes into account the manufacturing point of view, which is new compared to the nowadays approach. The low level of abstraction corresponds to the final stages of the development cycle in which both designs are completely defined and detailed.

The paper is organized as follows. Section II is dedicated to the presentation of the hierarchical methodology. More precisely, we describe the pattern that can be used for each abstraction level and the refinement mechanism. In section III, we present the industrial context and apply this methodology on a simplified example. Finally, we conclude by presenting some related work in sectionIV and the main perspectives of this work in sectionV.

II. Methodology

A. An approach by levels of abstraction

For many complex products, like aircraft, the definition of the final product is an input for the definition of the industrial system. Furthermore, manufacturing architects handle detailed product definition elements, such as screws or cables, that only come up in the completely detailed product design. This state of affairs is problematic, as the aircraft design work begins its cycle of development with general concepts, such as a wing or a landing gear, corresponding to high levels of abstraction. Having the final product design, and consequently the design of the corresponding industrial system, at this level is obviously impossible with the current approach. In order to achieve our goal of simultaneous design, there is a need to model the product and the production designs whatever the level of granularity.

We propose, in the tradition of architectural frameworks, a hierarchical approach based on views where each view corresponds to a layer of abstraction. As [4], we use a mechanism that makes explicit the transition from one level of abstraction to the next. In [3], we proposed a pattern dedicated to the A320 manufacturing use case that could be specialized in concrete classes for each level of abstraction. This specialization was explicitly described for the lowest level of abstraction but we did not define the associated transition mechanism between levels. We present here a more generic version of the pattern, applicable to assembly lines, and that will be explicitly specialized for each level of abstraction of our example in the following sections.

The pattern is composed of the following elements (as is illustrated on Figure 1 with classes in strong line):

- *Physical Element*: physical part of the product. This is the bridge between the design world and the manufacturing world. Depending on the granularity, a Physical Element can be a constituent element of the product (wing, cockpit for an aircraft, power-train, body for a car, etc.), a module (dashboard, engine, etc.) or a very detailed part of the product (screw, cable, etc.);
- *Design*: design of the product, i.e. the definition of all physical elements composing the product and the technical way they are assembled together. It is composed of Physical Elements and has a *level of maturity* feature that is directly linked to the level of abstraction considered in our methodology;
- *Function*: service that a Physical Element contributes to provide. A Physical Element can be associated with several Functions and, conversely, one Function can be provided by several Physical Element. For instance, the ballpoint in a pen could be associated with the writing function, or an inertial measurement unit could be associated to the navigation function or to the attitude, velocity and position functions;
- *Operation*: action that must be performed in order to manufacture the product. A key point here is the *precedence* constraint between operations. It represents the fact that an operation cannot start before some others are finished, for technical reasons. For example, there is a precedence constraint between the operation "*screwing a screw*" and the operation "*making a hole*", or between the operation "*move a furniture*" and the operation "*fix the furniture*". In addition, an operation has a attribute *duration* which is the time required to perform the Operation.
- *Location*: the physical location at which the operation takes place. This can be a very precise localization, as required when assembling several equipment on an aircraft. It can also be a geographical position as in the case of logistic aspects, when operations involve moving an element from one building to another or from one factory to another;
- *Port and Connection*[1]: two classes that allow abstraction of physical elements that are not yet specified at a given design level, but that specify the connections between two Physical Element. More precisely, the Port class is provided with four attributes to specify the flow: *flowType* which indicates the type of flow (air, water, electricity, etc.), *flowIn* and *flowOut*, two booleans which indicate if the flow is incoming, outgoing or both and *flowValue* which is the quantity of flow going through the port.

Because it is a generic pattern, the precision will depend on the level of abstraction. For instance, Operation, that consists to build the product, can be quite abstract for high-level models

[1]We use the *SysML* terminology here.

and intermediate level ones. For example, an aircraft equipping Operation could be "*fix a pipe*" or "*lay the floor*".

B. Refinement from one level of abstraction to another

Our methodology is based on the abstraction of the physical elements and their connections. Therefore, the refinement mechanism can be split into the two following processes.

1) Definition and refinement of physical elements and associated operations: A physical element, like an embedded computer, is not just an object in our model. It is also a precise specification that is given through 3D modeling tools. For us, a physical element is therefore linked to a set of data, exogenous to our model, which specifies its weight, size, etc. In the high levels of abstraction, there can be a lot of uncertainty about this data or can even be completely unknown.

For the example of the embedded computer at an early stage of the development cycle, an imprecise idea of its size, weight and location is the only information available. Following the pattern, at this level, we define a very abstract Operation "*computer installation*" with a duration equal to a rough estimation of the installation time. From there, at each step of refinement, as the design data of the element is getting more detailed, it is possible to refine the associated Operation and installation times or replace them with more specific ones, until the final design of the Physical Element is reached. Functions are also refined between levels: at each step, functions from level $N+1$ are all the technical functions necessary to provide services represented by functions of level N (level just above in the hierarchy).

2) Refinement of connections and ports: One of the key points of our approach is that, at a high level of abstraction, we do not need to consider all the real elements that connect Physical Elements together. For instance, at level 0 (highest level), we will consider an airplane wing and an engine that are both Physical Elements connected to each other, but we do not need to explicitly consider the elements that connect them. This abstraction is done using the Port and Connection classes. Back to the example, this connection is modeled by two instances of Port (one for each Physical Elements) and an instance of Connection linked to those ports. In the next step of refinement (level 1), the connection is refined into physical elements, such as a gas hose and an electric harness, which are themselves connected through ports, on one hand to the wing on the other hand to the engine. Formally, each Connection of a level N is refined into a Physical Element in the level $N+1$. Ports in level N remain in Level $N+1$, possibly with updated attribute values, and new Ports and Connections are created between the old Physical Elements and the new ones.

The process is then repeated until the complete description of the product is provided (attachment systems, switches, valves, screws and bolts, ...). In the final step, there is no more Connection type object, nor Port as they have all been refined into Physical Element. All the components of the model are Physical Elements directly connected together, as shown in [3].

III. An aeronautical industrial example

A. Context

In the aeronautics field, the increase in demand, and therefore the increase in aircraft sales, leads to the need for an increase in production rates. This can be achieved either by duplicating assembly lines or by modifying the aircraft design to get a faster manufacturing. To make an optimal financial choice, there is a need to assess the performances of each of these two options. To put it simply, duplicating a factory will be extremely expensive but will make it possible to double the production (which is not necessarily the goal to achieve), whereas a design change will be potentially much cheaper but will allow to manufacture just a little more.

While the performance of an assembly line duplication is quite easy to assess, the impact of a design update can be hard to evaluate and it requires to have a good understanding of the interactions between the design and the production system. On this point, there is a major difficulty for the aircraft design office to anticipate and understand the impact of a design change on the production, as it is managed by different teams at the assembly line level. Moreover, it is not necessarily easy for design teams to identify the bottlenecks of a given assembly line, especially for old aircraft programs for which the digitization process is not complete yet. The current process is really time-consuming as the impact cannot be evaluated until the new design is completely detailed.

Therefore, there is a need to assess the impact of an aircraft design not completely detailed, which can be seen as an abstract design, on the industrial system performance. The methodology described in the paper applies to this case, and being able to model a new design and the current industrial system at a high level of abstraction allows to assess the performance of the global solution. This performance is quantified here through the expected production rate.

B. A dedicated model

We focus more specifically on the use case that aims at increasing production rates on a real assembly line in Airbus. This assembly line is composed of stations, which are the physical space in which the aircraft section is equipped along with the associated tools and parts. In order for the aircraft to be completely equipped, it has to go through all the stations of the assembly line in a given order. The aircraft stays for a given constant duration, called *TAKT*, at each station of the line. When this duration is over, the aircraft goes to the next station of the line or is shipped to another plant if it was in the last station.

To handle this assembly line, we enrich the previously defined pattern with specific technical classes as illustrated on Figure 1[2]. More precisely, we specialize classes of the pattern the following way:

[2]As proposed in [5], we chose, on Figures 2, 3 and 3, to give a more intelligible representation of the object diagrams by playing with shapes and colours. For instance, connection objects are represented by a line and port objets by a box with the same shape as the SysML ports with provided and required interface.

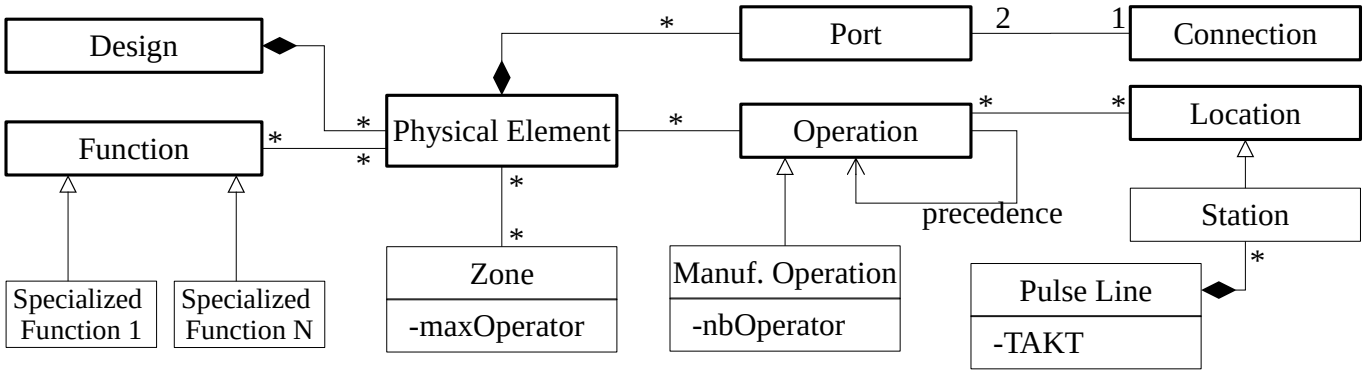


Fig. 1. Example: product and production class diagram.

- *Station*: physical space of the assembly line in which the aircraft section is equipped. Station is a specialization of the pattern's class *Location*;
- *Manuf. Operation*: operation inheriting from the pattern's class *Operation* that allows to define specific attributes such as the number of operators required (*nbOperator*) to perform the operation;
- *Specialized Function*: function that enrich the pattern's class *Function* with dedicated attributes.

We also add the following classes:

- *Zone*: physical area of the aircraft in which a manufacturing operation is performed. In fact, an aircraft is divided into manufacturing zones that are characterized by their geographic perimeter. A Zone has a *maxOperator* attribute representing the maximum number of operators that can simultaneously work in the zone ;
- *Pulse Line*: assembly line composed of the stations that altogether deliver completely equipped aircraft sections at every TATK.

C. Refinement illustration

In this paper, we focus on an very simplified example involving two elements that are inserted in a new design: a device (*Eqt*) and an extraction fan. The device considered here is an electronic element such as an embedded computer or the aircraft dashboard (its precise nature is not relevant for this case). The fan is an extraction fan used for cooling *Eqt*. In this section, starting at a given level of abstraction N, we show how this simple example is modeled and refined. The details about the origin of the data presented in the model are not provided in this section but in the next one.

Figure 2 illustrates the model instantiated at a level N. For legibility reasons, we do not detail the Function, Design and Pulseline objects in this figure. There are only two Physical Elements: the *Extractor Fan* and the *Eqt*. They are coupled together through Ports and Connection objects. We use here a *SysML* notation,i.e. we have chosen to graphically represent the ports by a small rectangle attached to the Physical element and the Connection objects by a line that connects those two ports. The type of the flow going through the two ports is *air*, expressed in $kg.s^{-1}$. The flow is going out of the port

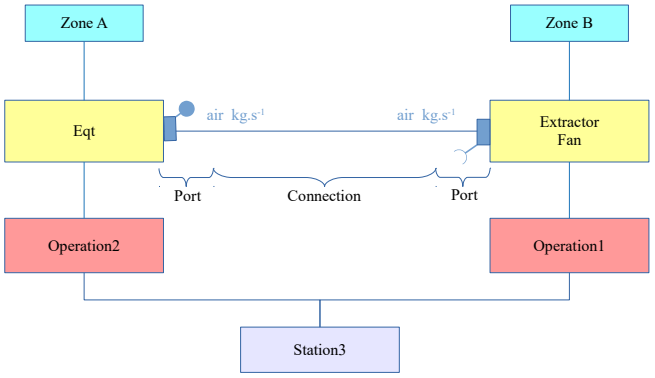


Fig. 2. Example model instantiation at level N.

of *Eqt* and is going in the port of *Extractor Fan*. At this level, it is already known that these two elements are in two different zones, namely *ZoneA* and *ZoneB*. Operations associated with these elements are abstract: *Operation1* and *Operation2* are respectively the "*installation of* Extractor Fan" and "*installation of* Eqt" . For the moment, there is no precedence relation between the two operations since there is no constraint on the ordering of the installation of these two Physical Elements. Finally, those two operations are performed at station 3 on the assembly line.

A instantiation of this example at the next level, $N+1$, is illustrated in Figure 3. This instantiation refines level N (Figure 2) in the following way:

- the connection object between *Eqt* and the *Extractor Fan* from level N is replaced here by the element *Ducting Pathway*;
- new connections are created to link this new element to the others: a first one between *Eqt* and *Ducting Pathway* and a second one between *Ducting Pathway* and *Extractor Fan*, along with the associated ports;
- as *Ducting Pathway* goes through the two zones associated with *Eqt* and *Extractor Fan*, it is linked to both of these zones;
- a new operation *Operation3* "*installation of Ducting*" is associated with *Ducting Pathway*;

- even if the operations are quite abstract, it is possible now to define precedence constraints between them. For instance, the *Extractor Fan* must be installed before the *Eqt* and *Ducting Pathway* can be installed;
- duration of *Operation2* and *Operation1* are updated according to new data;
- *Operation1* is still performed in station 3 of the assembly line, but *Operation2* is transferred to station 4. *Operation3* is also performed in station 4.

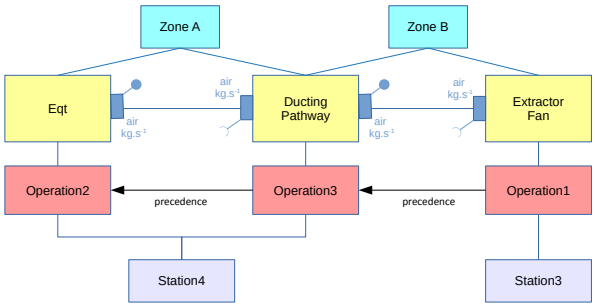


Fig. 3. Example model instantiation at level $N+1$.

We continue to refine the current example and present the result at level $N+2$ in Figure 4:

- each Connection of level $N+1$ is refined by introducing a new Physical Element. More precisely, the *Ducting Pathway* is connected to *Eqt* through an Physical Element called *Socket 1* that represents the way *Eqt* and *Ducting Pathway* are connected to each other;
- these new elements are associated with their respective Zone;
- Operation instances are also refined. This time, the refinement of *Operation2* creates two operations: one related to the installation of *Eqt* (*Operation2.1*), and one related to the installation of the socket (*Operation2.2*); the former is still associated with *Eqt*, while the latter is associated with *Socket 1*. The same applies for *Extractor Fan* and *Socket 2*;
- *Operation3* is refined in *Operation3.1* and it is no longer performed at station 4 but at station 3;
- the precedence constraint among operations of level $N+1$ are also refined. For instance, the precedence between *Operation2* and *Operation3* is replaced by two precedence constraints, respectively between *Operation3.1* and *Operation2.2*, and between *Operation2.1* and *Operation2.2*.

At this level, all the elements are still quite abstract. For instance, the Socket 1 between *Eqt* and *Ducting Pathway* has also to be instantiated into a specific Socket, with which it will be possible to update the associated installation operations. Zones A and B might also be refined and split into smaller zones in the lower intermediate levels. As the cycle of development continues, the new data on the physical elements can allow the architects to realize that the *Ducting Pathway* cannot be one element (for instance, because of its length) but must be split into several pathways connected together. In that case, it is possible to locally backtrack at level N, divide the pathway into as many as required smaller ones, and refine again the relevant part of the model.

The sequence of refinements leads to a final instantiation of the aircraft design and manufacturing in which the Connection and Port objects are not required any more. Indeed, in our approach, Ports represent the abstract notion of interface, the place where two elements are connected. However, the last level represents real objects, at least objects that will be manufactured. All elements must therefore have a physical reality and be attached to a manufacturing operation. In the same way that the concept of man-machine interface is concretized in reality through the keyboard, the mouse,... our concept of Part is concretized by a physical element which is really the interface between two other elements, like a valve or a plug.

So, this final instantiation can first be enriched in order to take into account practical manufacturing aspects, such as logistics, tooling, operators schedule, etc. Therefore, it provides data to the existing manufacturing tools that perform, for instance, logistic simulation. It can also be connected to physical data to perform aircraft design assessments (acoustic, thermal, etc.).

IV. Related Work

In [6], authors define a Domain-Specific Language built on SysML and transformation rules to address discrete event simulators. Their purpose is to allow the business experts to define the indutrial system in their own terms, in details, and to automate the creation of simulations. They do not address the issue of design for manufacturability, they simulate different resource configurations and schedules operations for a single product design. The output of our refinement process could be the input for their approach.

In order to support the industrial system design, and more precisely for the warehouses, [7] gives a SysML methodology based on functional flows. Again, this work is not intended to address simultaneous engineering, but it could be used to enrich our methodology which does not take into account the manufacturing functional flows. Regarding the industrial system, we only focus on assembly line. In [8], the authors propose an architectural framework for designing the manufacturing system, incorporating concepts such as *shop floor*, tooling, machines or artificial hands. Always in the idea of enriching our model, [9] proposes an ontology for lifecyle management relatively manufacturing-oriented.

In our approach, manufacturing operations are an input. At each refinement stage, it is therefore necessary to give the sequence of operations attached to a physical element. Many works are focused on automatically finding the sequence of operations from a physical model [10]–[13]. These works do not consider complex objects, but only small elements, like a catalytic converter or transmission system. However, they could be a good starting point for defining operations in our refining process.

More focused on simultaneous engineering problems, "*Design for Assembly*" methods are techniques that aim to design

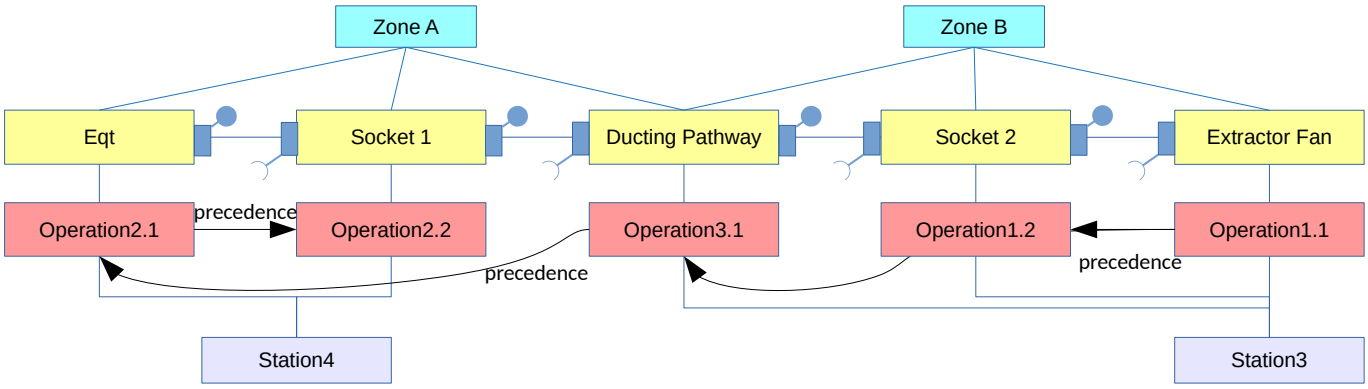


Fig. 4. Example model instantiation at level $N + 2$.

a product as a set of modules with an efficient assemblability [14]. Works like [15], [16] propose to support the designer, in preliminary designs, to take into account the manufacturability of the product. These approaches are very complementary to ours, they are located upstream of our refining cycle. Indeed, unlike us, they only aim to define the product, not the industrial system, and the preliminary designs produced correspond to the models we take as input.

V. Conclusion

In this article, we proposed a model-based approach allowing us to think design and production of an aircraft together. Our contribution is above all methodological. We presented a pattern to support a hierarchical modeling approach and a refinement method. Regarding automation, even if we do not address the problem in this article, some works have shown the possibility of using logic solvers to design assistance [17], [18]. This type of automatic analysis could be used to validate the integrity of our models and support design tasks. An example of automatic verification could target the flow attributes of Port objects: check that two ports connected to the same Connection object have the same type and that the flowIn and flowOut are consistent. From a more theoretical aspect, future work could consist in formally characterizing the transition from one model to another in our refinement process. For that, we will be able to rely on many existing works like [19], [20]. Finally, future work may also address the generalization of the approach. We have focused on aeronautical test cases, but our method seems sufficiently generic to be suitable for the manufacturing of other complex products.

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Design Thinking and Acceptance Requirements for Designing Gamified Software

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***Abstract*—Gamification is increasingly applied to engage people in performing tool-supported collaborative tasks. From previous experiences we learned that available gamification guidelines are not sufficient, and more importantly that motivational and acceptance aspects need to be considered when designing gamified software applications. To understand them, stakeholders need to be involved in the design process. This paper aims to (i) identify key requirements for designing gamified solutions, and (ii) understand if existing methods (partially fitting those requirements) can be selected and combined to provide a comprehensive gamification design method. We discuss a set of key requirements for a suitable gamification design method. We illustrate how to select and combine existing methods to define a design approach that fits those requirements using *Design Thinking* and the *Agon framework*. Furthermore, we present a first empirical evaluation of the integrated design method, with participants including both requirements analysts and end-users of the gamified software. Our evaluation offers initial ideas towards a more general, systematic approach for gamification design.**

***Index Terms*—Acceptance requirements, Design thinking, Gamification, Requirements engineering, Empirical evaluation.**

I. Introduction

Motivating people in accepting and using a software system is a crucial factor for the success of such systems [1]–[4]. *Gamification* has been identified as a mean to meet such *acceptance requirements* through the inclusion of game elements in systems that operate in non-game contexts [5] (e.g., air traffic management and decision-making [3], software engineering tasks [6]).

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It is worth noting that gamification is different from serious games where game playing is used to create a better understanding of a particular concept in a learning situation (e.g., emergency management training [7]). Although both serious games and gamification help to motivate users of a software application by making usage experience enjoyable, their design processes are different. Designing serious games requires a deep understanding of learning objectives [8], while gamifying a tool-supported task requires understanding the motivations driving users [2], [9]–[11]. Examples of motivations based on specific kinds of users are [12], [13]: **(i)** using the software in a collaborative/social way by interacting as much as possible with other users (socializers [12]); **(ii)** learning as much as possible how to use a system, for being able to help the others users, to be recognized as expert of a system (explorers [12]). Other motivation examples relevant for specific software contexts are: **(i)** fixing as many bugs as possible, while performing software testing, or **(ii)** identifying the most important requirements while performing requirements prioritization.

Current gamification solutions can be found both in academic and industrial software systems. On one hand, practitioners tend to use available gamification guidelines and resources provided in commercial platforms or in publicly available wikis[1], which neglect a deep analysis of users and usage context. For this reason, many gamified systems achieve poor engagement of users. On the other hand, scientific research literature offers methods from different fields, notably human-computer interaction, that ensure successful results but require a complex and expensive process of analysis. However, research literature on the evaluation of the effectiveness of the resulting solutions points out the limitations of current practices, identifies key concepts and discusses the need for better methods to design engaging software [2], [14], [15]. In particular, requirements analysis should be guided by systematic methods for exploring a design space of alternatives [1]–[4]. Such a design space is defined in terms of motivational,

[1]e.g., https://en.wikipedia.org/wiki/Game_mechanics

psychological, cognitive, behavioral factors [2] that influence the fulfillment of *Acceptance Requirements* [1], [3], [4].

An interesting example of gamified software lacking of acceptance from its users is DMGame. Specifically, it is a gamified collaborative requirements prioritization tool [16], [17] developed within the SUPERSEDE project[2]. The tool has been evaluated in the context of three industrial use cases. Moreover, the effectiveness of specific game elements was further investigated through a controlled experiment that confirmed a lack of acceptance by its intended users [16]. In this work, we consider the DMGame as an illustrative case study of a software system lacking of acceptance and, by using the novel method we propose in this paper, we improve its gamification on the basis of a deep, systematic analysis.

Specifically, the main goals of this paper are to (i) identify key requirements for a suitable method for designing gamified tool-supported tasks, and (ii) understand to what extent existing methods that partially fit those requirements, can be selected and combined to provide a suitable gamification design method. Moreover, we are interested in evaluating the resulting method.

To address the first research objective, we analyze related literature, observations collected during the DMGame case study and other experiences within EU projects (e.g., SUPERSEDE[2], Lucretius[3], DEFeND[4], PACAS[5], VisiOn[6], STREETLIFE[7]), and derive a set of requirements for a suitable gamification design method. We address the second one by analyzing characteristics of existing methods that can be related to the stated requirements of the method. Moreover, we propose two candidate methods that, integrated together, can result into a method that fulfills those requirements. One is *Design Thinking* (DT) [18], [19], a method for innovative design that has been applied in very different domains, ranging from IT, to Medicine and Architecture, which has been revisited from the perspective of requirements engineering, e.g. [20]. The other is the *Agon* method [1]–[4] for analyzing acceptance requirements and operationalizing them through game elements. The resulting method is called DTA (*Design Thinking & Agon*). In the context of our research we assess the effectiveness of DTA in terms of the degree of coverage of the stated key requirements, usefulness as perceived by its users, namely designers of gamified tool-supported tasks, as well as the quality of the resulting designed solution.

The rest of the paper is structured as follows. Section II presents the DMGame case study, the problem faced and lessons learned. In Section III, we propose the key requirements of a collaborative method for designing gamified software. Section IV shortly recalls the DT and Agon methods, and discusses how they individually satisfy part of the key requirements. In Section V, we propose DTA, the method that combines DT and Agon, and that aims at fully covering the key requirements. Section VI describes the empirical evaluation of the DTA method. Section VII discusses related work, and Section VIII concludes and outlines future work.

[2] SUPERSEDE is a EU H2020 project: https://www.supersede.eu
[3] Lucretius is a ERC project: http://www.lucretius.eu/
[4] DEFeND is a EU H2020 project: https://www.defendproject.eu/
[5] PACAS is a EU H2020 project: http://www.pacasproject.eu/
[6] VisiOn is a EU H2020 project: http://www.visioneuproject.eu/
[7] STREETLIFE is a EU H2020 project: http://www.streetlife-project.eu/

II. The DMGame Case Study

Software development projects have typically limited resources in terms of time and budget, thus it is essential for the development team to prioritize requirements and implement them accordingly. Tool-supported collaborative requirements prioritization tasks are increasingly used in software engineering practice, but are still rarely adopted by small companies [21]. Possible reasons for this fact have been investigated in the SUPERSEDE project[2], where a configurable tool-suite has been developed, which includes plugins for the popular issue tracking system JIRA[8] [22]. This tool-suite has been validated in the project's industrial use-cases.

The SUPERSEDE tool for supporting collaborative requirements prioritization is called DMGame [17]. It is a collaborative requirements prioritization tool, which allows the members of the development team to express their preferences on requirements priorities, according to one or more criteria, and provides a final requirements ranking by combining these preferences. The DMGame exploits automated reasoning techniques such as the Analytic Hierarchy Process (AHP) and genetic algorithms.

Gamification has been applied to foster team members' engagement [17], especially in those activities perceived as boring, such as expressing their preferences on a large set of requirements pairs, where the AHP method is used. Using the DMGame, a collaborative prioritization task is presented as a game, where decision makers are players, who can be assigned the role of opinion provider and of negotiator. Examples of game elements used in DMGame can be seen in the upper part of the screenshot depicted in Fig. 1. For instance, *accomplishment percentage* indicates to the user her progress on the assigned task, and *points* can be gained by the user according to specific rules (e.g., one rule is based on the agreement index with the other task's contributors). In the lower part of the screenshot in Fig. 1, pairs of requirements are presented (columns *First Requirement*, *Second Requirement*), and their relative importance according to *User impact* criterion can be expressed on a "1...9" AHP scale. In the DMGame version based on genetic algorithm, instead, requirements are presented in a list and the user can input her evaluation on their relative importance by moving up or down in the list each box representing an individual requirement.

The gamification effectiveness in DMGame has been evaluated by the two small/medium enterprises and the two large companies involved in the project, as well as in a controlled experiment with University of Trento master students [16]. The analysis of the collected data indicates that the gamification impact was quite limited. Although gamification increased slightly the level of engagement and flow, users did not perceive employed game elements as useful and sufficiently engaging.

[8] An agile software development tool: https://www.atlassian.com/software/jira

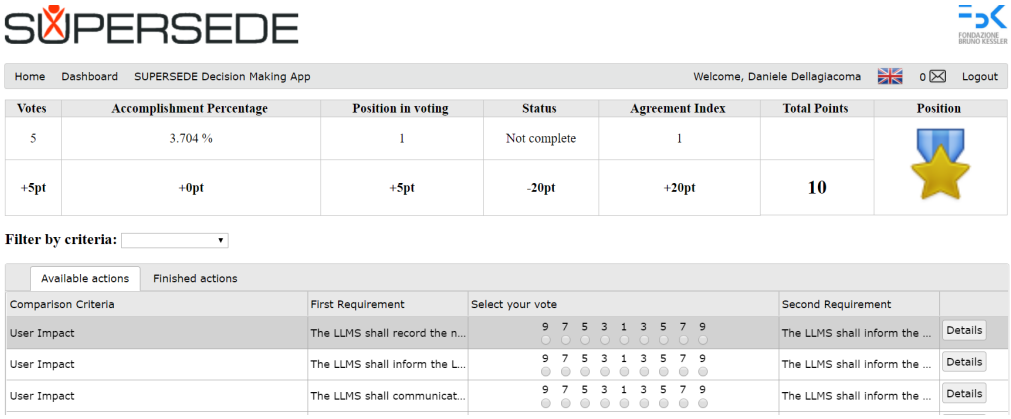


Fig. 1. DMGame: the GUI of the gamified AHP-based version [16].

Gamification in DMGame has been designed following practitioners' guidelines[1], but the resulting poor effectiveness can be seen as an indicator that guidelines are not sufficient [16].

A. Lessons Learned

The analysis of the literature, the DMGame case study, and experiences performed within EU projects (e.g., SUPERSEDE[2], Lucretius[3], DEFeND[4], PACAS[5], VisiOn[6], STREETLIFE[7]), allowed us to reflect on aspects concerning the gamification of tasks in terms of stimuli and game elements and, more generally, on the need of a structured method allowing to explore in a systematic, but creative, way alternative gamification solutions. We derived the next lessons learned.

LL1 : *A Wider, Creative, User-Focused Design Approach.* Points-based elements [16] have to be integrated with other gamification elements to amplify the engagement effect on users [1]. In fact, different kinds of users react in different ways when exposed to different stimuli generated by different game elements [13], [23]. Therefore, to find proper stimuli for engaging the intended users, it is needed a more sophisticated and user-focused gamification design [11], [24], [25]. Indeed, both in the literature and in real cases from the industry, there are many evidences revealing that, in most of the cases, a gamification design only points-based is not enough to obtain acceptance and engagement on the target users [13], [16], [17], [23], [26]. Thus, it is required a user-focused deep analysis aiming at individuating a wider variety of effective elements to use, for producing a more exhaustive gamification design, made of heterogeneous elements, really able to engage most of the different typologies of users [2], [10], [12]. Furthermore, having a broader set of effective gamification alternatives to choose, enables also the analyst to select, more easily, the most engaging elements fitting also the other system requirements, and to discard the ones being in conflict [1], [3], [4]. In fact, it happens that some gamification solutions, even being effective for the intended users, could be in conflict with important system constraints, and could potentially break other important requirements such as privacy and security requirements [3], [4]. Therefore, to enable the analyst to design a comprehensive gamification solution, made of all the elements needed to create a really engaging gamification solution for the intended users, not only based on points [16], requires also the employment of concepts and techniques highlighted in the next lesson learned;

LL2 : *Stakeholders Involvement and Collaboration.* Successful gamification requires a deep understanding of the users and their motivations also in relation to the task they have to carry out by using the software [1]–[3]. Furthermore, this calls for involving deeply the stakeholders in the design process, making them empathize with the task through creative [21] and collaborative design methods [17], for extracting profound motivations of people when involved in a gamified task in a given context. This enables analysts and stakeholders to identify collaboratively which design mechanisms can concretely motivate the intended users of a specific context [3];

LL3 : *Understanding Acceptance Requirements.* A deeper understanding of the social context of usage is needed [2], as well as the psychological, behavioral, cognitive considerations that help to determine how software should be gamified [3], [14];

LL4 : *A Systematic and Traceable Approach.* To address the above lessons learned, gamification analysts need a systematic approach [1]–[3] that is able to promote and balance collaboration and creativity during the design process [15], [17], [21]. Artifacts generated during the design process should support traceability of stakeholder characteristics, task objectives and acceptance requirements, so to support evolution of the gamified tool-supported task.

III. Key Requirements of a Method for Designing Gamified Software

Reflecting on the lessons learned presented in the previous section, which root in literature and practical experiences within EU projects (e.g., SUPERSEDE[2], Lucretius[3], DEFeND[4], PACAS[5], VisiOn[6], STREETLIFE[7]), we identified the following key requirements for designing gamified tool-supported tasks. We discuss them highlighting how they relate to lessons learned.

R1 : *Systematic, Traceable Approach.* This is derived from **LL1**, **LL3**, **LL4** due to the following reasons. Specifically, the method has to be systematic and traceable [1]–[3] (**LL4**) **(a)** allowing the exploration of most of the factors influencing the user in being motivated to use a system [2], [14] (**LL3**), and **(b)** employing effective techniques for analyzing and tracing those factors and designing mechanisms able to satisfy them [3] (**LL1**, **LL3**);

R2 : *Participation/Collaboration and Creativity*. The design method should support participation/collaboration by stakeholders, and also encourage creativity during the design process. These are derived from **LL2**. In fact, to address factors of "**R1 (a)**", techniques and mechanisms mentioned in "**R1 (b)**" [3] are needed as well as approaches that support deeply involving stakeholders [17], [21] (**LL2**) and making them to collaborate (**LL2**) in a creative way [21]. To involve stakeholders in the design is fundamental, because they have really the knowledge required for analyzing deeply the specific domain, the situation and the user [17], [21]. Collaboration [17] pushes them towards brainstorming finding more valuable ideas together. Creativity [21] fosters finding richer and more complete solutions. Thus, techniques mentioned in "**R1 (b)**", to maximize their effectiveness, should be executed in a participatory, collaborative and creative fashion [17], [21];

R3 : *Acceptance Orientation*. From **LL3** we derive that the design method should have an acceptance orientation, because the final aim of the method is to design engaging software for the user. Thus, it is fundamental to explore most of the factors (see "**R1 (a)**" above) that positively influence the user such as psychological, motivational, cognitive and behavioral factors [2]. These are usually referred to *Acceptance Requirements* [1]–[3] and related techniques [3]. They are crucial for selecting psychological strategies as design mechanisms to use to make the software attractive [1]. Thus, the method has to be acceptance oriented (**LL3**);

R4 : *Gamification Orientation*. The method should support the selection of gamification elements to operationalize acceptance requirements. This is derived from **LL1** and **LL3**. In fact, factors analyzed through acceptance requirements have to be mapped with gamification concepts able to fulfill such requirements. It is important to choose those concepts as well as to decide properly how to put them together in a coherent and effective gamification design [1]. Such method has to support both these aspects, namely it has to be gamification oriented. With gamification oriented we mean that the method should incorporate the gamification design knowledge [3] (**LL1**), and provide related techniques, able to support the analysts in producing a high-quality gamification design made of concepts, satisfying acceptance requirements, organized according to gamification best practices [1] (**LL1**, **LL3**);

R5 : *Context Characterization*. The method should support the characterization of the social context within users using the system. This is derived from **LL1** and **LL3**. The identification of acceptance and gamification strategies that are effective for a specific kind of user, depends strictly on the specific context variables [1]–[3] (**LL1**, **LL3**). Thus, such method has to support the characterization of context variables such as the human as a user and as a player [1], the goals and needs of the user, the task that the user carries out by using the software and related positive and negative user feelings, what can be produced by using the software and in which social context [2] (**LL3**). Moreover, a method supporting context characterization uses these considerations in individuating which acceptance and gamification strategies best fit the specific context [3] (**LL3**). Thus, this requirement is needed also for preventing the so called "paradox of mandatory fun", which is discussed for example in [27], that will result in a poorly accepted software application;

R6 : *Guiding Approach*. The design method should offer guidance to designers on how to design gamified software. This is derived from **LL1** and **LL3**. Specifically, such method has to provide a reference to analysts and stakeholders (**LL1**, **LL3**) meaning that it has to: **(i)** guide them in all the phases, by providing techniques supporting all the other aspects [1], [3], **(ii)** make them to explore as many as possible relevant elements [2] and, above all, **(iii)** provide suggestions concerning psychological strategies, gamification concepts and suitable best practices for the context characterization [1], [3];

R7 : *Solution Ideation*. The method should support various forms of ideation, including sketching, prototyping, wireframing and mockups [17], [21]. This is derived from **LL2**. This is beneficial to make more concrete the suggestions obtained and ideas produced. Thus, the method has to support the techniques mentioned above for devising a solution [17], [21] (**LL2**) in a collaborative and creative way.

IV. Selecting Candidate Methods

As an example of how we intend to understand if existing methods can be selected and combined to provide the gamification design method, we consider two methods, DT [18] and the *Acceptance Requirements Analysis* of the *Agon framework* [1]–[4], that separately are able to cover partially the requirements above. However, with this contribution, we are not claiming that DT and Agon is the only possible combination of methods for fulfilling those requirements. In fact, we do not exclude that other methods can be combined obtaining a method compliant with those key requirements as well as our combination.

A. Design Thinking

DT [18], [19] aims at boosting a state of mind towards innovation, leveraging on empathy with key stakeholders, in our case the intended software users. The DT method rests on a peculiar process, which involves different stakeholders (e.g., people playing different roles in a software company), who collaborate closely, generating many ideas and concepts, for devising a solution that best suits the initial problem. The DT process consists of the following five iterative steps, each one having its own objective: *Empathizing*, where participants empathize with the typical users of the software application to be renovated to understand their goals, needs and frustrations; *Problems Investigation*, where participants define the typical day of the user, by describing activities and positive/negative feelings; *Solution Ideation*, where participants creatively generate ideas and decide which should be used in next phases; *Prototyping* of a possible solution and *Solution Testing and Presentation*.

For each steps specific techniques can be used. For instance, in the first step, techniques taken from participatory design are usually exploited, such as the definition of *Personas*.

B. Agon: Acceptance Requirements Analysis based on Gamification

The Agon framework [3], [4] and its method [1], [2], [4] support the analyst in analyzing acceptance requirements and fulfilling them with gamification design concepts. Furthermore, Agon provides the analyst with models [3], techniques [1], [2] and a tool for executing its method, a systematic acceptance requirements analysis in which gamification is considered as solution mechanism. In a first phase, the analyst defines and elicits acceptance requirements on the basis of the context characterization. The method supported by Agon analyzes and characterizes the (as-is/to-be) software, looking for the crucial functionalities to be gamified, focusing on functionalities that are complex, or not attractive and whose fulfillment lead to the fulfillment of software goals. Moreover, Agon allows to characterize the user, specifying age or gender, her player categories (e.g., socializer, achiever, explorer and killer according to the Bartle's taxonomy of player types [12]) or her expertise regarding software usage. In a next phase the analyst can use the Agon Acceptance Model [3] to receive suggestions, as psychological needs and strategies that best fit the specific context [1], [2] identified in the first phase. As last phase the analyst can use the Agon Gamification Model [3], containing different gamification elements, for producing a gamified design as a solution [1]–[4].

C. Why Design Thinking and Agon?

DT and Agon constitute the complementary baseline for the method we envisage in this work called DTA (Design Thinking & Agon).

They were chosen for two reasons. Firstly they both build on the principle that users need to be motivated in order to use any method or tool. DT does this for its users, requirements engineers and stakeholders, while Agon does this for the end-users of a system. Secondly, together they address all the requirements identified earlier.

DT partially covers **R5** considering user characteristics, needs and goals, while Agon fills the DT's gaps by characterizing the user regarding her player characteristics and the social context where she uses the software to accomplish her goals. Though DT can partially consider context variables, we cannot define it as completely acceptance oriented (**R3**), because DT does not guide the analyst in using context variables for eliciting which psychological strategies to use for improving software functionalities, and which components fulfilling those strategies could be inserted. The same is for **R4**, because DT does not specifically consider gamification design and related techniques for enhancing software functionalities. While, Agon covers the **R3** and **R4** requirements. Furthermore, DT is partially systematic (**R1**) in the sense that, it provides process guidelines and proposes design mechanisms for analyzing relevant motivational factors, but those are focused only on a subset of relevant variables pertaining **R5** and **R3**. Accordingly, DT partially covers **R6** due to the lack in providing **R3** and **R4** suggestions. Agon is **R1** and **R6**, though, focusing specifically on **R3** and **R4** aspects and the related **R5** requirement.

In summary, DT enables a participatory, creative process, where solution prototypes are developed and validated as part of the exploration of the solution space, which fully covers **R2** and **R7** requirements. Thus, we propose DT as the backbone of DTA. On the other side, Agon provides key requirements engineering concepts for gamification design, such as acceptance requirements and context characterization. Moreover, Agon provides a systematic way to address those requirements by using gamification mechanisms, fully covering the **R1**, **R6**, **R3** and **R4** requirements.

V. The DTA Method

The DTA steps and key concepts are shown in Fig. 2. At the top, there are the steps derived from DT and at the bottom the ones from Agon. The arrows show contributions (suggestions) coming from Agon to DT. Next, DTA is summarized.

Context Characterization. The first step of DTA is the context characterization. In Fig. 2 are listed the context variables analyzed and characterized. The context variables include user characteristics [1], [4] (e.g., age, gender, etc.), user awareness regarding software usage, how the user perceives the task (e.g., communication level, clarity level, etc.) and the goal

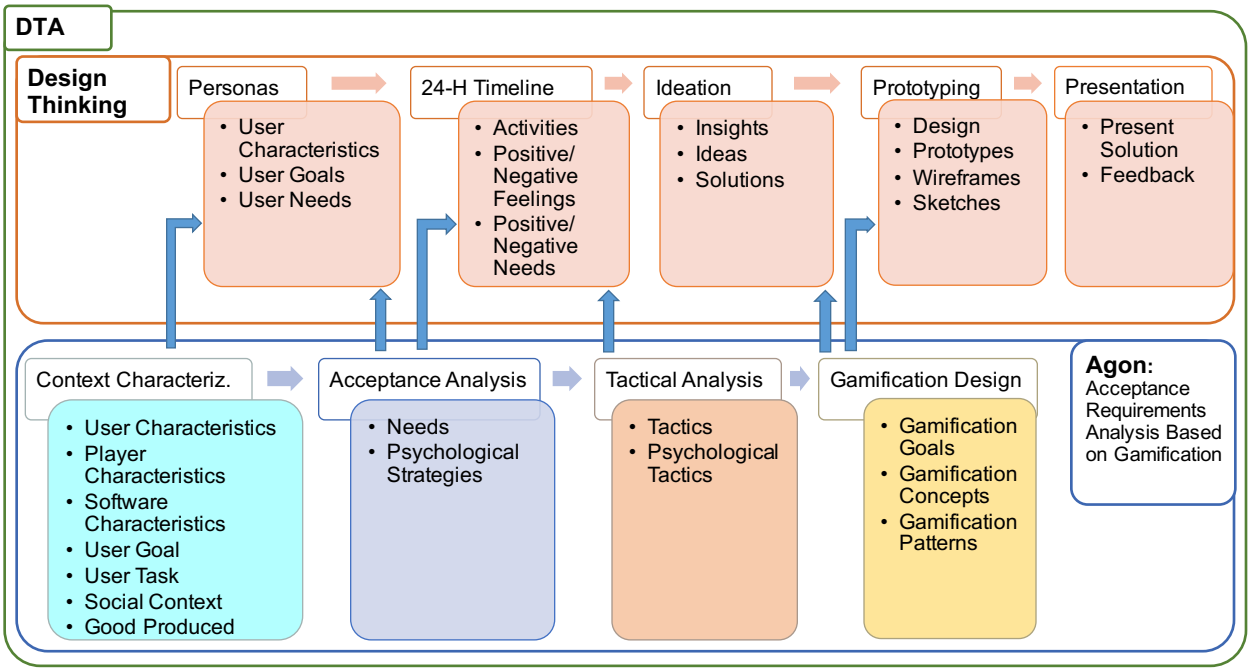


Fig. 2. The DTA method obtained integrating Design Thinking and the Agon Method. DTA steps can be iterated for further refinement of envisaged solutions.

related to the software use, in which social context the software will be used (e.g., hierarchical or neutral) and which kind of good is produced by using the software [2], [4] (e.g., private or public good). Another variable used to characterize the context is the player type [3], [4]. According to the Bartle's taxonomy [12], players can be divided into socializers (i.e. they desire to interact with other users and participate in an active and wide community), explorers (i.e. they desire to discover as many as possible parts of the system such as services and features), achievers (i.e. they prefer to gain rewards from the game) and killers (i.e. they want to prevail against other players). The context characterization can be accomplished beforehand by interviewing the users or stakeholders, or through questionnaires [3], [4].

Personas Characterization. Then, participants use the context characterization variables for defining collaboratively personas. Personas are fictional characters that represent the typical users of the system. Defining personas helps to understand users' needs, experiences, behaviours and goals. Moreover, participants receive as suggestions (thanks to the *Acceptance Analysis* of Agon [1], [4]) further information concerning needs, psychological factors and strategies that best fit the context and, above all, the user from different perspectives. DTA helps participants to collaboratively define personas providing suggestions from the context characterization, and users' needs and psychological strategies from the Agon acceptance analysis. Participants are free to decide to use such information, re-adapt them or add other user's needs which can be relevant in characterizing personas.

Problems Investigation. During this step, participants collaboratively discuss and compile the 24-hours timeline for describing the user activities of 24 hours, concerning software use and correlated tasks, and individuating the related user's positive/negative feelings and needs. This step, along with the previous one, helps participants to empathize with the typical users of the software application to be renovated. Participants carry out this step being helped by context variables, personas, needs and psychological factors and strategies suggested so far. Moreover, they receive as further suggestions (thanks to the *Tactical Analysis* of Agon [1], [4]) more concrete sets of possible psychological elements, tactics refining psychological strategies, that best fit the context. These suggestions give participants a broad set of elements to consider for describing more precisely the 24-hours timeline. For instance, software and task characterizations analyzed before, or the suggestions on psychological needs received previously, can help and speed up the participants in this step.

Solution Ideation. Here, participants collaboratively produce and discuss ideas. They can use all the elements collected so far such as characterizations, personas, 24-hours timeline and received suggestions (e.g., psychological and tactical strategies). Moreover, on the basis of collected elements, participants receive also gamification design suggestions (thanks to the *Gamification Design* of Agon [3], [4]). Such suggestions, being based on collected elements, are the most suitable gamification concepts and gamification design patterns for the specific context. For instance, they are the most suitable for the user to be motivated, the software to be used, the task to be carried out, etc. Thus, participants are deeply helped with ready-to-use gamification design suggestions that stimulate their creativity to produce more valuable ideas in less time.

Prototyping. In this step, participants put into practice ideas generated in the previous step. They collaboratively create sketches, wireframes, mockups or even prototypes of their ideas. As for the previous step, they can use all the elements collected so far, especially suggestions regarding gamification concepts

and gamification design patterns for the specific context.

Solution Presentation. Finally, in the last step, each team presents its gamification solution and prototype to receive feedback from the other teams.

VI. Evaluation

The DTA method fits the proposed requirements for a suitable gamification design approach by construction. An empirical evaluation can support us to get empirical evidences about the effectiveness of the method as perceived by requirements analysts and gamification designers. Moreover, we can get further empirical evidences by evaluating with end-users the quality of a gamified solution developed with DTA.

We use a case study evaluation. In the first case study (Section VI-A), we use DTA to understand how to improve the DMGame user's engagement by exploiting gamification. The existing DMGame version is considered, and the objective is to develop ideas and a prototype for improving user engagement in the DMGame tool. In the second case study (Section VI-B), we use an interactive mockup of the renewed DMGame, which was obtained by applying the DTA method, and ask end-users, of the original version of the DMGame, to evaluate it. Complete results of the evaluation are detailed in [28].

A. Requirements Analyst Perspective Case Study

This case study focuses on the perspective of the requirements analyst, who uses DTA to design a gamified software system. Our objective is to get an empirical evidence about the perceived usefulness of DTA for the analysis of requirements that can be operationalised in terms of gamification solutions.

Case Study Design. The participants to this case study are four members of the research team in charge of developing the DMGame tool and one of the author, who knows DMGame and Agon, and joins the team with the role of conductor of the case study. The agreed objective of the case study is that of improving the tool with respect to user engagement and gamification design aspects, and to address some issues related to acceptance that emerged in the previous evaluations with end-users. A post-study questionnaire is designed to assess as the study participants perceived the usefulness of DTA.

The case study conductor plans for the first step in DTA, concerning the context characterisation, that will be performed running a survey with DMGame users, and for the connected Agon-oriented steps (see steps depicted in the lower part of Fig. 2), thus preparing material to be used in a two-hours plenary session with the team. In the session, his role is mainly to guide the team following the five steps depicted in the upper part of Fig. 2 within the available time, and using the input from the Agon-oriented steps, but without participating to the discussion and design decision. The team members work in pairs during this session.

Case Study Execution. The first activities performed in this case study concerned the elicitation of requirements for the system to be gamified, that is the DMGame, and the context of the user such as user characteristics (e.g., level of expertise regarding software usage, how the task and the goal correlated to the software use are perceived, in which social context the software will be used). These aspects have been elicited through a questionnaire that was filled in by developers, analysts and designers from companies involved in the SUPERSEDE project[2], who are potential users of DMGame. Eleven replies to the questionnaire were collected. Main findings from their analysis are the following.

Most of the users of the DMGame are *males* and their age is between *31 and 40 years old*. Their experience with requirements prioritization tools is quite limited and they have never used requirements prioritization tools similar to the DMGame before. The goal of the DMGame is clear to them.

Referring to the usage of a gamified software system, users of the DMGame are mainly *socializers* (i.e. they desire to interact with other users, talk with new people, create new relationships and friendships, participate in an active and wide community) and *explorers* (i.e. users who desire to discover as many as possible parts of the system such as services and features and, by acting in this way, their aim is to acquire important skills and to become like a "Guru" for the other users, colleagues, especially for the novice ones).

These context characterization variables are used to derive a set of suggestions about psychological needs and strategies that best fit the specific context, to be used then in the planned DTA session. According to the Agon suggestions, the target users can be motivated to use the DMGame in different ways. The first one is to *give them just the perception*, that the use of the tool can provide some *benefits*. For instance, creating the perception that using the DMGame tool there are improvements in terms of their speed in deciding, quality of the decision, and, more generally, productivity or effectiveness of their work.

Another strategy is to show them that by using the DMGame tool they can obtain *personal benefits*. For instance, saving time for interesting activities, improving themselves and their skills to increase the chance for a promotion, and obtaining prizes for their activity.

One more strategy is related to the addition of elements for augmenting the *social influence*, supporting *social behaviour* and promoting *collaboration*. For example, in relation to the *social influence*, the user behaviour can be influenced by increasing the social relationships and suggestions (e.g., suggestions to use the system) from people who are considered important by the user. With the aim of increasing the participation of the individual, *social influence* can be used also by showing the user that it can improve her social status (e.g., with colleagues). Accordingly, it can be useful to show to the user that many people (e.g., colleagues) use the tool, and that the use of the tool is both *socially supported* (e.g., the company invests on improving the skills of the employees regarding the system usage, for instance by courses or online tools) and *socially pushed* (e.g., the company pushes in a positive way, i.e. not forcing, all the employees in using the software, for instance by showing some advantages).

Besides psychological needs and strategies, Agon uses context characterization variables to suggest gamification elements for that specific context. In this case, Agon suggests to

define *point systems*, in particular, assigning to users *skill points* (i.e. awarding the user for specific actions related to the usage of the system) or *karma points* (i.e. awarding for actions focused on social matters, for instance, helping/supporting a colleague in using a system; karma points can be redeemed then for other social matters, for improving social relationships among colleagues, for example, by giving the user the possibility to make gifts to other colleagues). These point systems require the definition of achievement rules for specifying when and in which way the user earns each kind of points. Points can be used to set leaderboards. Different kinds of *leaderboards* can be implemented, e.g., social leaderboards, time-dependent leaderboards or leaderboards connected to particular users roles.

Another gamification element suggested by Agon is the *badge* concept. In particular, the most suitable badge kind for users of our case study are the badges that should be awarded for successful actions. Furthermore, badges should be *publishable*. Also in this case, badges need to be supported by achievement rules. To support publishable badges, it is necessary to define a *virtual environment* where users can form a *community*. Moreover, the system can make suggestions to the users, for example: to recommend events (e.g., for taking part to system activities by collaborating with other colleagues, or for respecting system deadlines), to ask a user to motivate another user to attend an important activity for the system.

All the models, enclosing these elements, can be found online at [29].

The collected information gathered with the questionnaire proposed to former users of the DMGame tool was used as input to the two-hours plenary session, which started with the step concerning the characterization of the personas, and was followed by the analysis of the users' needs and psychological strategies suggested by the method. Each step is performed separately by the two team pairs, but results can be mutually shared under the conductor guidance. In the following step, the case study participants described a typical working day of a DMGame user, showing the positive and negative feelings related to each activity during the day. On the basis of the insights from these initial steps the team-pairs started thinking about a possible re-design of the system and how to gamify it. Furthermore, this ideation step was supported by suggestions about useful gamification elements to be exploited, based on the users' characteristics. In the prototyping step, each pair consolidated design decisions on paper prototypes.

In the last step, participants showed their prototypes and presented their gamification solution, produced by using the DTA method, to the other participants. Once the case study ended, we asked participants to fill in a questionnaire to evaluate the DTA method from the requirements analyst's perspective.

Case Study Results. The analysis of the results is based both on the post-session questionnaire completed by participants (Table I), and on the examination of the actual work produced by them. Generally, all participants agreed that the users' needs and psychological strategies proposed by DTA were clear. The same result has been achieved with the gamification elements. Regarding the appropriateness of needs and psychological strategies for the software and the target users, the participants agreed on their appropriateness. Also regarding the appropriateness of the gamification elements for the software and the target users, all the participants agreed on that. One of them strongly agreed that the gamification elements proposed by DTA were appropriate for the target users (Table I). For all these reasons, we can consider the clearness and appropriateness of the concepts proposed by DTA positive.

To verify the usefulness and the real usage of the concepts proposed by DTA, we need to look in more detail to the work done by participants. Most of the participants considered the users' needs and psychological strategies proposed by DTA helpful in defining personas. Most of the needs and psychological strategies suggested by DTA have been used by the participants, however not all of them. A similar observation concerns the needs used in defining the 24-hours timeline. This could be explained taking into account that DTA proposes needs that can be suitable for the different kinds of users, then it is up to the analysts to decide, also on the basis of the other kinds of software requirements and functionalities, which ones they prefer to consider for the specific needs of the stakeholders in their particular domain, in this case the one of the DMGame. The same applies for the suggested gamification elements. On the other hand, all the participants agreed about the usefulness of the proposed gamification elements, in a way that facilitates and enriches the design of the gamification solution (Table I).

B. User Perspective Case Study

Case Study Design. This second case study aims at evaluating the solutions, which have been designed in the case study described in Section VI-A. Precisely, in this case study we aim at evaluating the mockup that we developed on the basis of the design outcome of DTA, which was produced on paper. The interactive implementation is available online[9]. This mockup provides the specifications for a new version of the DMGame. It includes three main pages supported by few other pages. A screenshot of the main dashboard is depicted in Fig. 3, which includes most of the gamification elements that were proposed in the design of the new DMGame version. For instance, a *progress bar* indicates the progress of the user (the player) on an assigned prioritization task (see for instance button *Game 1*), also using a colour code. A *leaderboard* is depicted at the right-hand side, where the score of the user is shown in a ranked list of participants to the prioritization tasks (i.e. the active players). This score is computed taking into account points gained by the user as result of her contribution to the ongoing collaborative processes, including those depicted in the windows *chat* and *pinboard* respectively. The first one is a gamified *chat*, which rewards the users with points for communicating with other users, the second one is a *pinboard* where the user sees questions, answers and decisions shared among users. Details on the points gained for each different activity are depicted in the window labelled *total points*, which is placed below the *leaderboard* window.

[9]Available at https://u5dzh2.axshare.com/home.html

TABLE I
QUESTIONS ON CLEARNESS, USEFULNESS AND APPROPRIATENESS OF USERS' NEEDS, PSYCHOLOGICAL STRATEGIES AND GAMIFICATION ELEMENTS PROPOSED BY DTA.

N.	Questions	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1	The users' needs and psychological strategies proposed by DTA were clear.	0	0	0	3	1
2	The users' needs and psychological strategies proposed by DTA were useful in defining personas.	0	0	1	3	0
3	The users' needs and psychological strategies proposed by DTA were appropriate for the DMGame.	0	0	0	4	0
4	The users' needs and psychological strategies proposed by DTA were appropriate for the target users.	0	0	0	4	0
5	The gamification elements proposed by DTA were clear.	0	0	0	3	1
6	The gamification elements proposed by DTA were useful in defining the gamification solution.	0	0	0	4	0
7	The gamification elements proposed by DTA were appropriate for the DMGame.	0	0	0	3	1
8	The gamification elements proposed by DTA were appropriate for the target users.	0	0	0	4	0

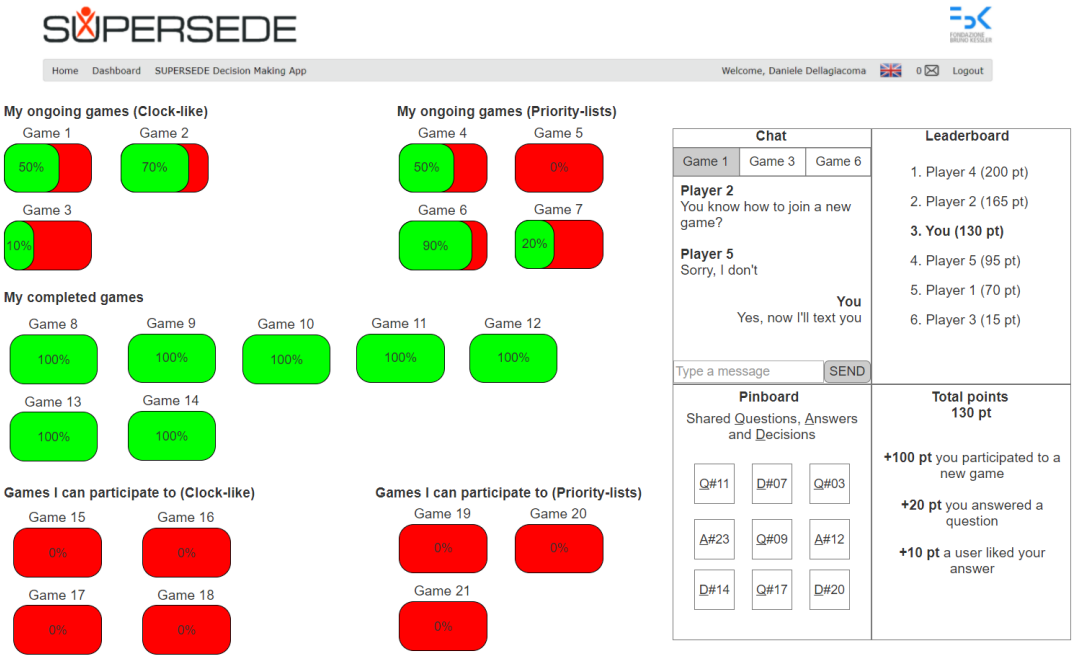


Fig. 3. Screenshot of the mockup generated by applying DTA: Main dashboard.

Other two GUIs are depicted in Fig. 4. The first one allows representing prioritised requirements according to a clock metaphor, where requirements to be considered first are moved (by "drag & drop" on the requirements box) in the first clock quadrant, and those that are less important in the last one. The second one allows to get an overview of the requirements to be prioritised for a given criterion, along three piles, namely high, medium, low priority piles. This allows the user to express a first coarse grained prioritization just moving a requirement from a pile to the one considered most appropriate. Within each pile requirements can be further ordered by moving them up or down, allowing the user to express a finer grain prioritization preference. Switching from one criterion to another allows the user to contribute to multi-criteria prioritization. The case depicted in Fig. 4 (right), shows three criteria, i.e. *User impact*, *Development cost*, and *Business benefit*.

In this study, we intend to involve people who are familiar with the DMGame tool, and that have already used it. Therefore, they do not need to try again the old version of the tool, before starting the evaluation with the revised mockup.

To evaluate the revised DMGame we defined the tasks that the participant to the study have to perform via using the interactive mockup, and designed a questionnaire, to compare the previous version of the DMGame with the new version, which was obtained by using DTA. These tasks require the interaction with the gamification elements and the different prioritization techniques. The questionnaire is divided into different sections, each aiming at validating a specific feature of the mockup of the new DMGame version, improved by using DTA. The first section concerns whether the new software functions address the *needs* of the typical user of the DMGame, elicited in the previous case study, more than in the previous DMGame version. The second section aims at comparing the *engagement* offered by the

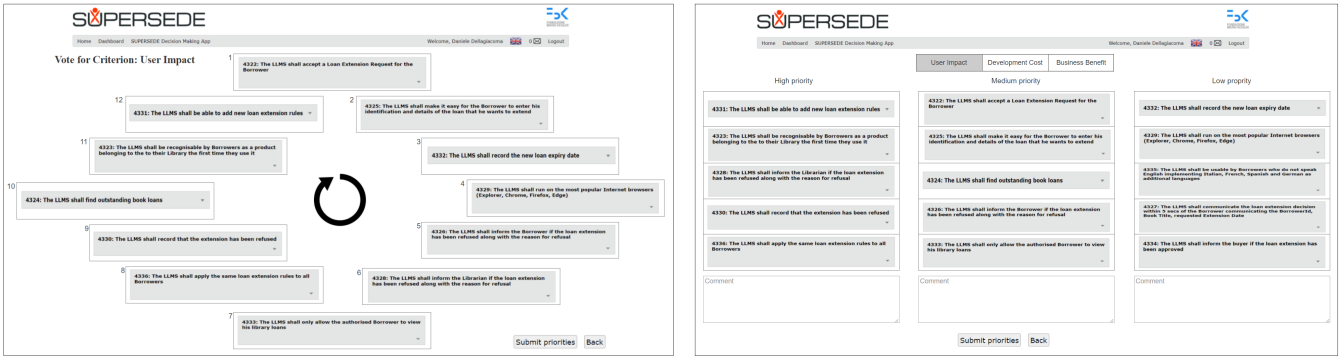


Fig. 4. Mockup generated by applying DTA: Clock-like requirement prioritization (left). Priority-list by criterion (right).

previous and the new version of the DMGame. In this case, the engagement is provided through gamification. The third section aims at comparing the *functions* of the previous and the new version of the DMGame. Specifically, the clock-like and priority-lists prioritization methods implemented in the new version of the tool. Finally, the last section includes open questions about strengths, weaknesses, and improvements of the revised DMGame.

Case Study Execution. Seven people agreed to participate to the study. They were provided with instructions to perform a few tasks with the interactive mockup, and then to fill in the questionnaire.

Case Study Results. Full charts and questionnaire replies can be found in [28]. The questionnaire begins with a description of the typical user of the DMGame. Then four questions to understand if his/her needs (elicited by Agon in the previous case study) are fulfilled by the new version more than the previous one. Here, participants agree that the new software functions address the needs of the typical user of the DMGame more than in the previous version. In detail, almost all the participants agree that the new version makes users perceive that the use of the DMGame can provide some benefits, more than the previous version. For instance, creating the perception that using the DMGame there are improvements in terms of their performance speed, quality, or effectiveness of their work.

Participants agree that the game elements implemented can engage users more than the previous version, and the engagement produced by these game elements can favour the quality and effectiveness of the requirements prioritization activity. Most of all, it seems that gamification can favour communication among users, and there are also positive results even concerning the collaboration among users that adopt the tool. Moreover, the new version shows an improvement in stimulating users in checking and improving the solution designed. The new version can also stimulate users in participating actively in the DMGame platform activities more than the previous version. Only one participant does not agree with this statement. To sum up, gamification has been strongly appreciated by participants. In fact, they think that the new version of the DMGame, improved by using DTA, represents a great improvement concerning the users' engagement compared to the previous version.

These results are also related to the two prioritization methods (i.e. clock-like and priority-lists), implemented in the new version, and to their usability, always focusing on the comparison with the previous prioritization method. Although both solutions have been appreciated and considered better than the previous one, the priority-lists solution has been preferred to the clock-like, as can be seen in Table II. In fact, participants do not completely agree that the clock-like method makes the requirements prioritization activity easier and faster than the previous version (questions 1 and 2 of Table II). Slightly better are the organization of on-screen information, and the quality and the effectiveness of the requirements prioritization activity provided by the clock-like method compared to the previous version (questions 2 and 3). On the other hand, the priority-lists method undoubtedly makes the requirements prioritization activity easier and faster than the previous version according to participants, as shown in questions 1 and 2 of Table II. Even the organization of on-screen information, and the quality and the effectiveness of the requirements prioritization activity provided by priority-lists method received a positive reception (questions 3 and 4).

TABLE II
COMPARISON BETWEEN CLOCK-LIKE AND PRIORITY-LISTS SOLUTIONS. AVERAGE ON A 5-POINT LIKERT SCALE.

N.	*Questions*	*Clock-like*	*Priority-lists*
1	The method makes the requirements prioritization activity easier compared to the previous version.	3.00	4.29
2	The method makes the requirements prioritization activity faster compared to the previous version.	3.00	3.86
3	The method provides a clearer organization of information on screen than the previous version.	3.43	4.14
4	The method improves quality and effectiveness of the requirements prioritization activity compared to the previous version.	3.29	3.86

In summary, participants considered the new version of the DMGame (improved by using DTA) better than the previous version, with respect to many aspects, and that it provides a greater engagement, thanks to the gamification elements introduced. On the other hand, two participants think that the

new version is still complex to be managed as it contains too many elements and information.

C. Threats to Validity

As described before, the results of the case studies are positive, but it is worth to mention some threats to validity, besides the known limits about generalizability that are inherent to case study evaluation.

In both the case studies, a threat is the absence of multiple iterations. Although the first iteration of DTA produced a satisfactory result, multiple iterations are a core part of the DT approach. In fact, case studies should be followed, at least, by another iteration to improve the result. Furthermore, the DTA method we are proposing is suitable for an iterative approach, and we suggest to use it in such way to have more accurate results coming from a very deep analysis supported and favoured by DTA.

Another threat is related to the number of participants. Although our results are very positive and participants' opinions are homogeneous, it could be beneficial to repeat the case study with more participants, even from different organizations, to further confirm our positive results. This is one of our future works.

Finally, DTA provides a method to design gamification solutions, but the final result can be influenced by many factors such as the skills of the designers. Moreover, the version tested by users is a (interactive) mockup. Only the most representative functionalities, for showing to users the potential new features, have been implemented. This has been enough to get relevant feedback from them. However, as a future work, we will repeat the case study with a completely implemented version.

VII. Related Work

Research literature in software engineering includes works on techniques for gamification design, as well as on the application of gamification to enhance software engineering methods, e.g., within requirements engineering tasks [30], [31], or to improve team engagement in a software development process [32]. An overview of the application of gamification in software engineering is reported in the mapping study presented in [6]. The rest of this section focuses on works closer to the context of this paper, i.e. works proposing gamification design approaches.

The MDA [33] approach is a formal and iterative approach to game design. It was developed in game design workshops and consists of three components: mechanics, dynamics, aesthetics. The aim of the MDA framework is to "bridge the gap between game design and development, game criticism, and technical game research". Although the authors present reasonable examples, it is unclear how the framework was developed, and key requirements such as **R1**, **R2**, and **R6** seem to be ignored. Similar gaps seem to affect another approach that proposes to use gamification patterns, which were derived from the analysis of several gamified systems [34]. The authors conducted a case study, but did not describe how design patterns were integrated and applied to the development process.

Deterding [35] introduces a gameful design method based on four steps where the designer uses skill atoms and design lenses. The method was applied in two case studies, but as stated by Deterding, "it lacks a formal empirical evaluation of its utility and usability" [35]. Although their work adopts a multidisciplinary approach, Deterding does not consider existing requirements engineering approaches. In contrast, concepts such as acceptance requirements are key in our approach.

Model-driven approaches for developing gamified solution have been proposed in [36], [37]. For instance, the framework described in [37] provides a graphical modelling tool that supports a gamification expert to design a gamification strategy. For example, in the education domain, a strategy could be: "A student who watches the introductory video gets 5 basic points". The framework provides also functionalities for automatic code generation, and real time monitoring of gamification strategies. Both these model-driven approaches focus actually on the design and implementation of a gamification strategy, which is defined by a domain expert, while in our proposal we take a requirements engineering perspective and focus on eliciting and analysing user needs and acceptance requirements first.

In [38] a situational method engineering framework for gamification design is presented. This framework allows to define the design approach to be used in a specific project by assembling method fragments, which are available in a method base that has been built by analysing scientific literature, descriptions of practical applications, and expert interviews. The framework provides guidelines for the selection and combination of method fragments, which rest on a set of design principles for engineering gamified software, and on contextual characteristics of the software to be gamified, such as business processes, corporate culture, and technological constraints. Moreover, the framework suggests to continuously monitor the effectiveness of the gamified application, after deployment, in order to evolve it according to the changing user needs. The framework has been evaluated by a group of experts and by applying it to an app for parking information that is based on crowdsourcing. While we can see interesting similarities and potential synergies between the design principles proposed in [38], and the requirements of the method presented in Section III, we propose a concrete approach, the DTA method, which combines two methods that together fit with the identified requirements. In particular, in our approach, Agon allows to capture acceptance requirements and, in combination with DT, covers the notion of context as described in [38].

The analysis of these works provides further evidences about the practical relevance of the discussed lessons learned and requirements of our method.

VIII. Conclusions

In this paper, we discussed lessons learned in developing gamified software applications, in light of challenges and open problems on the design and evaluation of gamified solutions, which are presented in several recent research works (e.g., [5], [6], [15], [32], [38], [39]). Indeed, the analysis of these works

provides further evidences about the practical relevance of the lessons learned proposed in this paper.

On the basis of the literature, our past experiences employing the Agon framework within EU projects [1]–[4] (e.g., SUPERSEDE[2], Lucretius[3], DEFeND[4], PACAS[5], VisiOn[6], STREETLIFE[7]), and the lessons learned we derived, we identified key requirements for a design method for gamified software, and proposed the integration of Design Thinking and Agon, as a design method called DTA (Design Thinking & Agon) that meets these requirements. We conducted a preliminary evaluation of DTA with positive results.

As future work, we will define a wider evaluation approach that takes into account some of the discussed threat to validity, and that will be applied to assess DTA. Moreover, we will evaluate the iterative characteristics of DTA, and investigate further how to take into account evolvability of acceptance and motivational requirements, while the gamified tool is in use.

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Bespoke: a Methodology to design Software Factories. A preliminary approach.

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***Abstract*—Software Product Line (SPL) field is meant to engineer families of related products to reduce development cost. Leveraging feature models for capturing variable and common aspects inside of a product family omits crucial concepts that need to be considered through designing system domain perimeter. At this level, Model Driven Engineering was integrated in SPL to facilitate variability implementation and management. MDE techniques rely on the DSML meta-model that describes the main concepts of the domain and their relations which allow system designers to work closer to the system domain as they can manipulate real concepts.**

The current work proposes a Methodology for Software Factories that aggregates both of the two aforementioned techniques to cover a large number of code generation strategies to derive products branching from a domain portfolio. The first phase consists in configuring a possible product line by transforming the domain metamodel DSML into a generic feature diagram. Secondly, the client uses the DSML to configure, by the guidances of the founded product line, the desired product. Hence, the Methodolgy Software Factory provides the engineer guidelines to derive the target product according to the configured product line.

In this work in progress paper, we propose to extend meta-metamodel inspired from MOF in order to integrate crucial FD semantics element into the DSML metamodel and by the way facilitate their conversion. Besides, in this regard, a transformation method is presented to handle the extended DSML metamodel.

***Index Terms*—MDE, Software Product Line, DSML, FD, Methodology, Software Factory, transformation method.**

I. Introduction

Software Product Line (SPL) is a discipline which receives increasing interest in both research and practice. It puts strong emphasis on the systematic development of products belonging to a common system family. Rather than developing each instance of a product line from scratch, reusable artefacts may be composed for the target of deriving similar systems branching from a domain portfolio. In other words, SPL governs a family of software products that share common set of features, which represent a logical unit of behaviour specified by a set of functional and quality requirements, and they differ each other according to variable aspects. This last, was defined as the ability of a software system or software artefacts to be extended, customized or configured to use in a specific context [1].

Thus, variability specifies parts of the system to be kept variable and not fully defined during design phase, which ensures a less development cost of its different possible existing versions.

Reliability analysis of SPL is summed up by how well various and common system parts and their relationships are clarified and managed. A key aspect of variability management is the explicit representation of the variability. Hence, variability model is used to capture commonalities and differences among variant possible products [2].

In this context, Feature Diagram (FD) is the most commonly used models type that arranges features as configurable units along a tree-structured decomposition hierarchy and provide user changeable customization of the software artefacts. Leveraging feature models for capturing variable and common aspects inside of a product family omits crucial concepts that need to be considered through designing system domain perimeter. At this level, Model Driven Engineering was integrated in SPL to facilitate variability implementation and management. MDE techniques rely on the DSML meta-model that describes the main concepts of the domain and their relations which allow system designers working closer to the system domain as they can manipulate real concepts. Besides FDs, DSMLs can take into consideration other information such as meta-information, rationales, documentation, traceability or viewpoints that are too far away from the "code" point of view (financial, projects, etc). However, DSMLs let engineers with a blank sheet of paper regarding the design of the software factory (i.e. the generative strategy).

In this light, our contribution unifies the two aforementioned trends by making the use of their gain and avoiding their boundaries. Hence, the starting point consists in transforming a DSML into FD, which allows a wide spread design of

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the domain system and its real concepts besides exploiting variability mechanisms offered by the Feature model. To do so, we propose in this paper a three levels architecture of the Methodology Software Factory which extends a meta-metamodel inspired from MOF by adding new attributes and by the way facilitate the conversion. Besides, a transformational method is presented, in this regard, to handle the extended DSML metamodel followed by an illustrative example to clarify the Methodology Software Factory workflow and the transformation steps.

The rest of the paper is organized as follows: Section II introduces some of the relevant related work. In section III , we present an overview of the Methodology Software Factory architecture followed by a transformation method in Section IV. In section V, we give a shade of light on some threads to validity of our current proposal. Finally, we conclude and present our perspectives in Section VI.

II. Related Work

As discussed earlier, a key step of the proposed Methodology Software Factory is the transformation process that takes as input the DSML metamodel and returns the corresponding FD.

At the moment, transforming DSML into FD is still in its infancy. In fact, two trends were proposed around the aforementioned orthogonal axe to link DSML and FD into one diagram as a first possible solution, or via UML profile, as a second one to facilitate the integration of FD semantics with UML components. However, at the best of our knowledge none of them proposed a method to transform DSML, as a corner stone of MDE techniques, to FD considered as the spinal column of SPL from which product derivation can be performed easily.

On the first hand, the method Clafer [3] is designed as a concise notation for metamodels, feature models, mixtures of meta and feature models (such as components with options), and models that couple feature models and metamodels via constraints (such as mapping feature configurations to component configurations or model templates). This method unifies feature and class modelling. In other words, it can naturally express feature models, while allowing for full class modelling and relating both types together inside of the same diagram which allows a better representation for variability between the solution and the problem spaces. However, there exists some issues to deal with the risk for incomprehensibility as soon as the system becomes complex. Besides, Clafer aims to represent software functionalities hence there exist a necessity to make adjustments to identify code links between model components and corresponding project code elements.

On the second hand, Possompes et al. [4] proposes an instrumented approach to integrate FD and UML metamodels with an appropriate semantic via UML profiles and a Rational Software Architect plugin . They choose to transform feature metamodel into UML profile to sum up FD existing semantics and by the way facilitating their integration. This profile reuses features related concepts by creating stereotypes that extend UML meta-classes to add these lasts or subtract them the corresponding FD semantic.

At this level, we claim that the common criticism of the aforementioned research is that they don't present a solution for transforming DSML metamodel into FD. In fact, they proposed new manners for either merging both of them inside one model, which affects the system comprehensibility, either including FD semantics with UML components via profiles. Hence, based upon the fact that DSML is more expressive to the system domain concepts and taking into account that FDs are one of the best structures tailored to represent variability and facilitating product derivation in SPL, we argue that it is worth to investment the transformation of DSML metamodel into a FD as seen in the Methodology Software Factory architecture.

III. Global overview of the proposed Methodology Software Factory

The objective of the current thesis as mentioned in [7] is to propose a Methodology Software Factory that covers a large number of code generation strategies to derive product variants belonging to a FD since this last was considered as the common variability representation formalism in SPL. DSML captures every important aspect of a software domain which are developed and refined as the system is created. Consequently, the relationship between SPL and MDE is not new in the literature since it mainly focuses on the use of DSML to specify application families. Our early research have led to the framework architecture depicted in Fig. 1.

In this work, we propose a framework with a three levels architecture to provide guidelines for the application engineer to implement a generative strategy employed to reduce product variant derivation costs. The framework is decomposed into three following levels: meta-metamodel layer (M3), the engineer metamodel layer (M2) and the user model layer (M1). The DSML metamodel (the definition of DSML) sits at the M2 layer, and as such it should be able to be described as an instance of some language meta-metamodel at the M3 level corresponding to the meta-metamodel inspired from MOF. This architecture is detailed in the following sections.

A. Extending meta-metamodel inspired from MOF

The meta-metamodel is situated at the highest level of abstraction. We extended the meta-metamodel inspired from MOF to allow their use in the DSML metamodel and by the way facilitate its transformation to the corresponding FD . In [6], Free Feature Diagrams (FFD) was presented as a generic construction that aims to give all extensions the same formal semantics. Based upon this generic notation, Gilles perrouin et al. [5] proposed FFD derived FD metamodel that recapitulates basic concepts existing in most various FD variants. In this context, we built our extension on the essential parts that could/should be found in FD metamodels and for which there exists no predefined explicit way to identify these crucial parts in the DSML metamodel. We extended the meta-metamodel by adding the following attributes to Attribute,

Class, and AssociationEnd classes. They are depicted on a sky blue background in Fig. 1. They are later specified inside notes attached to classes of the DSML metamodel.

- Attribute `Class.root` allows the engineer to specify which class of the DSML metamodel will later denote the top node in the generated FD. The transformation process will start from this.
- The node type decomposition can be usually OR, XOR, AND. In this context, `Class.variationPoint` denotes locations where variabilities of a certain functionality are introduced in the system and this explains how children features must later be related together in the FD.
- Features in an FD can be categorized into two groups: **primitive features** denote features that will influence the final product while **compound features** are just intermediate nodes used for decomposition. This information is made explicit with attributes `primitiveFeature` and `compoundFeature` in class `Class`.
- A component attribute in the DSML meta-model can be extracted and transformed as a feature in the generated FD. For this reason, we added attribute `isExtractedAsFeature` to the `Attribute` class. For instance, a enumerated attribute like **OS:{iOS, Android** could then be mapped to a feature with two sub-features. As for classes, not all attributes are relevant to become features.
- We extended the class `AssociationEnd` with attribute `follow` to determine which classed must be considered by the transformation once the process is transforming a current class into a FD. This will allow him to drop a "navigation layer" on the class diagram from the root to guide the transformation process by embedding the selected attributes (see above).
- Classes `Constraint` and `Constrained` with the `operands` association allows us to relate potential features together in constraints whose type is `typeConstraint`.

B. Configuring partially the product line

The M2 level categorizes the domain engineering in which the DSML metamodel meant to identify the domain concepts and families systems. At this stage the engineer annotates this metamodel by complementary informations to make the FD conversion more fluent and avoid the ambiguity of transformations rules specially for feature sets constraints and relations (i.e, or/xor groups and mutex/requires relations). Besides, these annotations serve to configure partially the product line chosen by the engineer. The FD generated is a generic model that will define the product line and sum up the possible useful variability mechanisms corresponding to each variation point according to the annotations sets added by the engineer. This FD will guide the Methodology Software Factory to determine the possible generative strategies that satisfy the defined constraints. For example, the transformation result of the annotated DSML metamodel situated in layer M2 in fig. 1 corresponds to a product line for train reservations. This partial configuration defines the major domain characteristic from which we can derive several product variants. In this example, the applications can be adapted for different levels of disabled passengers besides they can occur to a confident person for help whether a family member or a staff member.

C. The product configuration

The undermost layer in architecture characterizes the application engineering which encompasses all activities for developing the application requirements specification. In this level, the client uses the DSML to define his requirements. Thereafter, the DSML is transformed to FD to express the possible configurations of the desired product and the functionalities they intend to offer to users.

Once, the product line and the product were defined, Methodology Software Factory takes as input this FD which defines the application domain of the product, and produces as input the guidelines of how to implement the generative strategy chosen by the engineer according to M2 level generic FD.

IV. Preliminary result

Our preliminary results have led to the following transformation methodology to allow the conversion of DSML metamodel to the FD. In this section we present the transformation steps followed by an illustrative example.

A. The transformation method

The pillar principle is to permit the engineer to draw his own FD by annotating the desirable metamodel components and even choose their binding way by using the variation point and specifying the corresponding variants. These annotations allow the method to determine the type of the converted feature (mandatory or optional) and its cardinality, the features groups types (or, xor).

The transformation works as follow:

- We start from the class marked as `root` which becomes the root of the generated FD. This class must be unique.
- We then look for the set of children classes from the previous class. These lasts represent either the classes whose association ends are marked as `follow=true`, either declared as a variant object for the root. But a feature can also be an attribute in the root class the engineer decided to extract as a sub-feature.
- Once the children set is found, they are inserted as sub-features in the FD with the corresponding cardinalities. They are inferred from the cardinalities of the followed association ends.
- The transformation process goes on to explore the children in turn in a recursive way: a node N in a FD can be inserted based on a switch of multiple cases:
  1) if the node N is only declared as a variation point once, hence, all the variants corresponding to this object are collected and added as OR/XOR sub-features group according to the type of variation

point. The cardinalities of each variant in the metamodel DSML are kept for the generated FD;

2) if the node N is only declared as a variation point but several times, hence all OR-variants (respectively XOR) are created as OR sub-features (respectively XOR sub-features) to a first (respectively second) new compound node O (respectively M). Both of new created compound nodes are optional sub-features for N and are created to ensure the different nodes decomposition;
3) a node N is linked to all its children only by normal associations. These lasts are inserted as mandatory or optional features depending on their association lower bound. In other words, a sub-feature is marked as mandatory (respectively optional) if its lower bound is equal to 1 (respectively O);
4) a node can be annotated a variation point and also linked to other children by another association type. The idea here, is to insert the children corresponding to these associations as direct sub-features to N and devoting as many new compound nodes sub-features for N as many variation point types.

B. An illustrative example

In this subsection, we present a use case to clarify the architecture of the proposed Methodology Software Factory detailed in section III. In addition, to put the transformation method another way, here is an example to illustrate the aforementioned steps with each corresponding case.

The proposed use case describes a domain concerning the train booking realm. Starting from this metamodel DSML, several configurations could be derived.

A first one would allow passengers to use their smart device or a distributor ticket dispenser that is available in the stations to reserve a train while a second one (described in Fig. 1) offers extra facilities for disabled passengers by allowing them to use a confident person or to reserve a train adapted for their deficiencies. This process can run on web application platform or can be conceived as a smart device application with displaying personalisations. A DSML can describe a domain that encompass several types of systems and can thus hide several product lines, with each one their own feature model.

The transformation method: The transformation iterates through the list of considered DSML metamodel components. Each node is inserted according to its specific annotations and the corresponding children are treated recursively until reaching the leaves. The transformation applied on the DSML metamodel goes as follows:

- The first step of the transformation procedure initializes the FD with the root node `typeReservation`. This last has the following children: `TypeTrain`, `Platform`, and `typePassager`.
- Secondly, we insert `typeTrain` as a mandatory sub-feature of `typeReservation` since the cardinality varies between 1 to multiple. Since this last one is declared as an XOR variation point the corresponding variants are inserted below.
- Since, all `typeTrain` children are inserted, the mode moves to the next non treated children `Platform`. This last one is first inserted as a mandatory sub-feature for `typeReservation`, after that `device` is transformed to a mandatory Platform sub-feature and a new compound node called N is therefore created as XOR variation point to group `WebApplication` and `MobileApplication` variants. At this stage, once `Platform` node has no more children to explore the transformation process comes back to the of the last children and therefore `typePassager` is set up as follows.
- In this example, `typePassenger` here is declared as a variation point besides it is linked to `confidentPerson` and Handicap. Hence the transformation corresponds to first, the creation of `confidentPerson` and Handicap as optional sub-features since the lower bound cardinality is O. Second, since `typePassager` is declared as OR variation-point a new compound node was created to group all OR-variants features.
- Finally, the domain engineer decides to consider attribute **isOld** as a feature in the generated FD. Consequently it is transformed to an optional `typePassenger` sub-feature. According to the DSML metamodel `Handicap` and `train` **AdaptedToDisabledPassenger** are mutually exclusive. In other words the selection of one component implies the selection of the other. Hence we added the dashed line between the two aforementioned features. Besides we add another dashed line between `Handicap` and `ConfidentPerson` to ensure that each disabled passenger should be helped or accompagned with a `familyMember` or a station `staffMember` to guarantee his security.

Product configuration: At this stage, the client uses the DSML in M1 layer to present the application functionnalities. According to the example above, the client proposes an android mobile application conceived for blind and illiterate passengers. Hence, disabled users can use their smart phones or tablets to reserve adapted trains to facilitate their movement and the way they can reach the trains cabins. The aforementioned DSML is transformed by the way to the product FD. This last, as we have mentioned earlier, represents the input of our Methodology Software Factory which is guided by the partial configuration of the domain product line in order to determine the guidelines for employing a product generative strategy.

V. Potential weaknesses of the proposed transformation method

Multiple levels of validity threats have to be considered for the proposed transformation methodology.

Intuitively, there is a risk that the engineer will not use our extension in accordance with the hypotheses of the transfor-

mational process. This risk can be mitigated by using a MVC approach that would expose both the DSML and the resulting FD through real-time maintained views generated from the extended DSML.

The risk to get FD that are not well-founded can be avoided by demonstrating the correctness of the transformational process.

The risk to get FD whose semantics not valid can not be avoided as this is an immediate consequence of the engineer competence. In the same way, we can not be sure that the DSML is well-defined.

Finally, at this stage, we have stated that the method engineer expresses in the DSML metamodel classes whose semantics is strongly aligned with that of the features. Of course, our method is able to support information in the DSML that does not explicitly denote features (for instance, documentation, parameters, rationales, etc) but we have not confronted our method with DSML's that would take far too many liberties in relation to this assumption. This risk will be examined later by comparison with a sample of industrial or published DSML metamodels.

VI. Conclusion and feature work

The derivation of SPL variants is a practical challenge that entails extra efforts to reduce development costs. In this context, the objective of the current work is to propose a Methodology Software Factory that aims to cover a large number of product derivation generative strategies.

To do so, we proposed in this paper a three levels framework that aims at a first step to configure partially a possible existing product line by transforming the DSML metamodel into a corresponding FD. After that, the client can use the DSML to configure his desirable application. To ensure the first step, our preliminary results have led to extending a meta-metamodel inspired from MOF by new annotations to represent FD semantic element in the DSML metamodel. These permit to guide a transformational process to get a FD according to the engineer's knowledge of the domain.

As a future work, we are collecting a sample of existing DSML metamodels to ensure us that our method is compliant with legacy and independently designed DSML.

Secondly, we intend to implement the transformational method within the MetaDONE MetaCASE (www.metadone.be) environment to ensure that the added annotations on DSML metamodel allow us to obtain the complete views of the FD. After that, the transformations steps will be implemented with a Transformation Language program to get FD as first-class models (and no more only views) and continue then our research to envision the generative part of our method.

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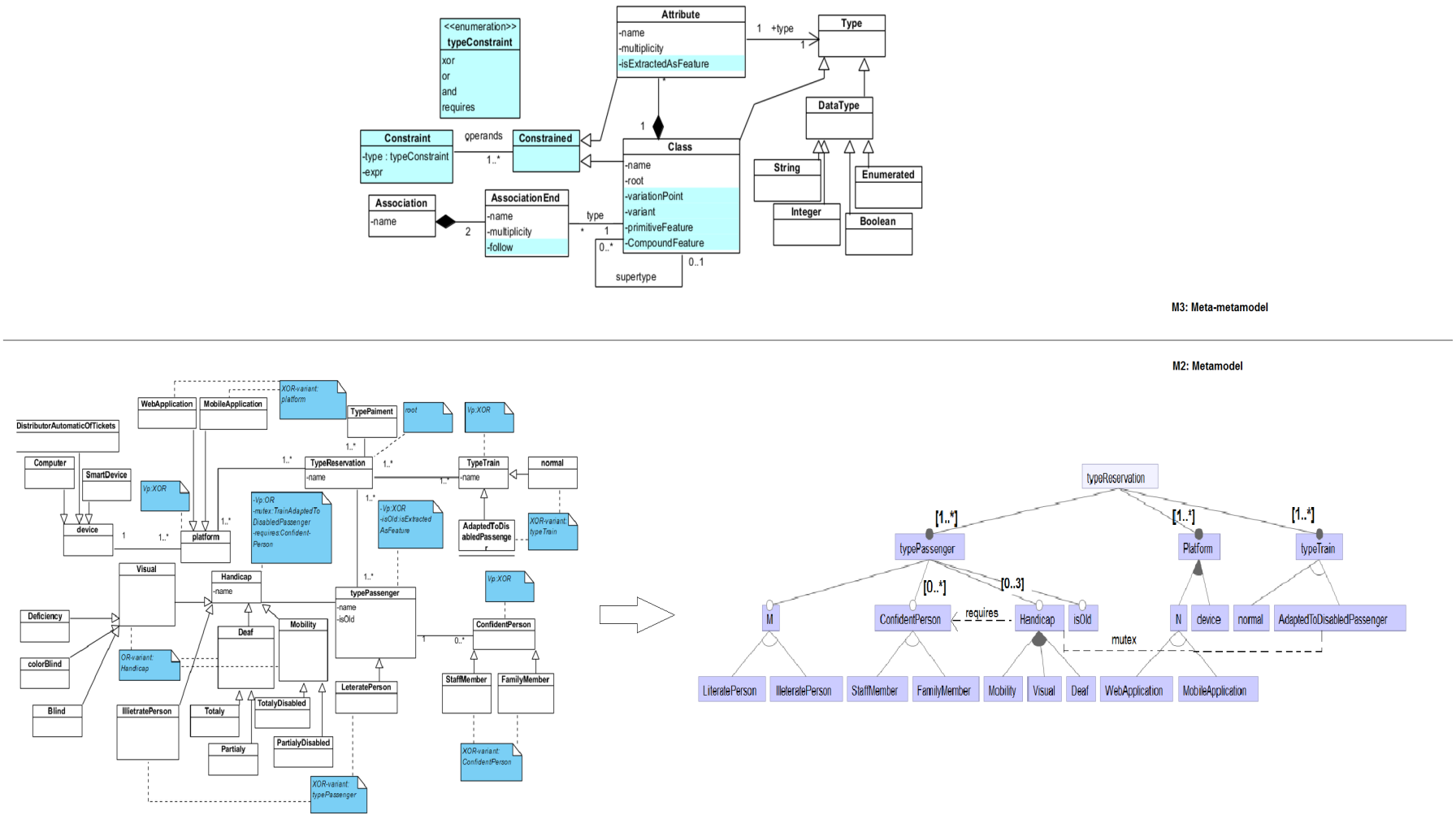


Fig. 1. Global overview of the Methodology Software Factory architecture

Reviewing the historical link between Business Process Management and IT: making the case towards digital innovation

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***Abstract*—Business Process Management (BPM) in the age of digitalization and globalization needs to become more innovative and creative. Information Technology (IT) helps to bring innovation in an organization's business processes. Our research objective is to incorporate prior studies related to the co-evolution between BPM and IT in order to explore insights and innovation trends resulting from this IT integration in the BPM discipline. We position the sampled studies against three BPM frameworks (i.e. BPM life cycle components, BPM core elements, and BPM context factors) to better incorporate their historical link with (new) IT. A Systematic Literature Review (SLR) procedure was followed, resulting in 1,198 research papers for content analysis. The review output is summarized in a BPM-IT evolution chart and an extended BPM framework. The evolution chart confirms that Industry 4.0, Blockchains, Internet of Things (IoT) and Ambidextrous BPM are the most rising trends. We conclude by digging deeper into the novel themes for researchers, BPM consultants and managers.**

Keywords*—Business Process Management, Digital Innovation, Information Technology, Systematic Literature Review.

I. Introduction

Business Process Management (BPM) is a dire need for organizations ranging from SMEs to large enterprises, and firms are using BPM capabilities to perform business functions in a more effective and efficient way. Since BPM capabilities incorporate internal and external knowledge in an organization, the emerging opportunities based on Information Technology (IT) seem thwarted without BPM capabilities [1]. The core insights of BPM (i.e. automation and transformation of business processes) focused primarily on IT-enhanced business performance or digital innovations. Digital innovation refers to the creativity and novelty in products and services by digital transformation [2]. Digital innovation thus influences organizational beliefs, values, structures and practices, leading to a cultural and environmental change. For instance, virtual collaboration, Internet-based devices and smart phone applications escalate collaboration among business functions by innovative means of new digital technologies [3]. Therefore, the co-evolution between BPM and IT facilitates digital innovations.

IT brings a revolution in every field, and technology infrastructure is a successful paradigm for many firms. IT plays a vital role for information management, information processing and communication in business processes [4]. Attaran [5] has studied how business process reengineering is linked to IT capabilities. The author also described an instance and reference level for a business process with business information and its need. The link and interaction between BPM and IT is evident in various business sectors. Recent trends include business intelligence, social media, blockchain, cloud computing, Internet of Things, and agile BPM.

BPM research was initiated with the major works on process reengineering [6] and process innovation [7]. Meanwhile, various theoretical and empirical methods have been used to scrutinize the BPM body of knowledge, such as the "Business Process Life Cycle"[8] and "BPM Capabilities and Maturity" [9]. Rahimi, Møller, & Hvam [10] discussed the integration of IT and BPM among organizational planning levels such as operational, managerial and strategic levels. While similar studies on the IT integration in the BPM discipline have been published [10], no systematic research is available that investigates the evolution of BPM along with IT alignment for the purpose of identifying IT trends and benefits of digital innovations in BPM. Thus, a theoretical gap exists to map this IT evolution with existing BPM frameworks and other relevant studies with respect to digital innovations. To investigate this research problem, the following research question is proposed.

RQ: What is the current state of the research regarding the link between BPM and IT?

We applied the Systematic Literature Review (SLR) technique of [11] to summarize existing studies combining IT and BPM. Based on this large-scale content analysis approach, we classified the sampled studies across three existing BPM frameworks in order to come up with an extended BPM framework and a historical BPM-IT evolution chart. This work contributes to practitioners by highlighting the indispensable need of making business processes more innovative by means of new IT.

The remainder is structured as follows. Section II presents the theoretical background that links BPM to IT, as well as the BPM frameworks used in our study. Section III explains our research method, i.e. SLR, including our search procedure with inclusion and exclusion criteria. Section IV demonstrates the results. Finally, the research outcomes and future research avenues are discussed.

I. Theoretical Background

The concept of BPM is related to work performance and efforts for bringing improvement into business processes. The transformation of inputs into outputs is a basic theme. BPM

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has the potential for organizational development because it includes features for process discovery, design, deployment, execution, interaction, control and analysis [12]. The term of BPM originates from the 1990s and was primarily associated with workflow management, enterprise resource planning, quality management, Six Sigma, Lean manufacturing, business process re-engineering and other similar fields [13]. The evolution of BPM from Total Quality Management (TQM) and Business Process Re-engineering concepts were given by [14] and [6] respectively. By then, researchers in the field of BPM were seen as newcomers. Afterwards, scholars started to describe BPM with various approaches such as a "Life Cycle" approach [15] and a "Management" side [16]. For instance, [17] published a handbook on the BPM life cycle components ranging from the process discovery phase to the process evaluation stage.

Regarding the future of BPM, [18] sees potential in research streams regarding an explorative BPM shift, value-driven BPM and customer process management. These streams are affected by the rising need for digital innovations. For instance, [19] presented thirty-one BPM case studies by categorizing them across BPM context factors and summarizing their insights from previous frameworks.

The remainder of this article primarily relies on the BPM life cycle, the BPM core elements, and the BPM context factors.

A. Frameworks regarding the BPM Life Cycle

The first BPM-specific life cycle studies originate from two decades ago, with [20] proposing a BPM life cycle with four steps including process design, process configuration, process enactment and process diagnosis. In 2006, [21] replaced process enactment with execution and control. Furthermore, [22] proposed a BPM life cycle with admiration and stakeholders in the center, and containing the main steps for design, analysis, configuration, enactment and evaluation. Alternatively, [23] presented another model with strategy development, definition and modelling, implementation, monitoring and control, and optimization and improvement. Studies were progressing in this area since [24] identified the BPM life cycle as the continuous improvement of a process.

While many related studies of BPM life cycles exist, our emphasis is on [17] because this is the base of most recent BPM studies. Their BPM life cycle is an iterative sequence of phases, starting from "Process Identification". The process identification phase aims at identifying which business process is most suitable and beneficial. Process goals and objectives are first defined per business process to ensure a strategic alignment [25]. Then, business processes are prioritized after qualifying the minimum criteria of selection for any particular process.

The second phase is "Process Discovery", which refers to making a list of tools and techniques used in the whole process [26]. For instance, a car manufacturing process requires parts, equipment and other assembly tools, and also needs a good technique to join them.

The third phase is "Process Analysis", which focuses on identifying issues in "as-is" processes and on setting priorities to resolve those issues [19]. Then, the "Process Re-Design" phase intends to find solutions for those issues. Also an optimum implementation plan is developed [27].

Afterwards, the "Process Implementation" phase covers the practical installation or implementation. This phase implements all changes that were identified in a previous step. It also implements the IT infrastructure as a whole system, assigns tasks to the respective person or machine, and describes the activity of people involved in the work. This phase also provides new data to the participants and deals with cultural activities. An important role of "Process Implementation" is managing organizational change which has an impact on processes [28].

The last phase is "Process Monitoring and Controlling", which is responsible for monitoring, redesigning and implementing a business process. In this phase, all hindering factors and errors are identified, not only corrective actions. Since the control of a business process and its outcome leads to exploring more ideas, the life cycle is triggered again [29].

B. Frameworks regarding the BPM Core Elements

After BPM life cycle studies, another significant aspect relates to core elements or critical success factors of BPM. Thus, many researchers have presented some frameworks in this respect. For instance, Trkman [1] presented a best fit between an organization's business environment, business processes and tasks. Furthermore, [8] presented six capability areas along with 17 sub areas based on the BPM life cycle and supported by different management philosophies such as a process-oriented culture and structure, among others. Alternatively, [30] contributed with ten good principles of BPM for capability development. For instance, context-aware BPM intends to create a business process that best fits in a particular organizational context. Finally, [31] summarized prior studies by presenting six core elements of BPM, which are frequently cited in the literature. Independent of the framework, the BPM core elements need a holistic consideration within organizations because these elements are discussed in the BPM literature as capabilities or critical success factors for BPM adoption and progression.

Given their widespread acceptance in the literature, we continue working with the BPM core elements of [31], including methods, IT, strategic alignment, governance, people and culture. Since methods and IT are already part of the BPM Life Cycle, we subsequently introduce strategic alignment, governance, people and culture.

Strategic alignment implies matching the organizational goals and strategies with specific business processes [31]. In other words, business process capabilities should be designed and improved in a way that they support particular strategies of an organization [19].

Furthermore, governance refers to those decisions and actions for assigning specific roles and responsibilities to each level of BPM. For instance, a quality manager in a restaurant will check the food quality. Governance also defines a set of rules for quality maintenance, and certain control measures are used to manage an entire end-to-end business process [32].

Thirdly, people have a vital role in the understanding and adoption of a new process model. Their skills and knowledge help enhance the efficiency and effectiveness of a business process. To improve a process, people should replace a traditional approach with novel mechanisms [33]. Therefore, organizations should ensure a proper collaboration and coordination among those people working in the same process, including employees, operational and middle managers, and stakeholders [31].

Finally, culture covers a core set of norms, values and beliefs of an organization and its stakeholders. Culture is also considered as a "soft factor" that, if supportive to BPM, strongly affects BPM adoption and success [34]. It is an unwritten and internal factor that leads to specific attitudes and behaviors among process participants.

C. Frameworks regarding the BPM Context Factors

The BPM context refers to relevant information that has an impact on business process execution. Many BPM context factors have been discussed in the past. For instance, [35] highlighted task uncertainty, size and environmental factors. He argued that task uncertainty leads towards complex processes. Furthermore, [34] studied BPM context factors for a BPM-supportive culture in an organization. Also [36] presented technological, environmental and organizational factors that play a role in BPM adoption.

While several studies exist on various dimensions of BPM context factors, [37] presented a broad framework for a better understanding. Their framework includes (1) a goal dimension, (2) a process dimension, (3) an organization dimension, and (4) an environmental dimension.

First, the goal dimension emphasizes plans related to BPM projects, and actions required to attain them. This dimension covers an ambidextrous BPM approach including an exploitative and explorative BPM dimension. Exploitative BPM is based on traditional or previously known tools and techniques, such as TQM, Six Sigma, Lean and continuous improvement [18]. On the other hand, explorative BPM refers to more creative and innovative thinking, such as social media applications and agile techniques [38].

Secondly, the process dimension emphasizes that organizational processes could be customized, automated, creative and artistic. In the era of globalization and digitalization, the process style and approach are dynamically changing. Creativity, innovation and knowledge management are significant for this shift. Therefore, the framework divides BPM into two types, namely for knowledge-intensive and non-knowledge-intensive business processes, and this depending upon the need and nature of work [39].

Regarding the organization dimension, business processes are designed either organization-specific or function-specific. Some processes are inter-organizational (i.e.. to coordinate, communicate and share things with other firms), whereas others are intra-organizational (i.e. responsible for the internal tasks of an organization). Therefore, it is difficult to manage both internal and customer-related processes [40]. Organizational context factors are defined in terms of contingency theory. Especially the size and structure of an organization are fundamental reasons of difference. For instance, larger organizations usually have a strong vertical and horizontal differentiation. Sometimes it matters how organizations respond to specific fields such as agile or quality management. Another promising aspect is organization culture, as previously explained as a BPM core element [41]. In addition, the resource potential and resource management of an organization are crucial for BPM because an organization cannot do BPM projects without financial and IT resources [42].

Finally, the environmental dimension includes factors outside the organization that can influence BPM projects, namely social, economic, cultural and political factors. Since these factors can create uncertainty and risk, researchers have stated that environmental instability is inappropriate for BPM projects [43]. Environmental characteristics that influence BPM include internal capabilities of BPM, relationship and interest of stakeholders, flexibility in systems and culture, and competiveness [37].

II. Research Methods

We applied the systematic literature review technique to analyze the BPM-IT co-evolution in more detail, and to demonstrate emerging themes along with the existing BPM frameworks of Section II. More specifically, we followed the SLR procedure proposed by [11].

A. SLR Hypotheses

According to [11], researchers may use hypotheses to identify and report findings that actually support the developed hypotheses. For instance, [44] performed an SLR on BPM maturity models and developed four hypotheses to incorporate their SLR results. Similarly, [45] developed 12 hypotheses while performing an SLR on the theory of supply chain enablers. Similarly, [46] used an SLR hypothesis for exploring service-oriented system engineering challenges. Likewise, in order to understand the current situation and past research in the domain of BPM and IT, we first developed two research hypotheses (Table I) based on our research question (Section I) to perform an SLR on the BPM-IT co-evolution.

TABLE I. Research Hypotheses

Hypothesis
H1: Information technology opens new avenues for BPM research and practices, resulting in new themes emerging from new IT support in business processes.
H2: In the era of disruptive information technology, BPM growth is shifting from an organizational or managerial side towards digital innovation and explorative BPM.

B. SLR Protocol

After formulating the SLR hypotheses, we developed our SLR protocol in line with [47] (Table II). A Systematic Literature Review Protocol typically includes a definition of research question(s), search sources, search items, search strategy, inclusion and exclusion criteria.

TABLE II. Systematic Literature Review Protocol

Research Question	RQ: What is the current state of the research regarding the link between BPM and IT?
Search Sources	Web of Science (Retrieval date 30 OCT 2018)
Search terms	• Combining "Business Process Management" and "IT"/"ICT"/"Technology"/" Information Technology". • Combining "Ambidextrous Business Process Management" and "IT".
Search strategy	Search queries with keywords in the "Topic"
Inclusion Criteria	• Included paper according to search terms and source • WBS papers written only in English
Exclusion criteria	• Duplicates • Irrelevant studies if they are does not covers BPM and IT interaction terms

C. Search Source and Search Method

We restricted our search to the Web of Science (WBS) library database because this search resulted in a large number of sampled papers. WBS is recognized for only containing peer-reviewed papers of high-ranked journals and conferences. Information such as titles and author names are listed in a structured way, and results are convenient to retrieve [48]. After following the first step of Table III, all searched titles and abstracts retrieved from the Web of Science were exported to MS Excel for an initial listing. In step 2, the titles and abstracts were screened for their relevancy to our topic, resulting in 194 papers to be considered as not applicable (e.g. because they dealt with other studies such as a chemical process). Since different keywords were used in step 1 to maximize the search horizon, 452 papers were duplicates and could be removed in step 3. Hence, we excluded all duplicate studies and those studies which were irrelevant in concepts

(i.e. based on their abstract, even with relevant titles). We included only those studies that are related to the link between BPM and IT (or ICT or technology). The main criterion for including a study was that any of our predefined keywords had to be present in the title, or otherwise the same nature of study had to be determined in the abstract. Finally, in step 4, we conducted a title-based and abstract-based content analysis for 1,192 papers.

TABLE III. OUR SEARCH METHOD

Step 1	Search from Digital Library	Web of Science (WBS)
	Retrieval date	31.10.2018
	Total Number of retrieved papers	1,838 papers
Step 2	Conduct relevancy scanning, including removal of Not Applicables	- 194 papers
Step 3	Remove duplicates	- 452 papers
Step 4	Select papers for initial analysis	1,192 papers

D. Search Criteria

Since our study aimed at collecting a substantive set of previous works on BPM with IT, the choice for proper search criteria was paramount (Table IV). "Information Technology" is a broader term and many substitute words have been used in the literature (e.g. IT, ICT or technology). Therefore, we also used those alternatives as search keywords to cover a broader span of research papers. Moreover, by including an explicit search keyword referring to ambidexterity in the BPM discipline, our search procedure also explicitly acknowledged the innovative and creative side of BPM in order to examine the research contribution and BPM practices in that area. More precisely, the search queries of Table IV were applied on the selected digital library (i.e. "Web of Science") on the 30th of October 2018.

TABLE IV. OUR SEARCH CRITERIA

First Keyword	Second Keyword	Total No. of results
"Business Process Management"	"IT"	1,171
"Business Process Management"	"Technology"	483
"Business Process Management"	"Information Technology"	146
"Business Process Management"	"ICT"	38
"Ambidextrous Business Process Management"	"IT"	0
Total		1,838

E. Classification Scheme

Our final sample of 1,192 papers (step 4, Table III) was coded with the help of the Nvivo 12 software tool. There are many software tools such as NVivo and Altas that can be used for coding and analysis of literature [49]. After importing the data in Nvivo 12, nodes were developed. Initially, one node was created per sampled paper. For example, for the title "Met4ITIL: A process management and simulation-based method for implementing ITIL", the node "Implementing ITIL" was created, which was further categorized within the "Process Implementation" node. Afterwards, the different nodes were grouped and aggregated on a third, second and first level (Fig.1). This means that, during coding, similar nodes were grouped as a cluster. For instance, all nodes related to business process modelling were placed together.

Due to the large number of 1,192 nodes, we classified the nodes into three hierarchal levels based on a bottom-up approach and independent of existing frameworks (Fig.1). Finally, at the "First Level", we ended up with a classification of 16 main nodes, indicating that our sampled studies were divided into 16 broad categories. The second-level of hierarchy contained 48 sub-nodes, and was thus also an important unit of analysis. The third-level hierarchy was only used when a second-level node had many studies in order to gain a better insight into the differentiation of covered topics.

Fig.1 illustrates that the first classification level could have direct nodes or sub-levels. Similarly, the second level could have direct nodes or sub-levels as well. On the other hand, level three could only have direct nodes.

In order to place nodes into their appropriate level of main nodes, we conducted a content-based review of each paper's

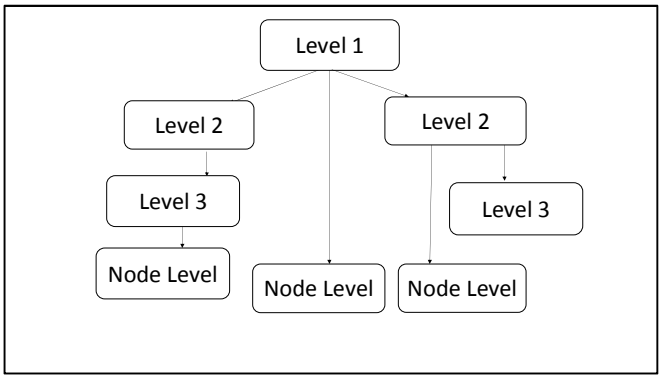


Fig. 1. Hierarchal level of our classification scheme

title and abstract to ensure accuracy of the results.

A mapping to existing BPM frameworks was done once the bottom-up coding phase was finalized, in order to supplement our empirical results with a theoretical top-down approach.

III. RESULTS

The results are presented along the bottom-up approach and the top-down approach, respectively. Regarding the bottom-up approach, we first present an overview of all classification nodes on the first hierarchical level, before digging into the two most represented nodes. Afterwards, in the top-down approach, we map each level-one node to three existing BPM frameworks (Section II).

A. Bottom-up approach : Hierarchical level 1

Table V provides an overview of the 1,192 sampled papers on hierarchical level 1, along their year of publication. While analyzing trends in the field of BPM and IT, we observed that our sample comprised publications over 28 years (i.e. starting from 1991 to 2018). Given this large timeframe, Table V shows the publication years as 5-year intervals, except for the last three years from 2016 to 2018 (i.e. which is when our sample was taken).

The ambidextrous BPM field (i.e. node number 16 in Table V) is entirely new and only seven publications were observed in the last three years, while no research work seemed to be initiated before. Given the increasing need for digital innovation, a potential research gap seems to be present in this area.

"Social BPM" (i.e. node number 14), "Innovation, Creativity and Digital Innovations" (i.e. node number 12), and "BPM and IT/IS/ICT" (i.e. node number 04) are other nodes closely related to the growing topics in BPM and IT. More specifically, for new trends in IT alignment with BPM, we observed a pattern showing that more research was related to the internet revolution after 2006, and Internet-based

TABLE V. AN OVERVIEW OF THE SAMPLED PAPERS ON HIERARCHICAL LEVEL 1, ALONG THEIR YEAR OF PUBLICATION.

Node	Node name	Number of articles per five years						Total number of articles and %
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2018	
1.	BPM Life Cycle Components	0	6	42	135	170	95	**448 (37.5%)**
2.	BPM & IT/IS/ICT	1	2	14	44	76	56	**193 (16.19%)**
3.	BPM Orientation	0	2	4	26	31	23	**86 (7.21%)**
4.	BPM Application and Usage	0	1	3	17	27	31	**79 (6.62)**
5.	BPM Architecture	0	2	3	36	18	4	**63 (5.28%)**
6.	BPM Outcomes	0	0	1	13	26	19	**59 (4.9%)**
7.	BPM Capabilities and Maturity Models	0	0	1	14	22	17	**54 (4.53%)**
8.	Organizations, Behaviors & HR	0	1	2	12	10	11	**36 (3.02%)**
9.	BPM Tools	0	1	3	5	13	7	**29 (2.43%)**
10.	Daily Management	1	0	1	7	10	10	**29 (2.43%)**
11.	BPM Research and Methods	1	2	5	6	7	4	**25 (2.09%)**
12.	Innovation Creativity and Digital Innovations	0	0	0	6	11	7	**24 (2.01%)**
13.	Data and Task-focused BPM	0	1	5	5	8	5	**24 (2.01%)**
14.	Social BPM	0	1	0	2	5	12	**20 (1.67%)**
15.	BPM Ontologies	0	0	0	5	6	5	**16 (1.34%)**
16.	Ambidextrous BPM	0	0	0	0	0	7	**7 (0.58%)**
	Total	**3**	**19**	**84**	**333**	**440**	**313**	**1,192**

communication technologies have intervened the BPM field for support and success. For instance, in the "BPM and IT/IS/ICT" category, only 17 papers were found in 15 yearsfrom 1991 to 2005, whereas 176 papers were published in the last 13 years. Hence, the Internet infusion plays a vital role.

Next, in "BPM Research and Methods" (i.e. node number 11 in Table V), a gradual adoption of research work was observed on methodologies and research designs because over the 28 years some work was observed yearly.

Furthermore, the managerial side of BPM has been on the rise since the turn of the century. This particularly accounts for "Data and Task-focused BPM" (i.e. node number 13), "Daily Management" (i.e. node number 10), "BPM Orientation" (i.e. node number 03) and "Organizations, Behaviors & HR" (i.e. node number 08).

On the first level, we only classified broader level nodes. Because of the massive number of publications, we developed 48 second-level nodes for the 16 first-level nodes. Most of the work on combining BPM with IT was noticeable in the "BPM Life Cycle Components" (i.e. with 448 papers for node number 01). Secondly, 193 sampled papers were relevant to "BPM & IT/IS/ICT" (i.e. node number 02). Since these nodes turned out to be the most important parts in business processes for IT, we subsequently discuss them in more detail.

B. Hierarchical level 2: BPM life cycle components

Because of the massive number of publications on the "BPM Life Cycle Components", we divided this node into sub categories. Each sub node is illustrated in Table VI. We further sub-divided this knowledge domain on the basis of a minor difference but still with a large number of studies. For instance, for "Business Process Modelling" (i.e. sub-node number 01), we collected 169 papers, while we had 47 publications for "Business Process Improvement" (i.e. sub-node number 03). Sub-nodes were also dependent on the nature of its study relevancy, as illustrated in Table VII which digs deeper into the third level of hierarchy. In "Business Process Modelling", the sub-node "PetriNets" in the context of the BPM-IT co-evolution originated after 2001 (i.e sub-node number 4), whereas earlier it was more linked to workflow management rather than to the name of BPM.

TABLE VI. A HISTORICAL OVERVIEW OF THE SAMPLED PAPERS WITHIN "BPM LIFE CYCLE COMPONENTS" (SECOND-LEVEL NODE)

Node	BPM Life Cycle Components	Number of articles per five years						Total number of articles and %
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2018	
1.	Business Process Modelling	0	0	13	49	68	39	169 (37.72%)
2.	Business Process Mining	0	0	4	11	23	12	50 (11.16%)
3.	Business Process Improvement	0	2	8	12	15	10	47 (10.49%)
4.	Workflow Management	0	0	10	21	11	4	46 (10.26%)
5.	Business Process Design	0	0	2	14	10	10	36 (8.02%)
6.	Business Process Analysis	0	2	2	11	11	6	32 (7.14%)
7.	Business Process Implementation	0	2	2	4	15	6	29 (6.47%)
8.	Compliance in BPM	0	0	0	6	7	1	14 (3.12%)
9.	Business Process Monitoring	0	0	0	2	6	2	10 (2.23%)
10.	Business Process Constraints	0	0	0	2	4	1	7 (1.56%)
11.	Business Process Mapping	0	0	0	2	0	2	4 (0.89%)
12.	Business Process Rules	0	0	1	1	0	2	4 (0.89%)
	Total	**0**	**6**	**42**	**135**	**170**	**95**	**448**

TABLE VII. A HISTORICAL OVERVIEW OF THE SAMPLED PAPERS WITHIN "BUSINESS PROCESS MODELLING AND BUSINESS PROCESS IMPROVEMENT" (THIRD-LEVEL NODE)

Node	Business Process Modelling	Number of articles per five years						Total number of articles and %
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2018	
1.	General Modelling	0	0	9	36	50	23	118 (69.82%)
2.	BPMN Notation	0	0	0	5	7	11	23 (13.6 %)
3.	Languages for BPM	0	0	3	5	8	5	21 (12.42%)
4.	Petri Net	0	0	1	3	3	0	7 (4.14%)
Total								**169**
Node	**Business Process Improvement**							
1.	General BPM Improvement	0	0	3	8	10	5	26 (53.31%)
2.	Engineering (e.g. Requirements engineering)	0	0	1	3	4	5	13 (27.65%)
3.	Business Process Re-Engineering	0	2	4	1	1	0	8 (17.02%)
Total								**47**

C. Hierarchical level 2: BPM & IT/IS/ICT

We now turn to the node with the second highest number of studies based on the search criteria, namely "BPM &IT/IS/ICT". This part was also divided into sub-nodes up to the third classification level. Table VIII and Table IX illustrate the second- and third-level sub-nodes along their publication years.

Table VIII shows seven sub-nodes within "BPM & IT/IS/ICT". The sub-node of "BPM & IT alignment" was covered with 43 papers. While a few alignment papers were published in the 1990s, a gradually increasing trend was presented afterwards.

Nonetheless, the sub-node with the highest number of studies was "New IT", representing 88 papers as shown in Table VIII (see level 3 in Table IX). The concept of new IT was evolving prominently after 2011 with 71 papers in 8 years. As the name indicates, this sub-node reflects recent technologies and their link with business process management. Examples of concepts included were agile BPM (i.e. 19 papers), business intelligence (i.e. 18 papers), cloud computing (i.e. 24 papers), Internet of Things (i.e. 7 papers), and other new IT innovations such as Industry 4.0 and Blockchain (i.e. 20 papers). Cloud computing was the mostly studied phenomenon revealed in our analysis.

TABLE VIII. A HISTORICAL OVERVIEW OF THE SAMPLED PAPERS WITHIN "BPM & IT/IS/ICT" (SECOND-LEVEL NODE) AND "NEW IT" (THIRD-LEVEL NODE).

Node	BPM & IT/IS/ICT	Number of articles per five years						Total number of articles and %
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2018	
1.	New IT	0	0	3	14	39	32	88 (45.59%)
2.	BPM & IT Alignment	1	1	4	10	15	12	43 (22.27%)
3.	BPMS	0	1	1	7	10	8	27 (13.98%)
4.	E-Business	0	0	3	3	3	3	12 (6.21%)
5.	Web-Based BPM	0	0	3	6	3	0	12 (6.21%)
6.	MIS and BPM	0	0	0	4	3	1	8 (4.14%)
7.	BPM & ERP	0	0	0	0	3	0	3 (1.55%)
Total		**1**	**2**	**14**	**44**	**76**	**56**	**193**

TABLE IX. A HISTORICAL OVERVIEW OF THE SAMPLED PAPERS WITHIN "NEW IT" (THIRD-LEVEL NODE).

Node	New IT	Number of articles per five years						Total number of articles and %
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2018	
1.	Cloud Computing	0	0	0	1	15	8	24 (27.27%)
2.	New IT Generic	0	0	0	5	6	9	20 (22.72%)
3.	Agile BPM	0	0	1	0	12	6	19 (21.59%)
4.	Business Intelligence	0	0	2	8	4	4	18 (20.45%)
5.	IoT	0	0	0	0	2	5	7 (7.95%)
Total		**0**	**0**	**3**	**14**	**39**	**32**	**88**

D. Top-down approach

During the top-down approach, the first-level nodes were attached to their corresponding factors from the three selected BPM frameworks (Section II), resulting in an extended BPM framework (Fig.2). These established frameworks comprehensively include the BPM life cycle, the BPM core elements and the BPM context factors.

a) BPM Life Cycle

In the BPM life cycle components presented by [50], the BPM infrastructure is a main construct. We added the "BPM and IT/ICT/IS" and "BPM Tools" nodes to "BPM Infrastructure" because BPM tools and IT/ICT/IS provide an integration among components. [17] developed a BPM life cycle initiating with the "Process Identification" phase. We linked this step to the "BPM Rules" node as rules/policies identify a process, while studies on "Business Process Mining" and "Business Process Improvement" were considered under the umbrella of "Process Discovery" because different sets of techniques can be used for process discovery. Studies on "Business Process Constraints", "Business Process Analysis" and "Business Process Mapping" were collectivity represented in the "Process Analysis" phase as we found publications for constraints, the analysis and mapping relevant to process analysis. Furthermore, "Business Process Design", "Business Process Modelling" and "Business Process Improvement" were also put as a part of "Process Redesign" because improvement requires to develop designs and models using tools, techniques and languages. Studies on "Business Process Implementation" were attached with the same name: "Process Implementation". Implementation includes workflows, hence "Workflow Management" publications were placed under "Process Implementation". "Business Process Compliance" and "Business Process Monitoring" studies were positioned in "Process Monitoring and Controlling".

Interestingly, studies on "Data and Task-focused BPM" were generic studies related to the entire BPM life cycle because data and task management are useful in the entire BPM life cycle. Similarly, BPM ontologies were related to all life cycle components as the naming and relationships are involved in each step of BPM Life cycle.

b) BPM Core Elements

As a second framework, Rosemann's core elements were reconsidered (i.e. "Strategic alignment", "Governance", "People" and "Culture"). Studies on "BPM Architectures" and "BPM Capability and Maturity Models" were placed under "Strategic Alignment" given the fact that both are related to strategies. Likewise, the "BPM Capability and Maturity Models" node was connected to "Governance" because it contains works on this aspect as well. "Daily management" was categorized in both "Governance" and "People" because daily management requires continuous operations management and governance, and revolves around people (customers and employees). The "Organization, Behaviors and HR", and "BPM Orientation" studies were linked to all four core elements of BPM because those studies involve organization structures, function-related studies, human resource management and introductory works on BPM regarding strategy, governance, people and culture . On the other hand, the "BPM Outcomes" node was only included in the "Governance" part. The "Social BPM" node was another important theme related to "People" and "BPM Infrastructure" as it covers social aspects and social media.

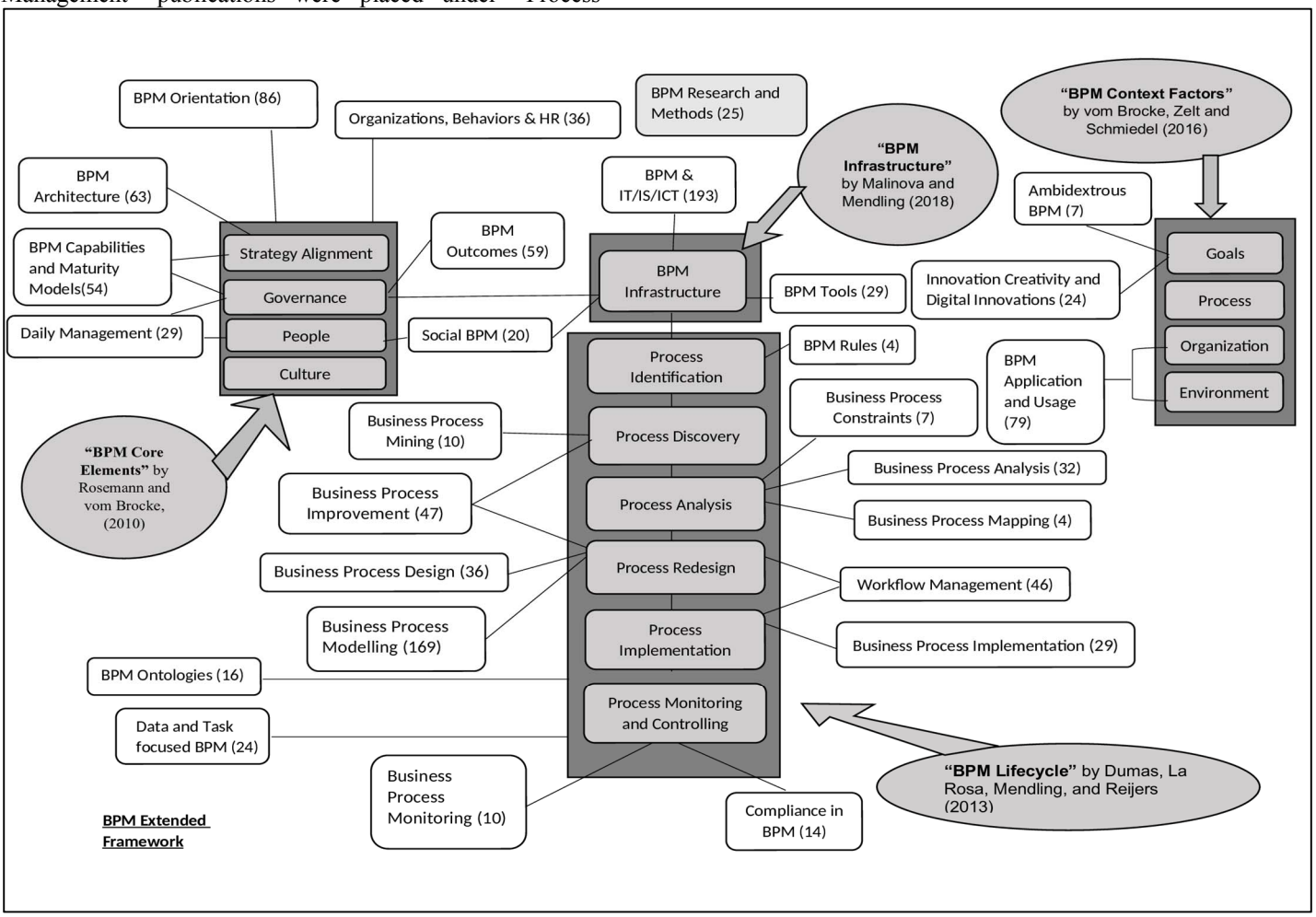


Fig. 2. The coverage of an extended BPM framework in our sample, based on BPM-IT evolution.

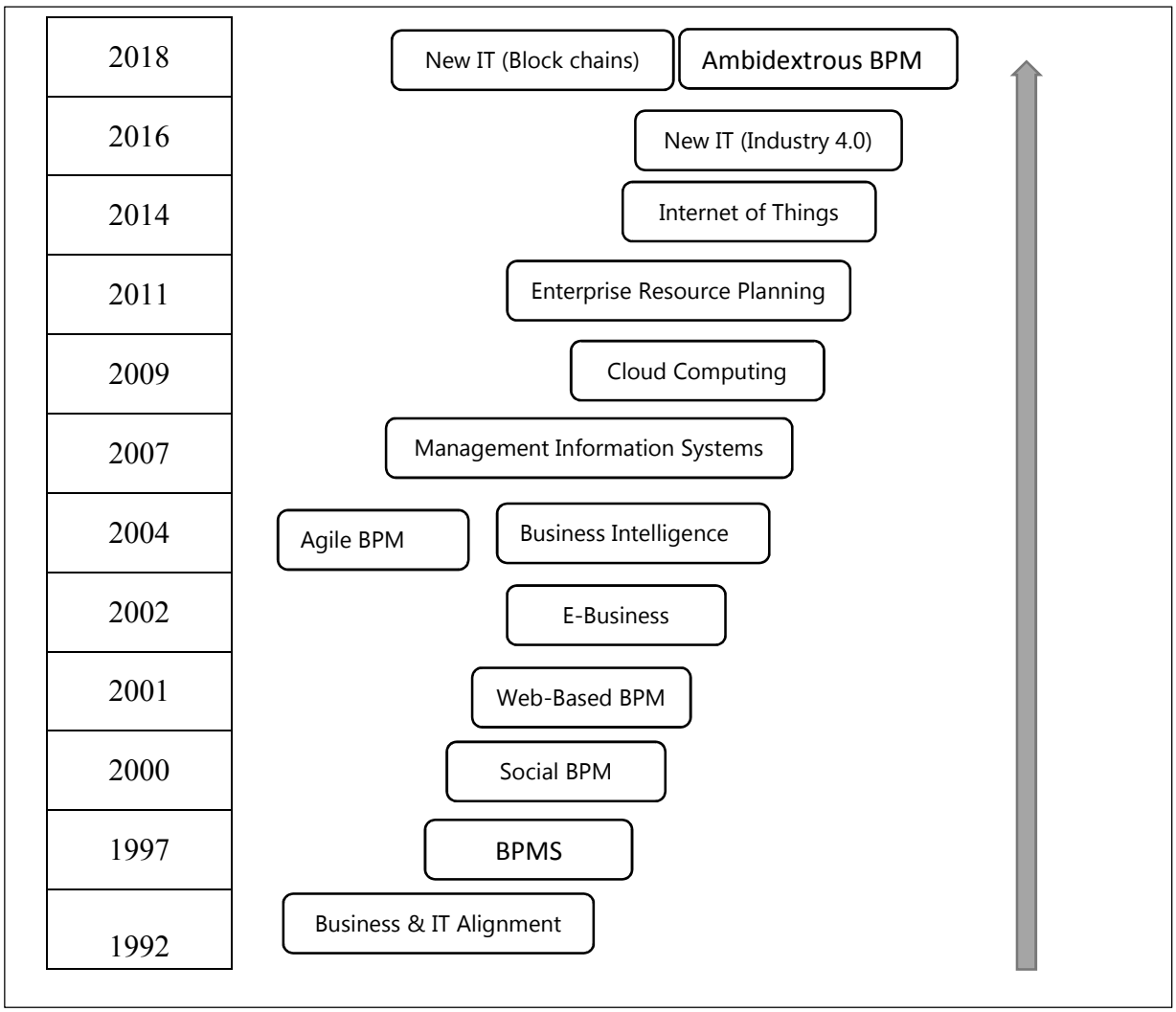


Fig.3. BPM-IT Evolution chart

c) BPM Context Factors

Finally, the presented work of [37] provided us with four factors of context identification in organizations, including goals, processes, organization and environment. Related to our SLR, the "Ambidextrous BPM" and "Innovation, Creativity and Digital Innovation" studies were added to "Goal Identification". Ambidextrous BPM is a novel approach and organizations are mainly in the planning phase to switch towards an ambidextrous side. The "Process" dimension was inherently discussed in detail within the "BPM Life Cycle" nodes. Furthermore, the "BPM Applications and Usage" node covers BPM uses in various levels of an organization's internal and external environment, and therefore included in both context factors concerning "Organization" and "Environment".

By combining the different BPM frameworks with our SLR results, Fig.2 visualizes an extended BPM framework. A separate tab was included for the "BPM Research and Methods" studies because this node contained general studies on research methods to let the BPM discipline advance. This comprehensive framework helps take a more holistic point of view or a bird eye view of all types of studies in the field of IT-induced BPM so far.

E. BPM-IT Evolution Chart

We now combine our findings in a BPM-IT evolution chart based on the above-mentioned SLR analysis with fourteen themes, (02 from Table V "first-level", 06 from Table VIII "second-level", 04 from Table IX "third-level" and 02 from sub-node 5 of Table IX "node-level"). This chart was developed with a simple mechanism, as illustrated in Fig.1: we used specific keywords and then developed the nodes. To build Fig.3, we used the BPM and IT-related nodes and sub-nodes. The evolution chart (Fig.3) ranges from 1992 to 2018, and indicate(s) the year in which the first article in that particular sub-node was published generically.

For instance, Fig.3 starts from "Business & IT alignment" in 1992, with a research paper titled "Business Process Management through Information Technology", which was the earliest paper in our sample with respect of those keywords and search results. After 1992, research has been adding for this specific link of BPM and IT alignment. Alternatively, the first research paper for MIS was found in 2007(in WBS). Since this year may seem rather late, we did an extra check in other databases, for which we observed later years (e.g. 2009 in Scopus). After this year, other studies have been focusing on BPM and MIS. The same reasoning applies to the initial papers for ERP, social BPM and other nodes. The right arrow in Fig.3 indicates that more research was published about the collective themes up until 2019, namely starting from "BPM and IT Alignment" upwards to reach "New IT (Blockchains)" and "Ambidextrous BPM" that appeared for the first time in 2018. The chart visualizes recent trends with an emerging uptake in academic work joined with BPM, starting with "BPM and IT Alignment" in 1992, "BPMS" in 1997, "Social BPM" in 2000, "Web-based BPM" in 2001, "E-Business" in 2002, "Agile BPM" and "Business Intelligence" in 2004, "Management Information Systems" in 2007, "Cloud computing" in 2009, "Enterprise Resource Planning" in 2011, "Internet of Things" in 2014, "Industry 4.0" in 2016, and "Blockchains", and "Ambidextrous BPM" in 2018.

Information technology is an ever-changing phenomenon that consistently supports humans in the form of gadgets and tools for employees. In the past, we already observed the terms of "social" and "media" distinctively, while more recently BPM seems to profit from social media. For instance, during our search and further mapping, we already found a "Social BPM" publication for social capital and BPM in 2000 while in later years the sampled articles were covering social networks, social software and social media links with BPM.

"Alternatively, the first explicit connection between Enterprise Resource Planning (ERP) and BPM was found in 2011 on the basis of search results for specific keywords (i.e. IT and BPM). Previous publications can be found for ERP alone or with BPMS or with software. For example, in 2003, a paper was published with the title "Enterprise Resource Planning: A Taxonomy of Critical Factors", which was selected but which is not directly related to BPM.

Our results are thus more keywords-oriented and various themes were mapped with the concerned nodes."

IV. DISCUSSION AND RESEARCH AVENUES

We now discuss our findings from the perspective of the predefined SLR hypotheses, and derive promising research avenues as mentioned in our recent sampled articles.

A. Research hypothesis 1

Our SLR showed that the BPM discipline grows rapidly by IT intervention. Therefore, our first hypothesis (given below), correctly clarifies that it inaugurates corridors.

H1: Information technology opens new avenues for BPM research and practices, resulting in new themes emerging from new IT support in business processes.

The results indicate that new IT such as "Cloud computing", "Internet of Things", "Industry 4.0", "Blockchains", "Agile BPM", and "Business Intelligence" have a significant contribution or coverage in BPM applications in various business units in term of publications. Social BPM or BPM based on social media usage is also a new phenomenon. Consequently, many studies are witnessed. For agenda-setting purposes, we excluded (old) IT that have already been induced in BPM (e.g. web-based BPM, ERP, E-business, MIS and Business-IT alignment) from this discussion. Moreover, to forecast new IT trends in BPM, it is inevitable to oversee only the most recent studies. Thus, only BPM contributions over the last three years in the context of new IT were summarized and analyzed, resulting in new research ideas presented in Table X.

TABLE X. NEW IT AVENUES

Reference	Research Avenues/ Suggestions
Agile BPM	
[51]	Agile process modelling and application development
[52]	Knowledge-intensive agile business process modeling and implementation.
[53]	Agile process modeling, design, implementation and monitoring, or Agile BPM life cycle.
[54]	Agile BPMN
Cloud Computing	
[55]	End-user facilitation through public cloud services and customized cloud-based processes.
[56]	Workflow or process management collaboration on cloud infrastructure to provide scalability, flexibility and elasticity in fast process management.
[57]	Cloud-based, event-driven BPM from an explorative perspective.
[58]	Green and energy-efficient BPM to bring elasticity in business processes
Business Inteligence	
[59]	Run-time predictive BPM systems with business process interpretation and accuracy.
[60]	Automated BPM life cycle and intelligence BPM systems.
[61]	Artificial Intelligence and business intelligence in process management.
[62]	(New) IT such as IoT and Big data and (new) ICT in BPM for cyber physical worlds.
Internet of Things	
[63]	Internet of |Things and blockchains, a smart BPM approach.
[64]	Healthcare process management by IoT and remote sensing.
[65]	Industry 4.0 and IoT bringing innovation in business processes.
Industry 4.0	
[66]	BPM applications in Industry 4.0.
[67]	Industry 4.0 with advance ICT can bring revolutions in BPM.
Blockchain	
[68]	BPM success with blockchain technology for trust without central control.
Social BPM	
[69]	Social BPM contributions
[70]	Classification and evolution of social media for BPM with other technologies.
[71]	Structure, process and contents of Social BPM.
[72]	Task improvement through social BPM.

B. Research hypothesis 2

Research avenues have the potential to investigate in-depth qualitative and quantitative studies to dig out new IT involvement in escalating BPM capabilities and efficiency. The utmost need of continuous improvement in business units has reshaped BPM from exploitative BPM types to a mixed approach, referred to as ambidextrous BPM [18]. Moreover, BPM success is based on creativity and innovative ideas, and when combined with new IT leads to digitally innovated BPM. Hence, our second hypothesis ("*H2: In the era of disruptive information technology, BPM growth is shifting from an organizational or managerial side towards digital innovation and explorative BPM*") is addressed and discussed in Table XI, in which recent researches are compiled and new research avenues are proposed in accordance with the latest trends.

Despite all research avenues, process design and modelling turns out to be omnipresent in BPM in the sense that they remain the core factors for reshaping BPM towards its explorative side. Hence, based on prior literature, future BPM research seems to profit significantly from Design-Science Research (DSR) with its specific principles, practices, and procedures [73].

TABLE XI. AMBIDEXTROUS AND DIGITAL INNOVATION AVENUES

Reference	Research Avenues/ Suggestions
Ambidextrous BPM	
[74]	Ambidextrous BPM in the presence of (new) IT.
[75]	Exploitative and explorative BPM frameworks and role of (new) IT capabilities more specifically.
[76]	Exploitative and explorative organizational adoption, acceptance. Ambidextrous goals, process, and environment
[77]	Agile exploitative and explorative BPM. Big data Analytics in ambidextrous BPM.
[78]	Exploitative and explorative BPM and the link with other stakeholders, such as customers, competitors and owners.
[79]	Supply Chain management of various industries and exploitative and explorative BPM adoption and benefits
[80]	Ambidexterous processes in production, manufacturing and logistics
Innovation, Creativity and digital innovations	
[81]	Digital Innovation for sustainable business processes. Continuous Innovation and BPM
[82]	Selection of digital technologies through a decision matrix in a BPM environment
[83]	Smart devices, smart processes and smart BPM based on real-time innovation in planning and execution.
[84]	Customized BPM via cognitive technologies. Business Intelligence and BPM. Increasing efficiency by blockchains.
[85]	Information Management in BPM through digital technologies

In short, BPM is gaining a new life in the era of digital innovations due to, among others, Blockchain, Industry 4.0 and IoT.

V. CONCLUSION

This study revealed that the BPM discipline has rapidly grown after the Internet boom. Nowadays, the term of "new IT" is used for different types of emerging technologies, and their role in BPM is increasingly investigated. For instance, with the rise of new IT, some novel concepts are derived, such as BPM based on social media or (more recently) agile BPM.

This work has demonstrated a systematic evolution of the BPM-IT link starting from the early 1990s until 2018, and this in terms of technologies and their usage in a BPM environment. In addition, our SLR has uncovered sixteen new themes that are emerging. Therefore, we have classified a substantive set of research articles that simultaneously deal with BPM and IT along existing BPM frameworks, including the BPM life cycle components, BPM core elements and organizational context factors. More specifically, we supplemented those framework by linking existing BPM themes with new constructs, resulting in an extended BPM framework. Our research output resulted in research avenues derived from ongoing research and specifically by exploring the BPM-IT context.

In sum, this study opens a gateway for scholars to empirically investigate the emerging IT themes within the BPM discipline. For instance, scholars may be guided by qualitatively testing the novel links through detailed interviews or by designing novel artefacts supporting process analytics based on DSR. As such, future work will enable industry people, business executives, software developers, operational and process-related managers to better apply BPM by reviewing the past trends.

Beside these contributions, we acknowledge the limitation of using only one academic database, albeit with more than 1,000 papers in our final SLR sample. However, no significant differences were detected when searching in another database, Scopus. For instance, we got 483 results with the key words "Business Process Management" AND "Information Technology" in the Web of Science, in contrast to 412 results in Scopus. More databases will be considered while performing the SLR for BPM and New IT in our future work.

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Exploring the Impact produced by the Industry 4.0 on Enterprise Architecture Models

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***Abstract*— *These days, organizations, especially industrial ones, are facing the impact of a new industrial revolution named Industry 4.0 (I4.0), which aims to change drastically the way organizations do business, interact with customers, manufacture their products and organize their production. To deal with these challenges, organizations continually adapt their enterprise models and renew their supporting Information Technology (IT). We focus on Enterprise Architecture (EA) models as a particular kind of enterprises models giving complete representations of enterprise components. Assuming that the organization has already developed its EA models, we aim to explore which components of EA models could be affected by an I4.0 transformation. In order to accomplish this research work, we selected TOGAF and RAMI4.0 as the most widespread frameworks of EA and I4.0 respectively. We compare these two frameworks for identifying a set of potential impact points. Our goal is to assist EA leaders while integrating the I4.0 components within the EA To-Be models.*

Keywords— Enterprise Architecture, Industry 4.0, TOGAF, RAMI 4.0

I. INTRODUCTION

Nowadays, enterprises are immersed in a high changing environment, specially characterized by a competitive context where exist many external and internal factors that force them to rethink and adapt business strategies and processes as well as to introduce new and versatile support technologies into their current Information Technology (IT) platform. Additionally, and specifically in industrialized domains, organizations are also facing the impact of a new industrial technology based revolution named Industry 4.0 (I4.0). This conception encompasses the digitalization of the horizontal and vertical organizational value chains which means that an organizational step-up to I4.0 transforms the whole organization including managerial, operational and decisional activities as well as business objects, resources and IT capabilities at all organizational levels [1], [2], [3], [4].

One of the most valued resources of nowadays business and industrial organizations are enterprise models (EM). An EM represents and arranges business internal context elements as well as describes their relationships and interactions. This kind of models may include descriptions of each enterprise element from high level goals and strategies to business process flows, human and financial resources, IT support components and systems as well as the link between them. EMs must also reveal stakeholders´ requirements by associating each requirement to a precise enterprise element description. For instance, when a new application must be incorporated into the current enterprise Information System (IS) architecture, including the adaptation of the data and application architectures, some changes must be also performed inside the current IT support platform and inside the current business process architecture. This should be done in order to guarantee that the new application is well integrated and, that it contributes to enhance enterprise's global performance. In addition, models help managers and project leaders to discern what is the current state of automated and manual systems, what are their connection with business processes execution and performance as well as what is the percentage of their contribution to business goals. For that and other IT reasons, we agree that enterprise models are valuable and useful means to supervise and control business functioning, to succeed Business/IT alignment goals and, in consequence, to achieve strategic business goals [5].

In order to certainly profit from having an enterprise model, organizations have adopted dedicated Enterprise Architectures (EA) frameworks, including their methods and practices to develop a set of prescribed EA complementary models. Many EA frameworks have been proposed. Among the more known and used there are Zachman [6], GEAF [7], and TOGAF [8]. Most of them consider the whole set of business and IT elements by prescribing similar sets of enterprise components under the name of EA reference model. We support our work with TOGAF because of its widespread reference model for representing a whole and significant set of enterprise concepts.

By the other hand and after few years, an innovative information technology based revolution started. In fact, this is a fourth industrial revolution called Industry 4.0 (I4.0). It transforms considerably the way current business and industrial organizations structure their work and functioning. For business organizations to adopt I4.0 means to set in a new business model, which is complemented by corporate innovations. These innovations allow enterprises to create new business value, products and services by exploiting new

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embedded information technologies. For instance, I4.0 combines Internet of Things (IoT) for interconnecting business objects with the standardization of digital tools, or Cyber-Physical-Systems (CPS) for monitoring and improving cooperative business functioning. I4.0 is associated to what it is called the smart industry which joins in digital and real worlds [9], [10] and [11]. For example, the enhancing of a business process may be done not only by including a new automated process, a CPS or an application but also, by exploiting business processes performance through the data generated from the record-keeping of business services execution [12], [13] [14]. The I4.0 revolution aims to arrange business and IT goals and intentions into the same direction, thus, it also targets to succeed business strategies by taking advantage of the newest and smartest IT [4].

Now, a main question arises: what happen with Enterprise models or, more particularly, with EA models and their positive assistance to deploy Business/IT alignment strategies and goals if a new IT exploitation model like I4.0 appears? Which components of the EA As-Is models are impacted and how to propagate impacts through the whole enterprise? Our main goal is to establish a propagation model of the I4.0 impact to be included into the To-Be models of EA. This ongoing research-in-progress paper approaches the first step of our proposal which consists in identifying different impact points (IP). In further research, the IPs will be used as a starting point to define different propagation strategies to integrate I4.0 components into the EA To-Be models.

The rest of the article is structured as follow: Section 2 describes the conceptual bases of our work, we first introduce TOGAF and we present RAMI 4.0 as the I4.0 reference model. In Section 3, we describe the comparison between the two frameworks and identify I4.0 impact points on EA components. Section 4 overviews main related works. Section 5 discusses findings and outlines our future work directions.

II. REFERENCE MODELS

A. TOGAF – Architecture Concepts Reference Model

As mentioned before, we have selected The Open Group Architecture Framework (TOGAF) [8] to identify the EA main components. TOGAF conceives and visualizes an enterprise from different and complementary perspectives. The Business Architecture, the Information Systems (IS) Architecture which is composed by the Applications and Data Architectures, and the Technology Architecture constitute three main perspectives as they cover the core of the EA content regarding the corresponding dimensions. Two additional architectural perspectives complete the reference framework by defining the EA strategy (principles, vision, requirements) and EA realization. These last two perspectives aim to keep trace of concepts and decisions while developing an EA project by following TOGAF Architecture Development Method (ADM).

Each architecture perspective aims to represent a particular set of enterprise elements (i.e. business goals, processes, actors, as well as information systems, databases, servers, software applications, communication links, etc.) through a specific architecture model; thus, while building a particular architecture model, architects just have to instantiate the corresponding enterprise concept according to the EA reference model. One of the practical uses of an EA is to positively contribute to succeed a precise alignment between business functioning requirements, business goals and business IT platform services. Table I contains the main EA components grouped by perspectives.

TABLE I. TOGAF ENTREPRISE MODEL COMPONENTS (ADOPTED FROM THE TOGAF CONTENT METAMODEL [8])

TOGAF Perspective	**Enterprise Model Components from TOGAF**	
	Phase	***Components***
Architecture Principles, Vision, and Requirements	Preliminary	Architecture Principles
	Architecture Vision	- Business Strategy - Technology Strategy - Business Principles, Objectives, and Drivers - Architecture Vision, Stakeholders
	Architecture Requirements	- Requirements - Constraints - Assumptions - Gaps - Locations
Business Architecture	Motivation	- Drivers - Goals - Objectives - Measures
	Organization	- Organization - Actors, Roles
	Behavior	- Business Services, Contracts, Services Qualities - Processes, Events, Controls, Products - Functions, Business Capabilities, Course of Action, Values Streams
Information Systems Architecture	Data	- Data Entities - Logical Data Components - Physical Data Components
	Application	- Information System Services - Logical Technology Components - Physical Technology Components
Technology Architecture	Technology Services	
	Logical Technology Components	
	Physical Technology Components	
Architecture Realization	Opportunities, Solutions, and Migration Planning	- Capabilities - Work Packages - Architecture Contracts
	Implementation Governance	- Standards - Guidelines - Specifications

B. RAMI4.0 – Industry 4.0 Reference Model

The Reference Architect Model Industry 4.0 named RAMI 4.0, proposed by the Standardization Council I4.0 (SCI4.0) aims to define and structure the main I4.0 enterprise elements, specially the disrupting technologies as a way to be followed by many industries all over the world [9]. This complex work has been an initiative of German industry managers and experts which are interested on I4.0 reference model consolidation. By now, a set of international I4.0 partners composed by Italy, France, USA, China and

Japan are discussing, completing and validating SCI4.0 standardization proposals [9].

The RAMI4.0 model has been conceived as a complementary integration of three enterprise dimensions called axes [9]. Axe I, Hierarchy, includes several levels: Connected World, Enterprise, Work Centers, Station, Control Device Field Device, and Product. It represents the factory as a hierarchy of interconnected objects. An enterprise is part of a connected world but inside, an enterprise is also a set of connected things: work centers, stations, control and field devices and, finally, products. Therefore, a factory creates products through the execution of production processes where enterprise smart objects interact to produce a product. Axe II is the Architecture dimension which contains a set of enterprise layers that represent an enterprise from six different abstraction levels from the high level of Business to the low level of Assets. The Business layer contains the organization and business processes. The Function one corresponds to the functions of the assets. The Information layer contains the necessary data. The Communication layer specifies the access to information. The Integration layer is essential to integrate virtual and real worlds thus, to make them function as an image through a mirror. An Asset is a physical object or thing in the real world. Axe III, Product Life cycle, allows to prescribe the design and maintenance processes for each type of product then to instantiate it.

Table II contains an abstraction of RAMI4.0 concepts and the relationships between physical and virtual enterprise objects.

The concept of I4.0 component is the central element of the whole model [15], [16], [17]. As examples of I4.0 Components we mention: machines, software services or applications, terminals, machine parts, controllers, sensors, etc. An I4.0 Component has an administration shell which contains the virtual description (image) of a business entity. Considering that the I4.0 component concept allows to describe any enterprise object or asset that has a role into the enterprise functioning, it may be located at any hierarchical enterprise level of Axe I. Thus, we marked this relationship with an "X" in Table II. An I4.0 component is a unique description of an asset, so it contains descriptions of corresponding elements at each Axe II layer; for instance, it may be an individual asset (entity, functionality, related data) as well as an interconnected object (communication and integration protocols). The virtual description of an enterprise entity is contained at the information layer. Finally, and related to Axe III, RAMI4.0 also habilitates designers to handle the manufacturing processes complexity by allowing to define sub-models by grouping I4.0 components according to particular domain criteria [9]. All these relationships are represented with an "X" in Table II´s columns.

TABLE II. THE 3D RAMII4.0 CONCEPTS MODEL GROUPED BY AXE

Axe		**Assets** (physical things from real world)	**I4.0 component** (virtual representation of a real world object)
AXE I: HIERARCHIE			
Connected world			
Enterprise			
Work Center		X	X
Station		X	X
Control Device		X	X
Field Device		X	X
Product		X	X
AXE II: ARCHITECTURE			
Business			
Function			X
Information			X
Communication			X
Integration			X
Asset		X	X
AXE III: PRODUCT LIFE CYCLE			
Type			
Design, development	Plan, simulation, prototype	X	X
Maintenance usage	Update, manual instruction, maintenance cycles	X	X
Instance			
Production	Product elaboration + data	X	X
Maintenance Usage	Facility Management	X	X

III. COMPARISON OF TWO FRAMEWORKS AND IDENTIFICATION OF IMPACT POINTS

After reviewing and comparing at the conceptual level both models, we specially found that they are conceived from different perspectives, one from a management viewpoint and the other from a technological operating one.

The EA models are mostly management oriented, thus model descriptions and their exploitation are concentrated on representing in detail every business element as well as its horizontal and vertical relationships. EA models are developed to understand business and to accomplish business strategies, to analyze possibilities of changes before implementing them or to manage and exploit business and IT capabilities; i.e. to contribute to attain business goals and implement business strategies. In that context, IT elements are considered as part of the whole set of enterprise elements and, obviously, as an essential mean to enhance business processes and strategies support.

By the other hand, RAMI4.0 has been conceived from a more operating perspective. i.e. from an IT exploitation perspective. This perspective conceives and prioritizes roles of smart interconnected business objects as means for increasing enterprise performance. The main focus of the I4.0 model is on how to embed IT innovations on the enterprise processes as smart objects. These objects have responsibilities not only for executing tasks but also for collaborating, monitoring, supervising, registering and communicating different vertical and horizontal organizational levels. That is possible just by

embedding I4.0 components at all business processes levels. An I4.0 component represents an enterprise entity or an object in the real world, so it may be located at any place into the factory hierarchy together with its virtual representation. Consequently, an I4.0 component introduction will impact elements from each level of EA models: Business architecture, IS (data and applications) architectures' models and, clearly, the Technology architecture models.

Additionally, most of the disruptive technologies that would enable industries digitalization to the I4.0 model, are Information Technologies associated to Big Data, Internet of Things (IoT), Machine to Machine (M2M), Cloud Computing, Human/machine interaction, robotic and 3D printing [11]. Therefore, the EA technology architecture and the IS architecture would be the most affected.

Since both sets of model elements have been conceived from different perspectives, we built Table III by following two steps concerning the conceptual elements showed in Tables I and II. For each TOGAF perspective (first starting with the architecture principles, vision and requirements perspective), we reviewed each EA concept definition and its explanation in the TOGAF document. Then, we revised for each RAMI axe (Table II) its detailed conceptual description in order to identify any potential effect of its I4.0 elements on the concepts of the EA perspective under review. We repeated this two steps procedure for each of the TOGAF EA perspectives showed in Table I.

Based on the comparison of the TOGAF and RAMI4.0 structures, we have identified different EA models´ components which could be potentially impacted by the introduction of an I4.0 component: the main conceptual element of the RAMI4.0 model. To identify a potential impact point of I4.0 component over an EA component means that any kind of change may alter current enterprise model elements. Thus, an IP mark indicates that, while defining the EA To-Be model, the EA leader ought to pay special attention to each enterprise model component that may be somehow impacted by the inclusion of new I4.0 components. The corresponding Impacts Points (IP) are represented, at a general abstraction level, in Table III. That is, the IS and Technology Architectures will be directly affected by an enterprise I4.0 evolution because I4.0 components must be explicitly included as part of these architecture models; consequently, the impact over current EA components, their change options and gaps must be carefully analyzed by project leaders before taking decisions. Besides, current architecture principles, vision and requirements must be also redefined and adjusted according to I4.0 principles and enterprise transformation needs.

TABLE III. POINTS OF IMPACT OF RAMI4.0 ON EA COMPONENTS FROM TOGAF.

Axe		Impact Points									
		Architecture Principles, Vision, and Requirements			*Business Architecture*			*Information Systems Architecture*		*Technology Architecture*	*Architecture Realization*
		Preliminary	*Architecture Vision*	*Architecture Requirements*	*Motivation*	*Organization*	*Behavior*	*Data*	*Application*		
AXE I: HIERARCHIE											
Connected world											
Enterprise											
Work Center **(i4.0 component)**			IP	IP				IP	IP	IP	
Station **(i4.0 component)**			IP	IP				IP	IP	IP	
Control Device **(i4.0 component)**			IP	IP				IP	IP	IP	
Field Device **(i4.0 component)**			IP	IP				IP	IP	IP	
Product **(i4.0 component)**											
AXE II: ARCHITECTURE											
Business			IP	IP	IP	IP	IP				
Function **(i4.0 component)**					IP	IP	IP	IP	IP		
Information **(i4.0 component)**								IP	IP		
Communication **(i4.0 component)**										IP	
Integration **(i4.0 component)**										IP	
Asset **(i4.0 component)**											
AXE III: PRODUCT LIFE CYCLE											
Type											
Design, development **(i4.0 component)**	Plan, simulation, prototype				IP	IP	IP			IP	
Maintenance usage **(i4.0 component)**	Update, manual instruction, maintenance cycles				IP	IP	IP			IP	
Instance											
Production **(i4.0 component)**	Product elaboration + data				IP	IP	IP	IP	IP	IP	
Maintenance usage **(i4.0 component)**	Facility Management				IP	IP	IP	IP	IP	IP	

According to general results of Table III, we envisage two complementary research directions concerned the essential transformations of EA conceptual models: the business and architecture management-oriented direction and the technical one. Both will be outlined at the conclusion section of this paper.

IV. Related Works

In order to position our research work, we reviewed some domain´s literature. The detailed survey could be found in [18]. We read management and technical practical works concerned the I4.0 phenomena from diverse perspectives.

First, we revised general management publications explaining what is I4.0 revolution, what are the main intentions underlying this revolution, what are the implicated technologies, how to introduce IT innovations into production processes for stepping-up to I4.0, what would be the benefits that enterprises may attend by implanting I4.0 technologies. Besides, we reviewed others works proposing blueprints, guidelines and practical recommendations to succeed an I4.0 transformation project, listing management and technology competencies required to participate and complete a transformation project, etc. [2], [10] and [19].

Additionally, we revised another group of I4.0 related research works concerning analysis and proposals of technical solutions to specific problems produced by I4.0. For instance, we overviewed technical works related to algorithms and software solutions to better monitor, analyze and improve process execution, as well as works about how to incorporate intelligence into business objects, to accomplish machine to machine (M2M) communications, to increase interoperability between specific IT infrastructure elements, etc. We include in this group the works considered as part of big data, data analytic solutions, etc. which are related to management and exploitation of the captured set of data from the performance of the enterprise processes [20] [21].

Several technical research works concern the definition of the RAMI4.0 architectural reference model as well as other similar I4.0 frameworks, which are proposed for arranging I4.0 implicated technologies [12], [22], [23], [24]. These works are strong relevant for this paper because we will settle enterprise architecture models relevance for the I4.0 transformation on the concepts underlying RAMI 4.0 model [15].

It is important to mention that after the I4.0 research survey presented by Yang Lu [11], where author proposes five categories for grouping I4.0 current research directions and outlines I4.0 future ones, we corroborate that the direction concerning our study has been low explored; i.e. the study of the effects of an I4.0 transformation on current EA models has not been much studied from the business concepts point of view. In that sense, there are some research works that propose to extend business process modelling languages like BPMN and ArchiMate in order to represent new I4.0 concepts and to support EA management, [25] et [26] respectively; but, all these propositions are placed at the technical implementation level. We place our research work at a higher abstraction level; it concerns the IT management context, so it surely implies management and technological platform issues but not with technical implementation details.

Finally, different sources mention the impact of digitalization on Enterprise Architecture. For instance, [27] suggests a meta-model-based approach to integrate Internet of Things architectural objects into the Enterprise Services, Architecture Reference Cube (ESARC). However, the enterprise should have implemented ESARC to apply their approach. Our approach is intended for enterprises with implemented well known EA frameworks. In their further works [28], the authors add a second perspective (value-based) to the digital strategy and include micro-services in addition to the Internet of things architecture to form a digital EA (DEA) reference cube based on TOGAF. They use the service-oriented architecture and micro-granular systems. In [29], the authors investigate how Digital Business Ecosystems (DBE) impact an EA developed using SOEA (Service-oriented EA) paradigm, more particularly, the GERAM framework. The authors mention the impact on the VO (Virtual Organization) level, wrapping level, Service level, and also on the organization level by interacting with DBE's providers.

V. Conclusion and Future Work

In this work, we explored the relationships between the models of TOGAF and RAMI4.0 in order to determine if there are some conceptual correspondences among them. As a result, we found that they are somehow compatibles; i.e., some EA models' concepts are the same or similar to those required by the I4.0 reference model; for example, all physical technological components. Accordingly, it is possible to reuse some of EA model components to complete those required by the I4.0 model. We supported our work with the TOGAF EA reference models because these models allow to represent the most common enterprise elements including business objects and, because they may be applied in most business and industrial domains. We consider that enterprise models are still being essential means to assist any enterprise change hence an I4.0 transformation.

As a contribution to practice, this comparison permitted to detect what are the set of enterprise elements, contained in current EA models, that may be considered as part of the EA To-Be state in order to reach an I4.0 evolution. Thus, EA and I4.0 designers and project leaders could distinguish what are the enterprise set of models and their elements, that should be deeply revised, completed and adapted.

Our future work will consist in elaborating a propagation model of the I4.0 impact on the definition of the EA To-Be models´ components. This will follow two directions: (a) a business-oriented direction that purposes to describe effects over enterprise business architecture including architecture principles, vision and requirements as well as over the management of EA development projects; and (b), a technology-oriented direction to analyze the detailed impact of the RAMI4.0 set of model components, prescribed standards

and design conventions over the technological and IS enterprise architecture models.

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Business Process Ambidexterity and its impact on Business-IT alignment. A Systematic Literature Review.

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***Abstract*—In the age of digital disruption, organizations face the growing need to both optimize existing processes, and to radically innovate and disrupt them. Business Process Management (BPM) has proven great value for process control and process optimization, however not for process disruption. Our Systematic Literature Review of Business Process Ambidexterity provides an overview of this nascent domain. In our research, we have divided all articles into two main strands of research, focusing on: (1) organizational capabilities enabling Business Process Ambidexterity, and (2) the actual dynamic balance between exploration and exploitation in BPM, which is enabled by the modelling and optimization stages in the business process lifecycle. As there is no widely accepted definition of Business Process Ambidexterity, we propose one for future use, based on the concept of paradoxical thinking. Business Process Ambidexterity may both enable, and be facilitated by digitalization; however, there is limited evidence that Business Process Ambidexterity enables Business-IT alignment. The main research gap is the lack of conceptual and practical guidelines on Business Process Ambidexterity implementation. Hence, this article encourages future research and provides preliminary guidance for practitioners.**

Keywords— Business Process Management, Business Process Ambidexterity, Organizational Ambidexterity, Business-IT alignment, Paradoxical Thinking, SLR.

I. Introduction

Today, we are facing the fourth industrial revolution driven by social, mobile, cloud and smart technologies (e.g. Artificial Intelligence, Internet of Things [IoT], blockchain) [1]. In order to reap benefits from such "new IT" and the disruptive opportunities for digital innovation, organizations need to find paths to radically innovate their business processes, while at the same time maintaining their existing streams of revenue. This contradiction lies at the heart of organizational ambidexterity, which is defined as mastering both evolutionary and revolutionary change [2], adaptability and alignment [3], or exploration and exploitation [4].

Organizational ambidexterity has received a lot of attention in academia, albeit not in the context of Business Process Management (BPM). The debate whether BPM is compatible with innovation – particularly disruptive, radical innovation – is still on-going [5]. There are some theoretical arguments supporting the notion that BPM's drive towards standardization and variation decrease may lead to organizations being stagnant and inward-looking [6]. Researchers argue that BPM mainly fosters incremental innovation rather than the exploratory or disruptive kind [7]. Ambidexterity poses a prominent challenge to BPM, as historically this discipline has been focusing on control and optimization rather than disruption, exploration and paradigm-shifting or radical innovation [8].

In the context of IT, BPM is considered to be the main enabler of business-IT alignment [9], driving digital transformation and disruption through digital technologies. The question whether BPM enables business-IT alignment in an ambidextrous setting remains unanswered.

Therefore, this paper intends to evaluate the extent to which the current body of knowledge on BPM addresses ambidexterity, by providing a Systematic Literature Review (SLR) of the nascent concept of Business Process Ambidexterity. Our main research question is:

RQ: What is the state of research into Business Process Ambidexterity, and its impact on Business-IT alignment?

Our review will provide a consolidated overview of research in this domain, highlighting the research gaps and limitations. It will also deliver guidelines for practitioners on how to foster Business Process Ambidexterity, and whether this can facilitate business-IT alignment in organizations.

The paper is structured as follows. Section II provides an overview of the theoretical frameworks used to evaluate the current body of knowledge. Next, Section III gives an overview of the SLR research method, the actual research procedure and the details of the research sub-questions. Section IV outlines the results, whereas Section V provides a discussion of the results highlighting the implications for academia and practitioners.

II. Theoretical Background

We start by providing an overview of the theoretical frameworks used in this study.

A. Organizational ambidexterity

The concept of organizational ambidexterity was introduced by [10], who proposed setting up separate organizational structures to manage contradictory forces in an organization. The organizational tension between exploration and exploitation can be traced back to the seminal work of

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[11], who described the inherently contradictory dichotomy between exploration and exploitation in organizational learning. Exploration can be defined as searching and experimenting, while exploitation drives profit from the results when optimizing an operation [4]. Ambidexterity has eventually been defined as the dynamic capability of balancing these two opposing activities [12]. More recently, the need to balance contradictory activities has been replaced with the concept of paradoxical thinking, where the tensions are actually beneficial and enlightening [13]. This evolution of the concept of organizational ambidexterity is visualized in Figure 1.

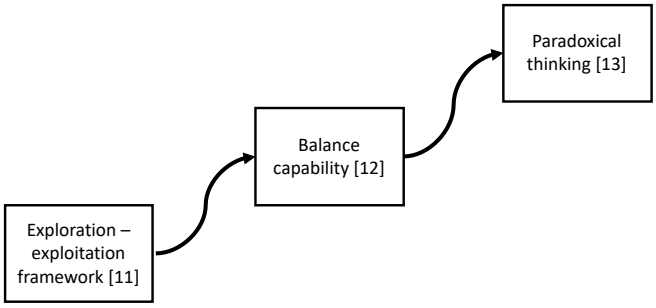


Figure 1. The evolution of the concept of ambidexterity in literature, based on [11], [12] and [13].

Ample empirical evidence proves that ambidexterity is beneficial for both organizations' productivity and innovativeness, in particular in uncertain market conditions [14]. Moreover, organizations with greater technological capability are proven to benefit to an even greater extent from ambidexterity, since the existing technological knowledge base makes it easier to exploit resources [15].

In academia, there is little agreement on how organizational ambidexterity is achieved. Researchers have proposed the following approaches:

- The historical differentiation approach focuses on separating the contradictory activities in separate organizational units (i.e. spatial separation) or time frames (i.e. temporal separation), creating the basis for the concept of **structural ambidexterity** [2].
- The integration approach stems from organizational learning and the innovation management literature, and centers on integrating contradictory activities in the same organizational unit. This approach defines **contextual ambidexterity** [3].
- Finally, senior managers' decision making can be put at the center of ambidexterity research, which is the basis for **leadership ambidexterity** [7].

Although researchers agree that all three approaches need to be integrated to deliver a complete ambidexterity capability [16], there is no conclusive evidence whether any of these approaches is more effective [13].

B. Business Process Management

Business Process Management (BPM) can be seen as all efforts to analyze and continually improve the fundamental activities of an organization's operations [17]. BPM has been proven to have a positive impact on the organizations' performance and competitiveness [18], in particular for business processes spanning different domains and departments [19].

Several attempts exist to categorize the main elements of BPM. For instance, researchers have proposed two key elements of process management: process control and incremental process improvement [20]. [21] have identified six core elements, or success factors of BPM: strategic alignment, governance, methods, information technology, people and culture. On the other hand, [22] proposed a framework capturing six main BPM capability areas and 17 sub-areas, based on organizational theories and a comprehensive sample of 69 business process maturity models. The capability areas are as follows.

- **Process modelling**: this initial stage in the business process lifecycle is dedicated to design and analysis of business processes;
- **Process deployment**: comprises implementation, enactment, measurement and control;
- **Process optimization**: improvement of the business process;
- **Process management**: covers daily management, as well as aligning with business strategy and stakeholder relationships;
- **Process-oriented culture**: process-oriented values, attitudes and behaviors;
- **Process-oriented structure**: process-oriented organization chart and governance bodies.

C. IT governance and Business-IT alignment

IT governance can be defined as the "definition and implementation of processes, structures and relational mechanisms" to support "business-IT alignment and the creation of business value from IT" ([23] p.2). At the core of this definition, [23] position the three main elements of IT governance:

- **IT governance structures** or formal devices to enable contacts between business and IT;
- **IT governance processes** or the formalization of IT decision making, and IT monitoring procedures;
- **Relational mechanisms** for participation and collaboration between business and IT.

Business-IT alignment is the other key component of the definition of IT governance. Alignment is aimed at ensuring that key IT resources are aligned with the organizational strategy in order to improve the organization's performance [24]. This notion has been one of the main concerns of IT practitioners and IS researchers for the past 30 years [25]. Studies have recently moved beyond the paradigm of aligning IT with business strategies, towards the concept of IT actually being the strategy, which can be conceptualized as the Digital Strategy [26]. [27] demonstrated a lack of convergence between IT alignment and BPM studies, and proposed to analyze IT alignment from the perspective of BPM.

Subsequently, the presented theoretical perspectives will be evaluated against our preselected article sample. For this research, we have selected the conceptual framework of [22], as it presents a complete model of both the business process lifecycle stages and the organizational capabilities, which will help us position and define Business Process Ambidexterity. We will analyze IT governance through the

lens of the definition of [23], covering the main components of IT governance, and linking them to the concept of Business-IT alignment.

III. Methodology

This Systematic Literature Review (SLR) was based on guidelines provided by [29] and [30]. SLR is a specific way of conducting literature reviews, aiming to standardize the literature review process through a strict protocol. [31] argued that, while SLRs have many limitations, they may prove beneficial when conducted based on specific research questions and a clearly delimited topic. This applies to our research, which focuses on the term of Business Process Ambidexterity, and has clearly defined research questions (see Table 1). A form of SLR which is worth mentioning in this context is the Systematic Mapping Study, which delivers a high-level categorization of research on a given topic [32].

TABLE 1. OUR SLR PROTOCOL, BASED ON BOELL & CECEZ-KECMANOVIC (2015).

Protocol elements	Translated to our study
1/ Research question	• SLR-RQ1 – In the context of which BP capability areas [22] has Business Process (BP) ambidexterity been investigated? • SLR-RQ2 – In which types of organizational ambidexterity [33] is Business Process Ambidexterity researched? • SLR-RQ3 – In which components of IT governance [34] is Business Process Ambidexterity researched? • SLR-RQ4 – Which evidence exists for a relationship between the development of Business Process Ambidexterity and IT alignment?
2/ Sources searched	• ScienceDirect • Emerald Insight • Springer Link • Reexplore • ACM Digital Library • Scopus • Web of Science • AIS Electronic Library (AISeL)
3/ Search terms	The following keywords were in the scope of the search: (*Business) process ambidexterity, organizational ambidexterity, business-IT alignment.*
4/ Search strategy	• Peer-reviewed journals and conference papers; • Theoretical and empirical studies; • No publication date limit, no sector limit; • Filters (when available): subject area restricted to business, management & accounting; computer science; engineering; economics, econometrics & finance. • The search terms were contained in the articles' title, abstract or keywords • Alerts were set up for search queries, in order to ensure completeness of the results till the finalisation of the paper
5/ Inclusion criteria	• Include only papers containing a combination of search terms, defined in the search queries; • Include only papers indexed in the sources searched from all periods until end-2018; • Include only papers written in English
6/ Exclusion criteria	• Exclude articles using the keyword "process*" with a different meaning than BPM; • Exclude articles using "ambidexterity" in a different meaning than simultaneous pursuit of explorative and exploitative goals; • Exclude articles without full access.
7/ Quality criteria	• Only peer-reviewed articles in the academic databases chosen • Following a validated and comprehensive BPM framework

A. Research question

The objective of our SLR was to understand the current state of research on Business Process Ambidexterity, and its relationship with Business-IT Alignment. Building on this, our RQ from section I was further divided into four SLR-RQs:

SLR-RQ1: In the context of which Business Process capability areas [22] has Business Process ambidexterity been investigated?

This research question was aimed to help us understand the state of research in Business Process Ambidexterity in greater detail, and to identify which BP capability areas of the framework of [22] (see section II.B) are most relevant in the context of Business Process Ambidexterity.

SLR-RQ2: In which types of organizational ambidexterity is Business Process Ambidexterity researched?

For this research question, we mapped the sampled articles to the two main ambidexterity types: structural and contextual (see section II.A). The leadership-driven ambidexterity type was not included in the scope of this SLR, since its focus is primarily on industrial and organizational psychology, rather than organizational processes and structures.

SLR-RQ3: In which components of IT governance [23] is Business Process Ambidexterity researched?

This third research question narrowed the scope of the preselected articles to the ones covering IT governance. This scope was compared to the three components of IT governance as defined in the model of [23]: (1) processes, (2) structures and (3) relational mechanisms.

SLR-RQ4: Which evidence exists for a relationship between the development of Business Process Ambidexterity and IT alignment?

Theoretical models and evidence [35] exist for BPM to act as an enabler of Business-IT alignment. In our research, we will look at specific links between Business Process Ambidexterity, and Business-IT alignment in an ambidextrous setting.

B. SLR strategy – search, analysis and mapping to theoretical frameworks

Our SLR search strategy is subsequently explained.

Step 1: database search

In August 2018, we searched for potential articles in the following databases: ScienceDirect, Emerald Insight, SpringerLink, IEEExplore, ACM Digital Library, Scopus, Web of Science, and AIS Electronic Library. We then used the predefined search queries, as outlined in Table 2. No publication date limit was set in the search. When available, filters were set to restrict the subject area to business, management, computer science, engineering, and economics. The search terms were contained in the articles' title, abstract or keywords. Following the search query, alerts were set up in order to ensure completeness of the results for December 2018 (i.e. finalization of the paper).

TABLE 2. INCLUSION CRITERIA FOR THE LITERATURE REVIEW

Research questions	Scope	Keyword	Wildcard search
All RQs	All databases in scope	*organizational ambidexterity*	*ambidext**
SLR-RQ1 + SLR-RQ2 + SLR-RQ3	All databases in scope	*exploratory business process*	*explor* process**
SLR-RQ1 + SLR-RQ2 + SLR-RQ3	All databases in scope	*(business) process ambidexterity*	*ambidext* process**
SLR-RQ4	Only the sample of *ambidext* process**	*Business-IT alignment*	*alignment*

After an initial review of the results, the wildcard search *explor* process** was removed from the scope of the research because it was bringing almost only false positives (i.e. not in the context of BPM). For SLR-RQ4, the search query was run on the sampled set of articles of *ambidext* process**.

The search results of the selected keywords are presented per database in Table 3.

TABLE 3. RESULTS OF THE SEARCH QUERIES IN THE SELECTED DATABASES

Searched keywords	*ambidext**	*ambidext* process**	*alignment*
ScienceDirect	319	65	8
Emerald Insight	194	66	9
Springer	114	0	0
IEEExplre	66	29	0
Scopus	1142	335	37
Web of Science	1145	373	36
ACM	10	2	0
AIS	59	22	0
Total	**3049**	**892**	**90**

Step 2: qualitative check of article sample

Based on the search results, a total of **892** papers was found (Table 3). In the following screening steps, duplicates were removed, as well as all papers using the keyword "process*" with a different meaning than BPM, and "ambidexterity" in a different meaning than a simultaneous pursuit of explorative and exploitative goals. In many cases, "ambidexterity" related to the literal meaning of the word: being equally adapted to use the left and right hand. In some rare occasions, it was also used to relate to other opposing activities in a single entity.

Step 3: mapping to theoretical frameworks

Following the above-mentioned screening step, the sample of papers was reduced to **47**. All articles were assigned a unique identifier: *Pxx* (Annex 1). In the final step, we carried out a full review of the sampled papers, in order to map them to the selected theoretical frameworks and research questions. The results of the mapping can be found on the following link.

The mapping between the articles in the sample and the research questions was done as follows.

For **SLR-RQ1**, the articles were mapped to one of the BP capability areas in the model of [22] based on the analysis of the full content of the article, and in particularly focusing on the findings of the research. The sampled articles focused on one (or multiple) of the stages in the business process lifecycle (i.e. process modelling, deployment, optimization and management), or on the broader characteristics of the organization (i.e. process-oriented culture and structure).

Regarding **SLR-RQ2**, the mapping to the two ambidexterity types was only provided when explicit links were made to structural or contextual ambidexterity in the research findings or the models defined in the article. In some sampled papers, an inexplicit ambidexterity type was deducted from the context of the article: articles focusing on exploratory processes in certain structural settings were assigned to structural ambidexterity. Similarly, articles presenting ambidexterity in a single business process, were assigned to contextual ambidexterity. On several occasions, no clear connection was found with any of the ambidexterity types.

In **SLR-RQ3**, the articles were mapped to one of the IT governance components only if the main finding of the sampled articles had an IT component (e.g. IT as the industry, IT as an enabler, moderator or outcome of the research findings). Once the link with IT had been established, the articles were associated with: (1) IT processes, provided that the researched processes were in the field of IT; (2) IT structures, if explicit reference was made in the research findings to IT structures, or (3) IT relational mechanisms, if the findings touched on collaboration of IT and business staff.

We continued with **SLR-RQ4**. A sampled article was associated to this research question only if the "alignment" keyword (i.e. in the meaning of business-IT alignment) appeared in the article's content. Within this limited scope, we evidenced the relationship between business-IT alignment and Business Process Ambidexterity.

The complete research strategy is visualized in Figure 2.

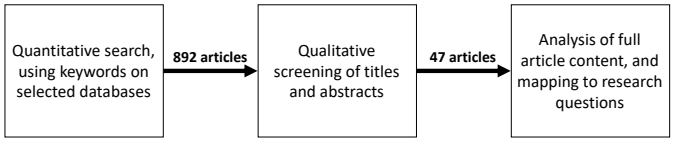


Figure 2. Summary of the SLR strategy

IV. RESULTS

A. Results for SLR-RQ1

Regarding SLR-RQ1, Figure 3 shows that the most common capabilities were process management (19 articles), process optimization (19 articles) and process modelling (9 articles), which are also the key phases where disruption and radical innovation can take place.

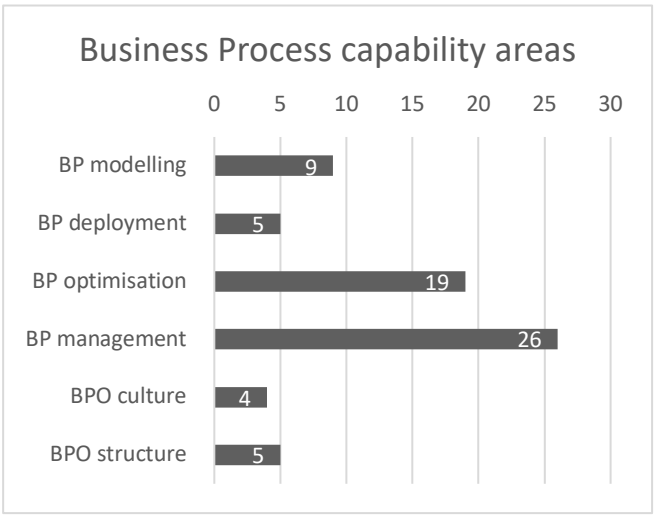


Figure 3. Mapping of articles with the BP capability areas [22] (N=47).

The distinction between the business process lifecycle capabilities, and the business process orientation provided us with an interesting angle to analyze Business Process Ambidexterity. Namely, we observed two main strands of research combining organizational ambidexterity and business processes:

- **Business Process Ambidexterity as a dynamic balance**: The process lifecycle capabilities strand is where business process modelling and optimization phases were intended to be highly innovative, disruptive, and eventually replacing the existing business process. This strand followed the definition and call for research by Rosemann (P15) for "*the corporate ability to create process designs that truly excite customers*". A good example of this approach was provided by P45 with the focus on process modelling, process standardization in P35, inter-organizational service processes in P19 and process improvement and redesign in P30, as well as a new product development process in P08 and P47. Finally, P37 focused on the role of IT-based BPM tools in achieving ambidexterity. In this context, Business Process Ambidexterity was defined as "*the dynamic equilibrium state of business process efficiency and business process flexibility*" (P09).
- **Business Process Ambidexterity as an organizational capability**: The process-oriented organizational capabilities strand focused on the broader organizational capabilities, which facilitated explorative business processes. This can be IT capabilities (e.g. P14, P34 and P39), big data capabilities (e.g. P28, P40 and P43), intellectual capital (e.g. P29), enterprise mobile system implementation (e.g. P33) or collaboration (e.g. P27). In this strand, Business Process Ambidexterity was defined as *"firm's capability for utilizing both process alignment and process adaptability*" (P10). A subset of this strand focuses on Business Process IT capabilities, which are ambidextrous (P18, P24, P34, P39).

The two approaches are not mutually exclusive. For instance, P42 provided a model of a "learning spiral process" where organizations follow of divergence and convergence path, between integration (contextual ambidexterity) and separation (structural ambidexterity).

It is worth noting that only five articles in the sample (P09, P15, P21, P22, P26) actually refer explicitly to the concept of Business Process Ambidexterity.

We now provide an overview of the state of research of ambidexterity in the six BP capability areas. We refer to Annex II for a detailed overview of the BP capability areas and dimensions of Business Process Ambidexterity in the article sample.

Process modelling

The process modelling phase played an outstanding role in process ambidexterity, since according to the first strand of research (see above), this is the phase where the actual design of disruptive and radically innovative processes takes place. P15 argued that process modelling should be driven by opportunity points (not pain points as is the case of traditional, exploitative processes) and be based on an opportunity-driven, "outside-in" approach. Following this, P21 proposed a fully-fledged process design framework, combining explorative and exploitative capabilities. They also proved that ambidexterity is self-reinforcing (through the positive correlation of explorative and exploitative capabilities). P45 designed a new method for ambidextrous process design, based on Design-Science Research.

Process deployment

There was little research in the field of implementing ambidextrous business processes. Regarding monitoring and control, P41 confirmed that Process Management can support both exploitative and exploratory processes, however, auditors applying ISO 9001 should take additional care to ensure appropriate understanding of exploratory processes.

Process optimization

P22 argued that the process redesign phase brings the greatest added value in Business Process Ambidexterity, and proposed an analytical framework for ambidextrous BPM rooted in value-based BPM and the customer confirmation/disconfirmation paradigm. P20 focused on the role of organizational learning in Business Process Ambidexterity; more specifically, in the domain of process optimization, P20 conceptualized ambidexterity as a balance between process control (i.e. via variation reduction through exploitative learning) and process innovation (i.e. via variation increase through explorative learning). P21 focused on a new process dimension: radical process improvement (in addition to process control and process improvement), which was defined as the core of process ambidexterity.

Process management

In the context of process management, the focus was on agility (P07), flexibility (P09, P14, P18) and ad-hoc problem solving (P16) in exploratory business processes. P30 proposed a holistic framework for explorative process management, focusing on innovation, capability development and business alignment. P47 categorized all business processes into three areas: new product development, supply chain management, and customer relationship management, and provided fascinating examples of radical and incremental innovation. Interestingly, P32

claimed that innovation in production and IT processes does lead to greater organizational ambidexterity, while this was not the case for logistics processes. The researchers explain this by the fact the logistics processes are less focused on exploration and radical innovation. P44 provided an organizational ambidexterity maturity model, based on Rosemann's six core elements of BPM [21]. P35 argued that big pharma enterprises following structural ambidexterity should focus on business process standardization to manage big data, whereas enterprises following contextual ambidexterity should rather focus on output standardization in a big data context. This can be explained by the need to mitigate the downsides of structural ambidexterity (interorganizational conflict, misalignment of processes within an organization).

Process-oriented culture

P16 highlighted the need for a culture that supports creativity, flexibility, search, experimentation, and risk taking. She also pointed out that BPM actually better explains the exploitation culture (security, discipline, control, improvement).

A recurring theme across several studies in exploratory processes was indeed search (P39). P34 focused on a broad and creative understanding of the business and the market, needed for exploratory processes.

Process-oriented structure

P03 provided insight into explorative processes by defining structures for explorative processes as "demand-side", client-driven and business-driven (as opposed to "supply-side" for exploitative processes).

B. Results for SLR-RQ2

As visualized in Figure 4, the sampled articles referred both to contextual ambidexterity (27 articles) and structural ambidexterity (19 articles). The prevalence of contextual ambidexterity can be explained by: (1) the definition of Business Process Ambidexterity, with its focus on balancing exploration and exploitation in one business process (see IV A); as well as (2) the growing consensus on the limitation of a purely structural approach to ambidexterity, as underlined by P21 and P35. In the context BPM, structural ambidexterity can be defined as organization-wide separation of explorative (often client-facing) processes, from exploitative processes. Interestingly, P08 argued that Total Quality Management (TQM) may facilitate contextual ambidexterity, but not the structural one, as TQM and Quality Assurance does not require the creation of new structural entities.

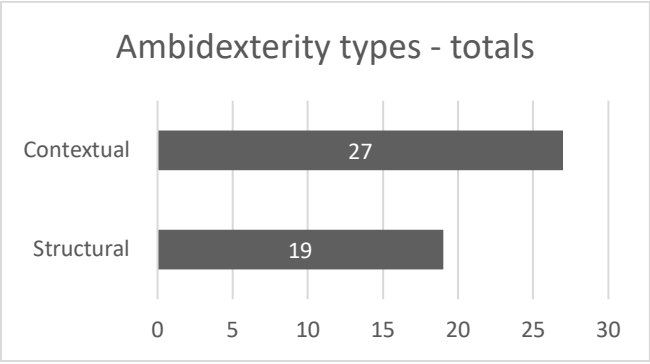


Figure 6. Mapping of articles to the Organizational Ambidexterity types (N=47).

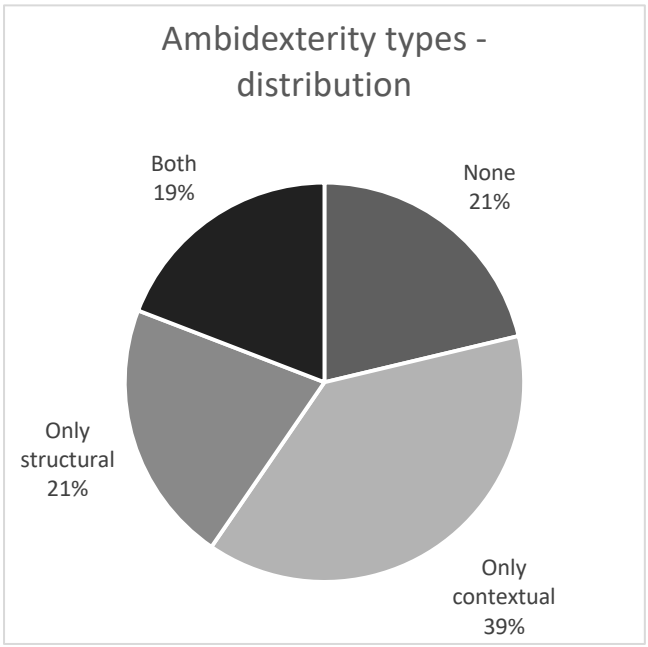


Figure 4. Distribution of ambidexterity types in the articles sample (N=47).

Since both ambidexterity types are not mutually exclusive, nine articles were assigned to both ambidexterity types, and ten articles to none, as presented in Figure 5.

C. Results for SLR-RQ3

The role of IT in BPM is paramount. This has also been reflected in our research sample: 36 out of 47 articles referred to IT. The most common governance terms were IT processes (36 articles), followed by structures (7 articles) and relational mechanisms (3 articles). Nevertheless, as argued by [47], companies need to leverage the three elements to fully deliver on ambidexterity. Therefore, one can argue that IT structures and IT relational mechanisms remain under-researched in the context of Business Process Ambidexterity.

P18 claimed that business value was created from IT using Business Process Management. P34 paraphrased Nicholas Carr by stating *"IT does not matter, business processes do*" [36]. This relationship between IT and BPM is visualized in Figure 6. It will be interesting to examine whether the same relationship applies specifically to Business Process Ambidexterity.

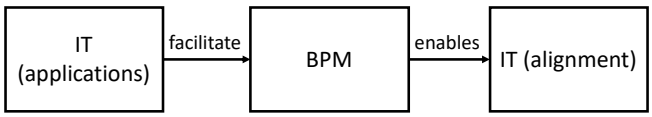


Figure 5. Dependencies between IT and BPM.

In the research sample, there was evidence that process ambidexterity does lead to greater performance, and this in the context of software development (P01), or ambidextrous IT capabilities (P34). P36 argued that digitalization can actually resolve the exploration/exploitation paradox, and they proposed three digitalization paths aimed at delivering ambidexterity: 1) assets digitalization, 2) digitally based process integration, and 3) disruptive analytics-led decision-making. Similarly, P22 claimed that digitalization leads to the greater importance of explorative processes, and P43 argued

that adequate information systems could help organizations benefit from ambidexterity. On the other hand, P31 provide evidence that ambidextrous IT processes support digital innovation, which indicates that digitalization and Business Process Ambidexterity could be self-reinforcing.

Considering the importance of IT for BPM, we can establish two research gaps: (1) no research into ambidextrous BPM governance, and its relationship with IT governance, and (2) no evidence for Business Process Ambidexterity facilitating business-IT alignment. The last point brings us to SLR-RQ4.

D. Results for SLR-RQ4

Based on the SLR, there was limited evidence for a relationship between Business Process Ambidexterity and business-IT alignment: only 4 articles provided some evidence of this relationship.

Researchers argued that business-IT alignment could lead to greater process innovation (P03) and organizational ambidexterity (P04). P10 provided a framework for ambidexterity facilitating business-IT alignment and P30 provided a method to evaluate processes, aiming to align business and IT. This is visualized in Figure 7. However, no clear evidence was found in the sample that Business Process Ambidexterity facilitates Business-IT alignment.

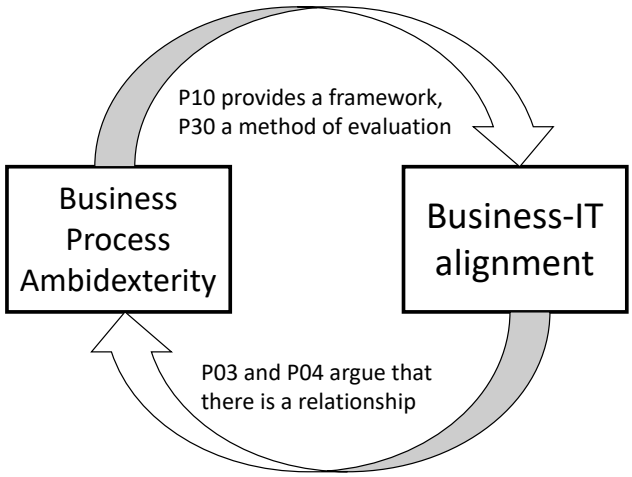


Figure 7. Relationships and dependencies between Business Process Ambidexterity and IT alignment in the article sample.

V. DISCUSSION

We now discuss our findings relative to the call by Rosemann in 2014 (P15) to focus more research on exploratory, inside-out and opportunity-driven business processes. Since then, several researchers have aimed to address this topic, which resulted in an increase in research in the last years (i.e. with 14 articles before Rosemann's call, and 33 articles since the call).

A. Conceptual framework and definition

Overall, there seemed to be notional parallels between the types of ambidexterity and the two other theoretical models in scope of our research. This may have been caused by common conceptual antecedents for all variables in the theoretical models. The underlying concepts could be defined as "processes", "structures", and "values and behaviors", as shown in Table 4.

TABLE 4. UNDERLYING CONCEPTS IN THE THREE THEORETICAL MODELS

Concept	**BP capability areas**	**Ambidexterity types**	**IT governance areas**
"Process"	Business process lifecycle areas	Contextual ambidexterity	Processes
"Structures"	BPO structure	Structural ambidexterity	Structures
"Values and behaviours"	BPO culture	Leadership-oriented ambidexterity	Relational mechanisms

Similarly, we can establish parallels between BPM and IT governance concepts (values for IT are based on [37]), as presented in Table 5. We have visualized the dependencies between the three variables in a visual model of our research, shown in Figure 8.

TABLE 5. PARALLELS BETWEEN BPM AND IT CONCEPTS

Concepts	**BPM**	**IT**
Alignment / efficiency	Exploitative processes	Core/Industrial IT
Adaptability / flexibility	Explorative processes	Agile IT
Balancing activity	Business Process Ambidexterity	Bi-modal IT

One of the key limitations of analyzing Business Process Ambidexterity was the lack of a clear definition or a widely recognized conceptual framework for "Business Process Ambidexterity". In order to address this challenge, we proposed to categorize the sampled articles into two main research strands: (1) those focusing on the dynamic balance between explorative and exploitative processes, and (2) those analyzing the organizational capabilities leading to process ambidexterity. As such, only five articles in the samples addressed explicitly the concept of "Business Process Ambidexterity".

Based on this, we have identified two definitions of ambidexterity in the article sample: (1) the first one focusing on firms' capabilities in a structural ambidexterity setting (see Table 6); and (2) concentrating on the "dynamic equilibrium" in the setting of contextual ambidexterity. Considering that the research into organizational ambidexterity has moved beyond the concept of "ambidexterity as a dynamic balance" (see Figure 1) [13] towards the notion of "paradoxical thinking", we propose a new definition of Business Process Ambidexterity based on P42, namely: "***Business Process Ambidexterity means benefiting from mutually enabling qualities of business process exploration and business process exploitation.***" This definition is aligned with the research of P07 and P21, who argue that exploratory and exploitative processes reinforce each other.

TABLE 6. DEFINITIONS OF BUSINESS PROCESS AMBIDEXTERITY

Ambidexterity concept	Definition
Structural ambidexterity	*"firm's capability for utilizing both process alignment and process adaptability"* (P10).
Contextual ambidexterity	"*the dynamic equilibrium state of business process efficiency and business process flexibility*" (P09)
Ambidexterity, as a paradox process	*"benefiting from mutually enabling qualities of business process exploration and business process exploitation"* (own definition, based on P42)

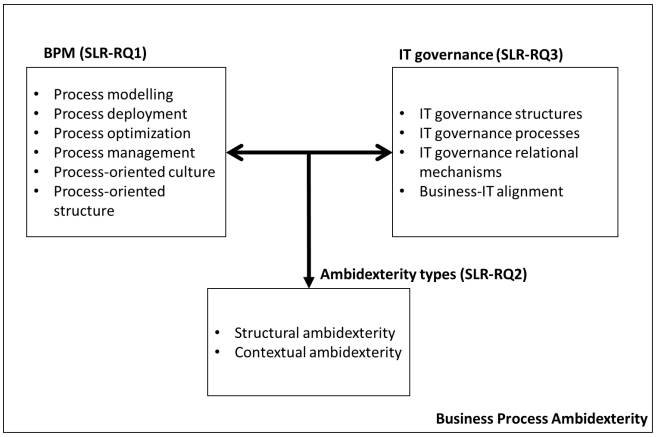


Figure 8. Conceptual model of our research, based on [2], [3], [22], [23].

B. Guidance for practitioners

Guidance for practitioners in this field still remains fairly limited. Looking at the business process lifecycle, Business Process Ambidexterity plays the most critical role in BP modelling, and optimization capabilities. Following this, a few researchers attempted to conceptualize new frameworks for the modelling phase of ambidextrous processes (P21 and P45), and the optimization phase (P22). We summarize the observed conclusions for practitioners in Table 7.

In sum, we present a decision model for implementing Business Process Ambidexterity in Figure 9.

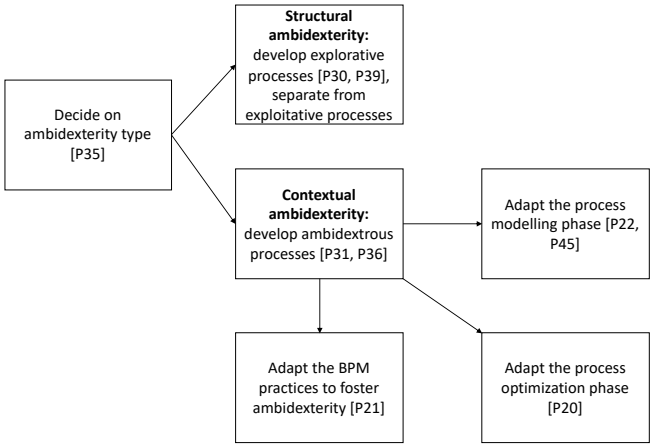


Figure 9. Decision model for practitioners

TABLE 7. GUIDANCE FOR PRACTITIONERS

Article	Guidance for practitioners
P03	Propose a ''scorecard'' to determine the extent to which an organization's Information Systems are ready to support process innovation.
P16	Managers should monitor whether BPM practices instill "exploitative" or "explorative" culture.
P20	Provide a framework to assess innovation of Business Processes.
P21	Advise to explore new processes as daily BPM activities, and look for synergies between radical process innovation and incremental process innovation. The authors also provide a measurement scale to guide BPM activities.
P22	Advise to add the customer perspective as a strategic objective to process design.
P26	Advise to enhance team innovativeness through process agility, and, to a lesser extent, standardization.
P27	Advise practitioners to invest in collaboration tools, to support employees working on explorative processes.
P30	Propose a new framework for explorative BPM, i.e. the proposed prioritization and categorization method (PCM).
P31	Recommend to invest both in IT exploration and IT exploitation in order to deliver digital innovation.
P35	Acknowledge that enterprises following structural ambidexterity (like big pharma) should focus on business process standardization to manage big data, whereas enterprises following contextual ambidexterity should rather focus on output standardization in a big data context.
P36	Practitioners should pursue digital transformation in order to balance exploration and exploitation.
P39	Researchers provide a framework helping practitioners decide whether to invest into explorative or exploitative capabilities.
P41	Auditors applying ISO 9001 should take additional care to ensure appropriate understanding of exploratory processes.
P44	Researchers provide a Maturity Model for Organizational Ambidexterity, based on BPM dimensions.
P45	Researchers provide a new process design method, based on Design Thinking, called "Ambidextrous Analysis of Business Process".

From a practitioner's standpoint, it is worth asking whether there is an actual need to develop ambidextrous capabilities for BPM. It could be a management decision to apply a BPM framework in an exploitative setting, and to use other more disruptive frameworks for exploratory purposes.

C. Research agenda

Considering that the concept of Business Process Ambidexterity is relatively new, we uncovered some relevant research gaps. The fundamental question of how Business Process Ambidexterity should be specifically implemented, remains unanswered in the literature so far. Should organizations focus on structural Business Process Ambidexterity, and as such concentrate primarily on explorative processes? Or, alternatively, should they design their processes to be both exploitative and explorative? How should they pursue both paths? The guidance for practitioners on how to build Business Process Ambidexterity into their enterprises is still fragmented (see Table 7).

Holistic research into all process-related capability areas also seems to be missing – in particular into the BP management capability, as well as the BP-oriented structure. Even though there is research focusing on the process modelling phase, the complete lifecycle of BPM has not been analyzed through the lens of ambidexterity. Moreover, in our SLR sample, there were no studies found about the enablers, the contingency factors, success factors or governance of Business Process Ambidexterity. Furthermore, no research into Business Process Ambidexterity was found in the public sector.

Despite the fact that business processes are closely intertwined with IT alignment (i.e. they are defined as the method to align IT and business), no research still exists into whether Business Process Ambidexterity facilitates IT alignment in an ambidextrous organization. On the other hand there is already evidence that digitalization may reinforce Business Process Ambidexterity. As such, the current article points to ample avenues for future research.

VI. Conclusion

In this paper, we have reported on an SLR of Business Process Ambidexterity and its relationship with business-IT alignment. We provided an overview of the main research strands, which are focused on organizational capabilities and the dynamic balance between exploration and exploitation (i.e. achieved primarily through appropriate process modelling and optimization). In this paper, we have also proposed a novel definition of Business Process Ambidexterity, bridging with the concept of paradoxical thinking, and which will pave the way for future research.

The main limitation of the research is the fixed scope of our article sample (i.e. limited by the search keywords), which has to some degree limited our horizon of the analysis. Other threats to validity include lack of access to some articles, and potential bias in the search on non-academic databases.

Nonetheless, we conclude that the questions of how to conceptually define Business Process Ambidexterity, how to holistically implement it and what its business value is, remain unanswered in the literature to date. Meanwhile, we offer scholars a conceptual framework, a definition, a research agenda with potential avenues as well as guidance for practitioners.

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VIII. ANNEX 1 – SLR ARTICLE SAMPLE

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IX. Annex 2 – Overview of ambidexterity dimension in the article sample

Capa-bility	Theme	Exploitation	Exploration	Ref
1. BP modelling	Focus	Execution, pain points	Change, opportunity points	P15
	Process design	Inside-out	Outside-in, opportunity driven	P15
	Process design	Risk-taking	Risk-averse	P22
3. BP optimization	Big data enablement	Increased efficiency, problem identification and solving, performance measurement of individual processes, improved decision-making processes and improved risk management	Increased customer centricity, improved agility and responsiveness to market changes, service innovation, knowledge acquisition, network management and business model experimentation	P28
	Process dimensions	Process control, incremental process improvement	Radical process improvement	P21
4. BP management	Activities	Refinement, choice, efficiency, implementation, execution, pursuit of first-order learning	Fundamental redesign and rethinking, challenging the status quo, building new processes drastically with a new resource base and divergence	P21
	Activities	Control based, exploitative learning	Process innovation based, exploratory learning activities	P20
	Categories of BPM practice	Exploitative efficiency oriented	Explorative variation decreasing	P34

Capa-bility	Theme	Exploitation	Exploration	Ref
	Process	Process alignment	Process adaptability	P04 P11
	Process	Process efficiency	Process flexibility	P09 P14 P18
	Process	Formalization, proceduralization	Ad-hoc problem solving, experimentation	P16
	Process	Process rigor, process standardization	Process agility	P07
5. BPO culture	Culture	Control, accuracy, discipline, security, improvement, refinement	Creativity, flexibility, search, experimentation risk taking	P16
	Terms	Mechanistic structures, tightly coupled systems, routinization and control	Search, variation, risk taking, experimentation play, flexibility, discovery, and innovation	P39
	Skills and competences	Deeper and more technical awareness of implemented systems and business process specifics	Broad and creative understanding of the business and market, also an overview of modern technological innovations	P34
6. BPO structure	IS projects	"Supply side'' (regular maintenance and upgrades and relatively simple new acquisition)	"Demand side'' (complex, strategic, innovation oriented and large scale change related)	P03
	Strategic decisions for innovation	Incremental innovator	Radical innovator	P47
	Technology	Running, optimizing, exploiting	Transformation	P10

Offline oracles for accessibility evaluation with the TESTAR tool

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***Abstract*—To manage the complexity of today's information systems, we need to investigate novel approaches for automated testing. In this paper we present two extensions to TESTAR, a state-of-the-art tool for testing systems through the GUI. We extend this tool with 1) a systematic and powerful approach for storing and querying test results through a graph database for offline oracles, and 2) support for accessibility evaluation of general applications for stakeholders with disabilities utilizing offline oracles. Furthermore, we conduct a preliminary validation of these extensions through a case study on the popular VLC Media Player.**

***Index Terms*—testing, automated testing, accessibility evaluation, graph database**

I. Introduction

A test oracle is a mechanism that distinguishes between a passed or failed test case. When oracles are checked during automated test execution (i.e. on-the-fly), this can increase CPU and memory usage and hence may slow down the System Under Test (SUT) or even the entire operating system. Moreover, if the oracle aims to test a property involving multiple SUT states, all relevant states must be determined and recorded in main memory. Therefore, execution of test oracles can affect the timing behavior of the SUT. This can be problematic when testing time-dependent or non-deterministic programs.

This paper leverages graph database technology to contribute novel, reusable and *offline oracles*. As opposed to the usual on-the-fly, or online, oracles that perform their evaluation on the current state-model of the SUT during testing, offline oracles perform their evaluation on stored test data asynchronously after testing, whenever the QA engineer desires.

As a second contribution, we provide a method to evaluate the *accessibility of general desktop applications* that uses the offline oracles powered by the graph database. For web content, the principal (ISO) standard in use at the time of our research was Web Content Accessibility Guidelines version 2.0 (WCAG 2.0) [1]. The standard provides recommendations to increase web accessibility for people with a wide range of disabilities. In Europe, WCAG 2.0 is part of procurement standard EN 301 549 [2]. WCAG 2.0 was proposed by the World Wide Web Consortium (W3C). The W3C also presents the WCAG2ICT [3] to provide guidance on how to apply WCAG 2.0 to non-web content, including software. In this paper we mechanize a subset of WCAG2ICT rules as a set of on-the-fly and offline oracles using the graph database. This is possible because the latter offers support for oracles that can be reused for general desktop applications and that can involve multiple SUT states.

The offline oracles and the accessibility evaluation described above have been implemented in the TESTAR[1] tool [4], a state-of-the-art tool for testing systems through the GUI. We describe a study on the popular VLC Media Player[2] as a preliminary validation of the effectiveness.

Outline: Section II describes the related work and the background for TESTAR. Section III describes how we leverage graph database technology to introduce support for expressive *offline* oracles. We discuss the formalization of WCAG2ICT to evaluate accessibility of general desktop applications in Section IV. Section V contains the VLC Media Player case study. We conclude in Section VI and describe future work.

II. Related work and background

The challenge of making good oracles is known as the test oracle problem [5]–[7]. Automation of test oracles is one of the most important parts needed for increased test automation. Literature on test oracles, such as Barr et al. [5] has introduced many techniques that are placed in 4 categories: specified, derived, implicit and human oracles. While none of these turns out to be completely adequate, the final source of test oracle information remains the human, who may be aware of additional informal specifications and domain-specific information. All forms of test oracles, even the humble human, involve challenges of reducing cost and increasing effectiveness.

Without adding anything, TESTAR can detect the violation of general-purpose system requirements through implicit oracles like those stating that the SUT should not crash, the SUT should not find itself in an unresponsive state (freeze) and the GUI state should not contain any widget with suspicious words like *error*, *problem*, *exception*, etc [8].

[1]https://github.com/TESTARtool/TESTAR_dev and http://www.testar.org
[2]https://www.videolan.org/vlc/index.html

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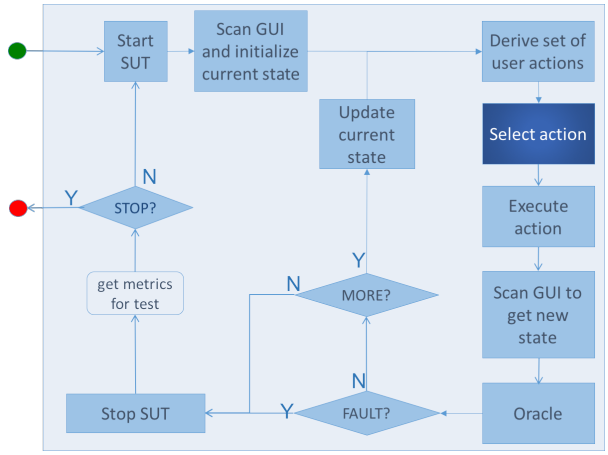


Fig. 1. *TESTAR testing flow*

The TESTAR tool checks the oracles on-the-fly, the way it works is summarized in Figure 1. First, the SUT is started and user actions (such as clicking a button, or filling in a textbox) are discovered from a tree model. The tree model is automatically derived from scanning the GUI through the Accessibility API. An action is then selected using a selection algorithm (at random by default) and executed and the new state of the GUI is inspected for failures by the oracles. If we want to test more, a new cycle of scanning, selection and execution is started.

Adding more sophisticated application-specific oracles to TESTAR requires the human tester to extend the default (Java-based) TESTAR protocol that applies the oracles and drive the tests in a TESTAR cycle. Java methods can be added that will execute the human specified oracles on-the-fly by checking each state we encounter during testing. This is the approach that has been taken in the industrial case studies we have undertaken so far [4], [9], [10].

In this paper we will take a different approach in two ways. First of all, the oracles we address here are in between the broad implicit oracles and the narrow application-specific specified oracles. Oracles here can be (re-)used when testing any application for evaluating the *accessibility* quality characteristic. Accessibility is becoming an increasingly important software property. European standard EN 301 549 [2] contains accessibility requirements for public procurement. Such requirements will continue to gain importance as the United Nations Convention on the Rights of Persons with Disabilities (CRPD)[3] is ratified by more and more countries. Many tools exist to evaluate accessibility, particularly for web content[4]. However, all these tools are for web-based systems and not desktop applications.

Second of all, the oracles we present in this paper are offline, i.e. they are executed after testing has been completed. Test oracles hence consist of database queries on the data that results from the test executions.

III. Offline Oracles with Graph Databases

Offline oracles use information stored during test execution, i.e. information about all the different "interesting" states that were encountered. This information provides a convenient way to support testing complex historical properties involving multiple SUT states. Moreover, this information can help to identify the root cause of a failing test since the relation between the actions and states is available in the database. Furthermore, it allows us to gain insights into the (historic) behavior of the application.

Test tools may output their test result data spread across multiple files in different formats. For example, TESTAR uses plain text log files, mathematical functions/metrics (CSV), visual representations like graphs or screen shots of the SUT, and meta-information recording what is tested and when. Other commonly used forms of outputs include a series of HTML files with test reports, and sometimes include a series of screen shots showing each test step. The question arises how offline oracles can make use of all this information about the SUT. To that end, we decided to store test data in a uniform, query-able format. The format should be sufficiently flexible to satisfy the following requirements:

1) It should reflect the relation between different states.
2) It should reflect the relation between a state and the active widgets in that state.
3) It should allow the user to retrieve the execution path of a state.
4) It should store a variable number of properties for a given state, widget or action.

The graph database solution has been implemented using OrientDB[5], a free, open source product. In general, graph databases support a natural way to represent the relation between the different states encountered in the execution path. OrientDB met all the needs to satisfy these requirements. Moreover, OrientDB provides multiple ways to query the database: graphs can be traversed using a Structured Query Language (SQL) dialect, or a Java API, or the Gremlin language[6] [11].

A. Design

To support graph databases in TESTAR, we export the information collected during test execution into the database. The data data model of a SUT in TESTAR consists of the following key types:

State contains the state of the SUT at a given step within the execution of the test. `State` can be used to discover the active widgets at a given moment.

Widgetis the representation of a visible object of the application. This can be a menu item, a title bar, a dialogue,

[3]https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html

[4]https://www.w3.org/WAI/ER/tools/

[5]https://orientdb.com

[6]http://tinkerpop.apache.org

etc. For TESTAR, only the widgets that are currently available for manipulation (active) are important.

Action is the type that is constructed by TESTAR from a `Widget`. `Action` describes the way to interact with the `Widget` and is used by TESTAR for instance to push a button, or to fill a text box.

Figure 2 shows the key elements[7] and their relation. A `Widget` is always related to a `State` and an `Action` can target a `Widget`. When an `Action` does not target a `Widget` it is applied to a `State` (for instance when "Escape" is the `Action`).

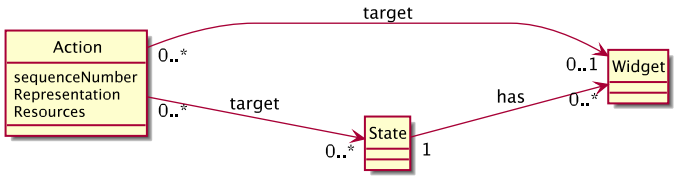


Fig. 2. Main structure of the internal model of the SUT constructed by TESTAR during test execution

The model presented in Figure 2 is used as the basis for the implementation of the storage of data in a database. Figure 3 shows how TESTAR stores the various properties in the graph database when the execution flow presented in Figure 1 is executed. TESTAR first scans the GUI to determine the initial `State`. This `State` is stored in the database. Next, all reachable `Widgets` are discovered. These `Widgets` are also stored in the database and have a has relation to with the current state. TESTAR will now select an `Action`, execute this `Action` and store the `Action` in the database. Finally TESTAR stores the new `State` in the database and enters the next test iteration.

B. *Offline oracles*

With the integration of the graph database in place, we are now ready introduce offline oracles. The key idea is to define offline oracles as queries to the graph database. We will use Gremlin here to express queries. Gremlin queries to traverse a graph $G = (V, E)$ look like this:

```
G.V o has("@class","Widget") o map("Desc")
```

This defines a so-called traversal through graph G starting from the set of vertices V. The second step (i.e. the part `has("@class","Widget")`) reduces V to a set V' with only vertices of type "Widget". The last step (i.e. the part `map("Desc")`), creates a V'' consisting of the same number of elements as V', but the vertices now only contain their "Desc" property.

Meaning that a traversal consists of a number of functions, called steps, which form a linear chain $(f \circ g \circ h)$ where the output of f is the input for g and the output of g is the input for h.

[7]State, Widget and Action all have more elements. For instance all properties discovered by the accessibility API are stored.

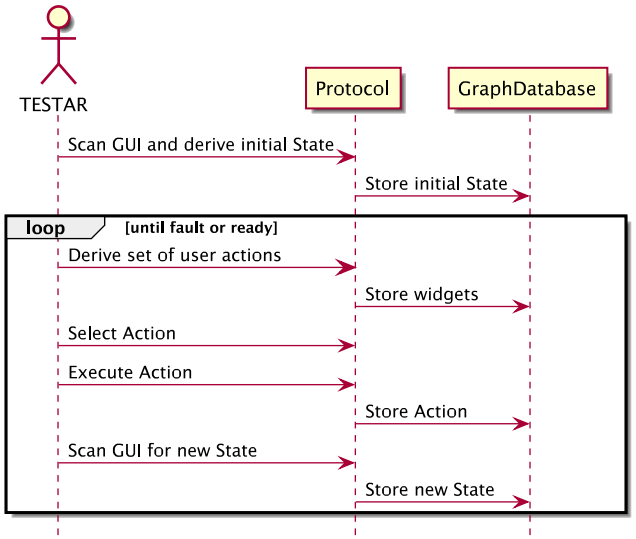


Fig. 3. Storing `State`, `Widget` and `Action` during the execution of an application in TESTAR

Now let us look at how we can define offline oracles. Below we define an offline oracle that queries information about the actions that were executed during testing.

```
1  list = G.V.has("@class","Action")
2      .map("@class","Resources",
3                    "Representation",
4                    "sequenceNumber"
5          )
6      .toList()
7  json = groovy.json.JsonOutput.toJson(list)
```

The query starts with the step `G.V` which again finds all vertices. This set is reduced by the step `has("@class","Action")` to a set of vertices of the type `Action`. The next step "maps" a filter of the indicated properties for each vertex. The result is collected in a variable `list`. In the next statement, this `list` is transformed into a JSON object. JSON was selected here since it is a standardized format which makes it easy to parse and present data (on, for example, websites). The result of this query hence is a list of JSON objects. Below we illustrate the first entry in this list:

```
1  {
2   "sequenceNumber": 0,
3   "@class": "Action",
4   "Representation": "LC (WC1szr01y3a1643044285,
5                      UIACheckBox,
6                      Regularly check VLC
7                      ) [  ]",
8   "Resources": "{userCPU:62,systemCPU: 187,..}"
9   },...
```

The property `sequenceNumber` indicates which position the given action takes in the order of executed actions on the SUT. The property `@class` indicates the type of object. The property `Representation` provides information about the Widget which was targeted by this Action, i.e. it is a Left Click (LC) on a checkbox labeled "Regularly check for VLC". Finally the `Resources` property provides information about

the state of the system at the time the Action was executed: here the CPU consumption was 62% userSpace and 187% systemSpace. Information like this can be used to get trend data on the performance of the application with respect to a given Action.

IV. Accessibility evaluation

In this section, we show how accessibility evaluation of *general* desktop software can be integrated in TESTAR. The output of TESTAR is an HTML report summarizing the results of the accessibility evaluation.

A. Accessibility standards

Various countries and organizations have formalized rules for the accessibility of digital products and services [12]. We selected WCAG 2.0 and its adaptation WCAG2ICT [3] to non-web content including software because it fulfills the following requirements:

1) It is applicable to general desktop software.
2) It contains automatable rules.
3) It is widely recognized.
4) It is not confined to one geographic area.
5) It is not bound to one group of disabilities.

Figure 4 depicts the components of WCAG 2.0 and how they relate to each other. WCAG 2.0 has a tree structure that comprises principles, guidelines and success criteria. There are four principles: Perceivable, Operable, Understandable and Robust ("POUR").

Each principle has one or more guidelines. Guidelines are basic goals that authors should achieve in order to increase content accessibility. Guidelines cannot be directly evaluated. For situations where evaluation is required, such as conformance certification, each guideline contains success criteria. Success criteria have a conformance level between A (highest) to AAA (lowest).

Not all success criteria can be fully automated. As an example, WCAG 2.0 success criterion 1.1.1 from Guideline 1.1 requires that all non-text content has a text alternative, except for special cases such as decorative content, which should not be presented to assistive technologies. To determine conformance, only a human can decide if an image like a logo is purely decorative. Therefore, the best an automated general purpose tool can do is raise a warning for images without an alternative text. Thus, accessibility experts remain indispensable for an accurate assessment.

On the other hand, desktop software often has many windows and the GUI components in these windows can have many different states. Experts will have a hard time evaluating the whole software, but automated tools can perform an extensive evaluation over night. Therefore, a (semi-)automated analysis tool can greatly increase the coverage of the experts' assessment.

B. Accessibility oracles

Oracles are mechanisms that determine whether a SUT has passed or failed a test. The accessibility oracles in this paper are based on the WCAG 2.0 success criteria. Success criteria typically have multiple requirements to meet. To make the design as modular as possible, oracles cover one aspect of a success criterion. Multiple oracles together may fully cover a success criterion.

TESTAR uses accessibility APIs to gather information about the SUT. These are the same APIs that assistive technologies, such as screen readers or magnification software, use to present the GUI. In principle, this means that TESTAR has access to the same information as assistive technologies.

We studied all accessibility rules from the WCAG2ICT and found that some cannot be automated, others are better automated with on-the-fly state oracles and others precisely with the offline graph database oracles. Consequently, we used both types of oracles in our work (see Figure 5).

Table I summarizes the WCAG2ICT guidelines and the types of associated oracles we defined (if possible).

Guideline	Description	On-the-fly	Offline
1.1	Text Alternatives	✓	
1.2	Time-based Media		
1.3	Adaptable		
1.4	Distinguishable		
2.1	Keyboard Accessible	✓	
2.2	Enough Time		
2.3	Seizures		
2.4	Navigable		✓
3.1	Readable	✓	
3.2	Predictable		✓
3.3	Input Assistance		
4.1	Compatible	✓	

TABLE I
GUIDELINES AND ORACLE TYPES

Three limitations prevented us from defining oracles for the entirety of WCAG2ICT:

1) The oracle would require actions from a human expert.
2) The oracle would require information that is not available from the accessibility API.
3) Evaluating the oracle on any GUI component would trivially lead to a pass.

A further challenge when defining oracles is that many success criteria require that all aspects of the SUT meet a certain requirement. For example, to assess keyboard accessibility, it is not generally possible to guarantee to visit all states, so unexplored parts of the SUT may still contain violations. In such cases, testing tools (including TESTAR) inherently cannot prove the absence of violations, because testing tools do not achieve full coverage of the SUT.

We next discuss if and how each of the twelve WCAG2ICT guidelines is covered by oracles.

- **Guideline 1.1 - Text Alternatives**

  Provide text alternatives for any non-text content so that it can be changed into other forms people need, such as large print, Braille, speech, symbols or simpler language.

  This guideline is covered by an on-the-fly oracle that tests for the presence of text alternatives on images. The text

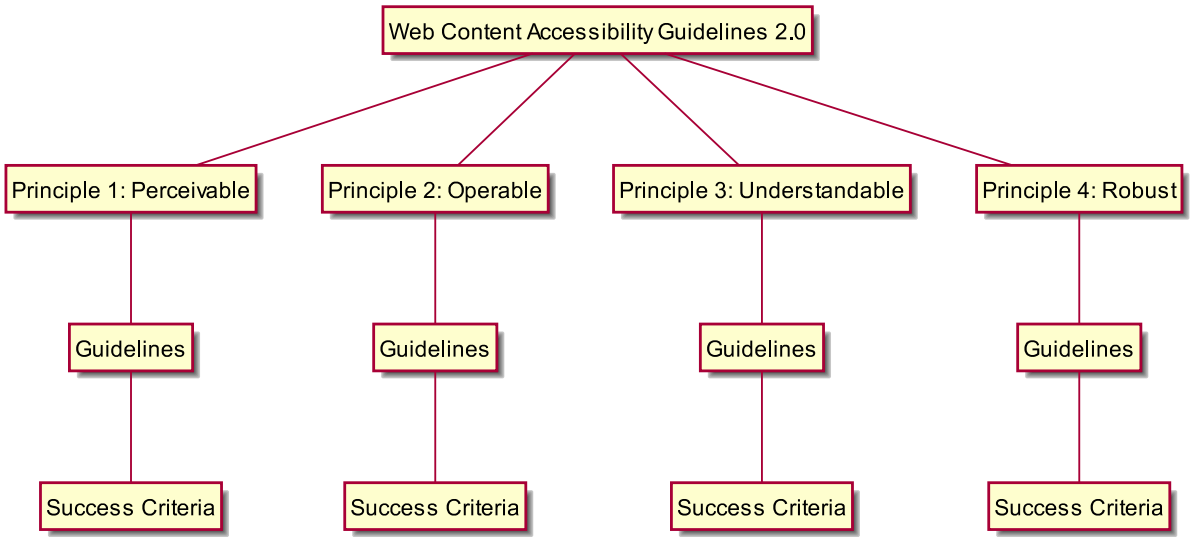


Fig. 4. WCAG 2.0 structure with principles, guidelines and success criteria

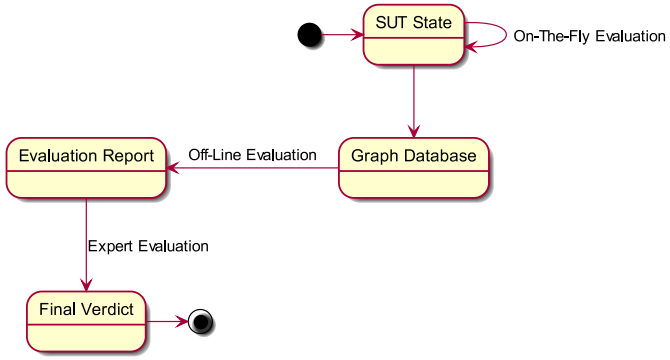


Fig. 5. Accessibility oracle types in TESTAR

alternative comes from the title of the widget as reported by the accessibility API. The oracle procedure treats an empty title as a missing text alternative.

- **Guideline 1.2 - Time-based Media**

  Provide alternatives for time-based media.

  This guideline cannot be checked with an automated oracle. It requires expertise because the information must form an equivalent alternative for the content. Determining this equivalence requires knowledge of the content and the alternative. Moreover, the presence of the alternative cannot be automatically detected, because there is nothing to programmatically distinguish it from other content.
- **Guideline 1.3 - Adaptable**

  Create content that can be presented in different ways (for example simpler layout) without losing information or structure.

  This guideline has no oracles. It requires expertise because the meaning and characteristics of information and the structural relationships must be determined. TESTAR can show the structure it can programmatically determine, but an expert is needed to link this to the actual information and structure.
- **Guideline 1.4 - Distinguishable**

  Make it easier for users to see and hear content including separating foreground from background.

  This guideline cannot be checked with an automated oracle. It requires expertise because it must be possible to control audio that automatically plays for more than 3 seconds. The presence of audio controls cannot be tested by TESTAR without specific configuration. It must be possible to pause or stop audio or to change its volume. There is nothing to programmatically distinguish such controls from other user interface components.

  This guideline also requires information that is not available from the accessibility API. Color must not be the only means to distinguish information. Besides the fact that TESTAR cannot identify the other means, the accessibility API we use also does not expose color information.
- **Guideline 2.1 - Keyboard Accessible**

  Make all functionality available from a keyboard.

  This guideline is partially covered by two on-the-fly oracles. The first oracle assesses how many widgets in a state have shortcut keys. If the ratio of widgets with shortcut keys and those without shortcut keys drops below a predefined threshold, this could indicate poor keyboard accessibility. The threshold is currently defined in the oracle procedure with a value requiring that at least one in three widgets has a shortcut key. An expert must still verify if the whole SUT is fully keyboard accessible.

  The second oracle tests for simple keyboard traps. If the same widget has keyboard focus in a number of

consecutive states exceeding a predefined threshold, this could indicate a keyboard trap. The threshold is currently defined in the oracle procedure with a value requiring that the same widget does not have focus more than five times in a row.

- **Guideline 2.2 - Enough Time**

  Provide users enough time to read and use content.

  This guideline cannot be checked with an automated oracle. It requires expertise because the amount of time and the way in which it should be provided depends on the content. Some content can be paused or hidden, while other content has adjustable time limits. TESTAR cannot determine these requirements without specific configuration.
- **Guideline 2.3 - Seizures**

  Do not design content in a way that is known to cause seizures.

  This guideline cannot be checked with an automated oracle. It requires expertise because the cause for seizures, anything that flashes rapidly or in a particular way, cannot be tested with the types of oracles we have at our disposal. Flashes can only be seen by observing a window for a period of time to see if it changes and by design, that is not how TESTAR works.
- **Guideline 2.4 - Navigable**

  Provide ways to help users navigate, find content, and determine where they are.

  This guideline is partially covered by an offline oracle that tests for ambiguous window titles. According to WCAG2ICT, the name of the software itself is a sufficient title if it describes the topic or purpose. The oracle cannot test if the titles describe the topic or purpose, since that requires interpretation from an expert, but it can find duplicate titles and warn the expert about them.
- **Guideline 3.1 - Readable**

  Make text content readable and understandable.

  This guideline is partially covered by an on-the-fly oracle that tests for missing language identifiers. The accessibility API we use exposes the locale of all widgets. The oracle procedure uses the locale on a window to determine the language and treats it as missing if the locale is equal to 0.
- **Guideline 3.2 - Predictable**

  Make non-web documents or software appear and operate in predictable ways.

  This guideline is partially covered by an offline oracle that tests for unexpected state changes resulting from keyboard input. When a user interface component receives focus, it should not initiate a state change. The oracle tests that when a widget receives focus, it does not change the state to one with a different "ConcreteID" property.

  The oracle queries the graph database for actions that should stay within the same window. To this end, we set a tag on these actions to mark them as navigating in the same window. On Windows, the actions are `Tab` and `Shift+Tab`. The other keys TESTAR tries may navigate to a different window. For example, the arrow keys typically move the cursor through text or menus and thereby stay in the same window, but they can also change to a new window if the widget they are used on triggers a window update. Tab controls are an example where each tab that is selected using the arrow keys updates the window.

  Next, the oracle filters the actions on the "ConcreteID" of the starting and the resulting state. If they are different, there was an unexpected state change. The oracle yields an error containing the window title from the resulting state.
- **Guideline 3.3 - Input Assistance**

  Help users avoid and correct mistakes.

  This guideline cannot be checked with an automated oracle. It requires expertise because the help consists of text descriptions, labels or instructions. TESTAR has access to the content, but cannot determine if it is adequate or actually helpful.
- **Guideline 4.1 - Compatible**

  Maximize compatibility with current and future assistive technologies and accessibility features of software.

  This guideline is partially covered by two on-the-fly oracles. The first oracle tests for empty widget names and the second one tests for unknown widget roles. Trivially, the accessibility API exposes the name, role and value of all widgets, thereby allowing them to be programmatically determined. Because an empty name or unknown role affects both TESTAR and assistive technologies, we regard them as errors.

C. Implementation

Our implementation extends the TESTAR protocol with new test protocols as well as classes to represent and execute the WCAG2ICT accessibility standard. Principles, guidelines and success criteria are captured by a corresponding class. The new test protocols coordinate accessibility evaluation with a particular standard. They are similar to the default test protocols in TESTAR. A protocol uses the implementation of an accessibility standard to perform on-the-fly and offline evaluation and to derive actions. A protocol receives evaluation results through classes that implement single results and a collection of results. Finally, utilities provide supporting functionality.

Figure 6 shows an example of interactions between the most important classes of our implementation. The figure visualizes the on-the-fly evaluation process. The protocol calls an accessibility standard, in this case our implementation of WCAG2ICT. This implementation recursively calls the accessibility standard as a whole, then the principles and finally the guidelines, but this is not a requirement. The accumulated evaluation results are returned to the protocol.

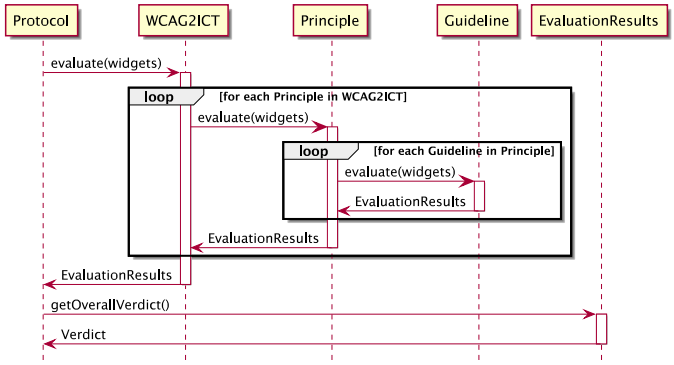


Fig. 6. Sequence diagram for accessibility evaluation with TESTAR

Below we show the implementation of an on-the-fly oracle that checks a violation of a success criterion for Guideline 3.1: Readable as described before, i.e. missing language identifiers.

```
1  public EvaluationResults evaluate(List<Widget> widgets) {
2    EvaluationResults results = new EvaluationResults();
3    SuccessCriterion sc =
4    getSuccessCriterionByName("Language of Page");
5
6    for (Widget w : widgets) {
7      if (AccessibilityUtil.isWindow(w) {
8            && AccessibilityUtil.getLanguage(w) == 0)
9        results.add(new WCAG2EvaluationResult(
10                       sc,
11                       WCAG2EvaluationResult.Type.ERROR,
12                       "Missing top-level  identifier",
13                       w)
14                 );
15     } else {
16       results.add(evaluationPassed(sc));
17     }
18   }
19   return results;
20 }
```

The method receives as a parameter the set of widgets that are currently in the state of the GUI of the SUT. After declaring some variables in lines 2-4, the method starts walking through the given widgets in line 6. If a widget is a window (line 7) and has a language identifier of 0 (line 8), then the method adds an error to the evaluation results (line 9-14). There can be multiple such results if a window has sub-windows, for example dialog boxes. When the widget is not a window or the window has a language identifier other than 0, the result is a pass (line 17). There can thus be as many passes as there are windows. The method ends by returning the evaluation results. The other on-the-fly oracles are implemented in the same way, although the types and number of properties they test differ.

Next, we illustrate the implementation of an offline oracle that formalizes a success criterion for Guideline 2.4: Navigable. Here we check that not too many windows have the same title.

```
1  private static final int SAME_TITLE_THRESHOLD = 3;
2  public EvaluationResults query(GraphDB graphDB) {
3
4    EvaluationResults results = new EvaluationResults();
5    SuccessCriterion sc =
6            getSuccessCriterionByName("Titled");
7
8    String gremlinTitleCount =
9      "_().has('@class','Widget')" +
10     ".has('"+ WCAG2Tags.WCAG2IsWindow.name()+"',true)" +
11     ".groupCount{it." + Tags.Title.name() + "}.cap";
12
13   List<Object> titleCounts =
14     graphDB.getObjectsFromGremlinPipe(
15     gremlinTitleCount, GremlinStart.VERTICES);
16
17   Map<String, Long> titleCount =
18     (Map<String, Long>)titleCounts.get(0);
19   boolean hasViolations = false;
20   for (Entry<String, Long> entry: titleCount.entrySet()){
21     if (entry.getValue() > SAME_TITLE_THRESHOLD) {
22       hasViolations = true;
23       results.add(new WCAG2EvaluationResult(
24         sc, WCAG2EvaluationResult.Type.WARNING,
25         "Possible ambiguous title \"" + entry.getKey() +
26         "\" appeared " + entry.getValue() + " times"));
27     }
28   }
29   if (!hasViolations) {
30     results.add(evaluationPassed(sc));
31   }
32   return results;
33 }
```

The method receives as a parameter the graph database that contains all the stored information about the executed tests till now. After declaring some variables in lines 4-6, the method starts defining a Gremlin query in a string on line 8-11. The query starts by selecting all vertices that are widgets (line 9) and that have the `WCAG2IsWindow` property set (line 10). These widgets are windows. The widgets are grouped (line 11) by their `Title` property. The result of executing this query on lines 13-15 is a map of titles and the number of times they appear in the graph database. The method then loops through these counts (line 20-27). Any count above a predefined threshold is a warning (line 21) because it means that titles are duplicated and hence ambiguous. If all titles have been tested and there were no warnings, the result is a pass (lines 29-30). The pass means that the query yielded no violations, so there is a single pass for the whole method instead of a pass for every title count that is below or equal to the threshold. The method ends by returning the evaluation results.

V. Case Study: The VLC Media Player

In this section, we provide a case study on the popular VLC Media Player[8] as a preliminary validation of the effectiveness of the solutions described in Section III and Section IV.

VLC has a very rich user interface with a large number of different user interface components. This results in a realistic load on the graph database, and a challenging case study for the accessibility evaluation. We discuss the expressiveness and performance of the graph database integration, and show the results from the accessibility evaluation.

A. Expressiveness

TESTAR currently outputs test data results in multiple files and in various different formats, as we shall discuss below. Due to the heterogeneous formats, this is not amenable to queries. The graph database solution offers a uniform, queryable data format. This allows queries to use *all* information

[8]https://www.videolan.org/

Log artefact	Description
sequence⟨number⟩	Log file containing detailed information about the actions executed in the sequence
sequence⟨number⟩_clusters	presents information about how actions and states are clustered
sequence⟨number⟩_curve	presents statistics per action
sequence⟨number⟩_stats	presents overall statistics for the sequence
sequence⟨number⟩_testable	presents detailed information about the executed actions

TABLE II
TEST DATA OUTPUT IN LOG FILES

captured during testing. Furthermore, it allows to write oracles that use multiple states encountered during test execution (since all of the encountered states can be stored). This was key for the definition of the accessibility oracles (see Section IV)

An important question to investigate is whether the graph database solution is sufficiently expressive to obtain the information previously gathered from the TESTAR log files. For each sequence, TESTAR stores 5 types of output files. Table II lists these types.

In Section III-B we showed a query that can retrieve the information present in log artefact sequence⟨number⟩ from Table II.

The information in the log artefact sequence_clusters⟨number⟩ from Table II can be retrieved using queries below:

```
1  list1 = G.V.has("@class","AbsState")
2       .in.groupBy{it.Abs_R_ID}{it.ConcreteID.next()}
3       .cap.next()
4  json1 = groovy.json.JsonOutput.toJson(list)
```

```
1  list2 = G.V.has("@class","AbstractAction")
2       .in.groupBy{it.AbstractID}{it.ConcreteID.next()}
3       .cap.next()
4  json2 = groovy.json.JsonOutput.toJson(list)
```

Both of these queries have the same structure. The first step provides the set of all vertices. In the next step, the set of vertices is reduced by applying the step `has("@class","AbstractState")` or `has("@class","AbstractAction")`. These steps result in a set of `AbstractStates` or `AbstractActions`. For each set the incoming `Edges` are grouped by the abstract id resulting in list of abstract id's combined with the concrete id's of the elements that share the `concreteID`.

The information found in the log artefact sequence_curve⟨¡number⟩ cannot be retrieved from the graph database. The artefact contains statistic information which is collected at the end of each `Action` execution. A solution would be to model this data as a set of properties on the "execute" Edge.

The information in the log artefact sequence_stats⟨number⟩ can partially be retrieved through queries on the model in the graph database. The number of unique states, unique action, abstract states and abstract actions can simply be found with a query that counts the vertices of these types. For example, the following query counts the unique actions:

```
G.V.has("@class","Action").count()
```

The information in the log artefact sequence_testable⟨number⟩ can be retrieved easily since all information is available starting from an `Action` vertex.

B. Performance

To assess the performance impact of the graph database integration, we measure two resources:

1) The time it takes to store data into the database
2) The amount of disk space required

Measurements are done with a micro benchmark using JMH[9], and an application benchmark with VLC. The measurements were carried out in a controlled (virtual) environment whose properties can be found in Table III.

Property	Value
Operating system	Window 10 64-bit
Number of CPUs	2
Memory	4 gigabyte
Disk size	32 gigabyte[10]

TABLE III
PROPERTIES OF THE VIRTUALBOX INSTANCE USED FOR TESTING

Table IV shows the setup configuration of JMH microbenchmarks.

Setting	Description	Value
Warmup	Number of iterations executed before the measurement starts. This is needed to minimize the impact of the JVM	30
Fork	The number of times the test is executed. Each time the test is started from scratch.	10
Measurement iterations	The number of times the test is executed within one fork	10
Measurement time	The time an iteration is allowed to last	1
Measurement timeUnit	The time unit in which the execution of the test is measured	TimeUnit.Milliseconds
BenchmarkMode	Type of benchmark which is executed. SampleTime, Throughput, AverageTime and SingleShot	SampleTime
OutputTimeUnit	Time unit to present the result	TimeUnit.Milliseconds

TABLE IV
CONFIGURATION OF JMH BENCHMARKS

a) Performance benchmarks: We have executed the following six benchmarks:

- **AddSateBenchmark.testAddState**: how long does it take to store a `State`
- **AddSateBenchmark.testAddStateTwice**: how long does it to update a `State`
- `AddActionBenchmark.testAddSingleAction`: how long does it take to store an `Action` in the database that is applied on a `Widget`

[9]openjdk.java.net/projects/code-tools/jmh

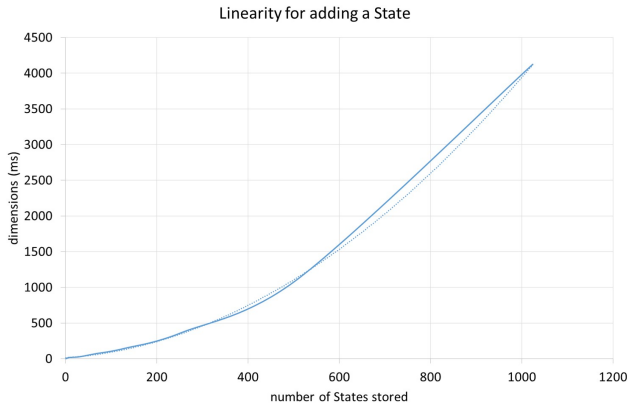


Fig. 7. Linearity for adding a state

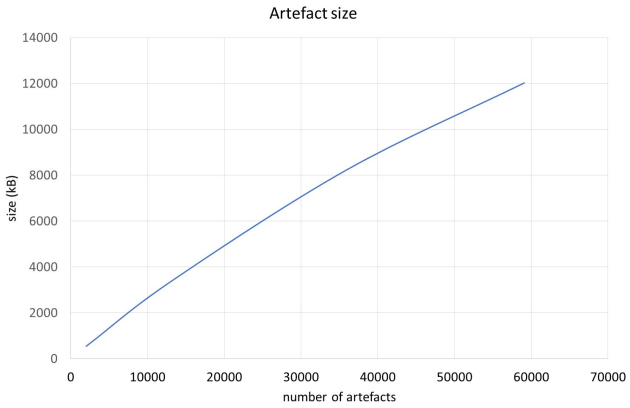


Fig. 8. Disk usage versus the number of artefacts

- **AddActionOnStateBenchmark.testAddSingleAction**: how long does it take to store an `Action` in the database this is applied on a `State`
- **AddWidgetBenchmark.testAddSingleWidgetToState**: how long does it take to store an `Widget` in the database
- **Linearitybenchmark.testAddStateLiniairity**: what is the impact of adding new states to an existing database already containing states.

Table V shows the average results over 100 measurements using the JMH SampleTime mode.

The simplest operation of the module `graphdb` is `addState`. It is expected that this operation takes the least amount of time, and the results in Table V confirm this. Adding a state twice does not require double the amount of time, since the second add operation only requires a lookup. The operation `addSingleAction` takes longer. This operation requires to additional lookups for a vertex compared to the operation `addState`. The operation `addSingleWidgetToState` takes longer as the operation `addSingleAction`. Although the operation `addSingleWidgetToState` requires less lookups, the operation adds an edge to three abstract vertices. an Action only has one abstract type. The `linearitybenchmark` shows the time required to store multiple states. Figure 7 plots the results. The formula $y = 0.0035x2 + 0.4295x + 15.922$ is a close fit ($R = 0.9999$) and shows that storing a state has polynomial behaviour.

The error shown in Table V is relatively large. In order to pinpoint the cause of the error, we repeated the test with an in-memory database. Although the average execution time will be lower, as expected, the error in these measurements is even higher. The most likely cause is that OrientDB has unpredictable execution time.

b) Disk Space usage benchmarks: OrientDB uses the local file system to store the data. Knowledge about how this data is structured, is important to understand how disk space will grow as more data gets recorded. Table VI lists the type of files that play a role in the discussion presented in this section. It is expected that the disk space will have a certain minimum value to store the minimum required data for OrientDB to work. The usage will increase as more data is entered in the database. In order to see how the database will grow, we executed a series of TESTAR runs with an increasing number of action steps in each run.

Figure 8 and Table VIII present the results of the measurements which were measured running TESTAR against VLC. The artefact size information is retrieved through the database console command "LIST CLUSTERS". The size information retrieved through this command deviates from the total size on disk which was measured using standard tools from the operating system. The size on disk is much larger than the size of the artefacts as presented by OrientDB. One of the objects stored on disk which introduces this overhead is the *.wal file. This is the "write ahead log", a log file that is used for recovery when OrientDB crashes. The write ahead log can take up a large amount of data. Especially the database with the results of the run with 5,000 samples suffers from this overhead. This database was used extensively to perform queries. The folder created by the database always contains a file name `OFunction.name.hib`. Table VII shows the results when we correct the disk usage for this overhead.

Figure 8 shows the required disk space in relation to the number of artefacts stored. From this figure it looks as if the growth can assumed to be linear.

We can conclude that the introduction of the graph database adds between three and five kilobytes of data to the required disk space for TESTAR for each artefact (Edge or Vertex) stored in the database. A test with 10,000 action steps adds 12,000 kilobyte of data. The required disk size to store this data is bigger, and depends for instance on caches and indices.

C. Accessibility

To validate the effectiveness of our accessibility oracles, we first manually evaluated the accessibility of VLC. This was done by one of the authors of this paper. This author is considered an expert on accessibility since he himself is blind and, being a computer scientists, heavily uses assistive and accesible technologies. We then applied TESTAR and it's

Benchmark	Iterations	Time (ms)	Error (ms)
AddActionBenchmark.addSingleAction	N/A	8.367	1.691
AddSateBenchmark.testAddState	N/A	6.138	1.053
AddSateBenchmark.testAddStateTwice	N/A	9.331	1.347
AddWidgetBenchmark.addSingleWidgetToState	N/A	12.064	2.102
Linearitybenchmark.testAddStateLiniairity	1	0.001	0.001
Linearitybenchmark.testAddStateLiniairity	2	5.580	0.982
Linearitybenchmark.testAddStateLiniairity	4	10.088	1.719
Linearitybenchmark.testAddStateLiniairity	8	18.634	4.168
Linearitybenchmark.testAddStateLiniairity	16	20.883	3.544
Linearitybenchmark.testAddStateLiniairity	32	29.493	3.996
Linearitybenchmark.testAddStateLiniairity	64	68.794	4.890
Linearitybenchmark.testAddStateLiniairity	128	144.181	8.622
Linearitybenchmark.testAddStateLiniairity	256	371.196	11.297
Linearitybenchmark.testAddStateLiniairity	512	1131.214	29.199
Linearitybenchmark.testAddStateLiniairity	1024	4124.888	126.170

TABLE V
RESULT OF THE BENCHMARK PERFORMED WITH JMH.

Part	Extension	Description
Clusters	*.pcl *.cpm	Files that contain the data (*.pcl) and files containing the mapping between a record's cluster and the real physical location
Write ahead (operation) log	*.wal	Log file containing all storage actions used for recovery in case of a crash
Hash index	*.hib	Hashes for the functions implemented by OrientDB

TABLE VI
MAIN PARTS OF THE ORIENTDB DATA STRUCTURE ON DISK

Scenario	OFunction .name .hib	*.wal	original disk usage	corrected disk usage
100	16,385	4,352	29,389	8,652
1,000	16,385	28,096	56,934	12,453
5,000	16,385	78,720	113,664	18,559
10,000	16,385	3,136	59,068	25,433

TABLE VII
DISK SPACE USED BY ORIENTDB IN KB (CORRECTED)

Scenario	Artefact size	corrected disk usage	Artefacts	Size per action
100	546	8,652	2,041	86.52
1,000	3,102	12,453	13,231	12.45
5,000	8,232	18,559	35,936	3.72
10,000	12,021	25,433	59,068	5.91

TABLE VIII
MEASURED DISK USAGE IN KB FOR TESTAR RUNS WITH AN INCREASING NUMBER OF ACTIONS

new WCAG2ICT protocol to test VLC and validate the added value that TESTAR provides to accessibility experts.

a) Manual evaluation: The main method experts use to assess accessibility is to identify and evaluate one or more typical usages in a system. Additionally, to verify that such a structured sample is adequate, it is also important to select a a random sample. This is roughly the approach suggested in Website Accessibility Conformance Evaluation Methodology (WCAG-EM) [13], an evaluation methodology for web accessibility that accompanies WCAG 2.0.

We chose to define and evaluate five key and typical uses of a media player. The five processes that we chose to manually evaluate in VLC are:

1) Opening a media file and starting playback
2) Pausing and resuming playback
3) Skipping in a media file
4) Getting information about a media file
5) Changing preferences

For the evaluation we then used the free, open source Windows screen reader NVDA[11] version 2017.4.

Process	Description	Evaluation Time[12]	Errors
1	Open and play	5 minutes	0
2	Pause and resume	15 minutes	5
3	Skip	5 minutes	2
4	Get information	10 minutes	5
5	Change preferences	15 minutes	6
Total		50 minutes	18

TABLE IX
ERRORS FOUND AND TIME SPENT IN MANUAL ACCESSIBILITY EVALUATION OF VLC

Guideline	Description	Errors
2.1	Keyboard Accessible	10
3.3	Input Assistance	1
4.1	Compatible	7
Total		18

TABLE X
ERRORS FOUND IN MANUAL ACCESSIBILITY EVALUATION OF VLC

Table IX and Table X summarize the results of the manual accessibility evaluation.

b) Automated evaluation: Next, we used the automated accessibility evaluation with TESTAR as described in Section IV. We set up TESTAR to use the random action selection algorithm and sequence lengths varying between 50 and 250 actions. After the evaluation finishes, TESTAR generates an HTML accessibility report summarizing the results. For space reasons, below we show an excerpt of such a report.

Example Accessibility Evaluation Report

- Sequence number: 1

[11]https://www.nvaccess.org/

- Unique states with violations: 6
  State: SC1o5dzzy307482039866
- Issues:

Type	Count
Error	20
Warning	2
Pass	76
Total	98

- Screenshot:Open in a new window
- Violations (on-the-fly evaluation)

Type	Criterion	Level	Widget	Message
WARN	1.1.1 Non-text Content	A	Possible missing text alternative	
WARN	2.1.2 No Keyboard Trap	A	N/A	Possible widgets missing shortcut keys
ERROR	3.1.1 Language of Page	A	VLC media player	Missing top-level language identifier

- Offline evaluation

Type	Count
Error	0
Warning	0
Pass	2
Total	2

To validate the quality of the evaluation results, we chose the evaluation report from the run with 150 actions. With 66 errors and 14 warnings (80 total violations), this provides a good balance between report length and detail. The run took 131 seconds, counted from the first to the last timestamp in the debug log file. On average, this means that TESTAR found a violation every 1.64 seconds.

Table XI summarizes the evaluation results. The **Total** column shows the total number of violations. The **False Positives** and **Outside VLC** columns show how many violations, both warnings and errors, were false positives (inside the SUT) or were outside VLC altogether. The **Verified Errors** are the remaining errors after subtracting false positives and violations outside VLC from the total.

Table XII compares the number of verified errors from TESTAR to the number of errors that we found when manually evaluating VLC. Both tables only show WCAG2ICT guidelines for which we and/or TESTAR found results.

To summarize, with our help TESTAR found 30 verified errors in half an hour, an error each minute on average. However, TESTAR can only evaluate certain accessibility rules, whereas an expert can evaluate all the rules in an accessibility standard. TESTAR is effective at finding errors for rules that it can unambiguously evaluate. On the other hand, TESTAR did not find some errors that were immediately apparent during manual evaluation, such as the inability to navigate through widgets in the main window of VLC using the keyboard. TESTAR can support an expert in finding technical violations such as widgets without a name, where an expert may miss a few widgets if there are hundreds to evaluate. Such technical evaluation tools for websites have existed for years and now TESTAR brings similar features to the desktop.

VI. Conclusion

In this paper we have introduced offline oracles, i.e. oracles that are executed after testing has been completed. Our offline test oracles consist of database queries on the data that has been stored during test executions. Furthermore, we have used this database and the queries to formulate oracles that test different accessibility properties of desktop applications. We have implemented these in the TESTAR tool and we have evaluated their performance and effectiveness. We have found that TESTAR support is affordable and valuable for an expert in finding technical accessibility violations: TESTAR discovered 30 verified errors in 30 minutes, whereas the expert manually found 18 errors in 50 minutes. Accessibility evaluation tools for websites have existed for years and now TESTAR brings similar features to the desktop. Due to space reasons, we could not include the full tool description and results of the case study. These are available in an extended version on the TESTAR website[14].

The TESTAR tool has a growing open source community and interesting future work lies ahead. An important aspect of the graph database and the information we store in it is the abstraction level. What does it mean that states and/or actions are equal? What level of abstraction is appropriate for different oracles? Besides that, we might want to store information available in the test environment into the database. This way information about unexplored states and the exploration curve can be retrieved. Furthermore we need to evaluate more desktop software with the accessibility oracles to get more insights into the level of support that is offered to the tester. And to go beyond accessibility to see in what other application areas offline oracles can be useful.

Acknowledgements

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Criterion	Description	Total	False Positives	Outside VLC	Verified Errors
1.1.1	Non-text Content	11	0	10	1
2.1.1	Keyboard	3	0	2	1
2.1.2	No Keyboard Trap	0	0	0	0
3.1.1	Language of Page	1	0	0	1
4.1.2	Name, Role, Value	65	12	26	27
Total		80	12	38	30

TABLE XI
VIOLATIONS FOUND IN ACCESSIBILITY EVALUATION OF VLC WITH TESTAR (150 ACTIONS)

Guideline	Description	Verified TESTAR Errors	Manual Errors
1.1	Text Alternatives	1	0
2.1	Keyboard Accessible	1	10
3.1	Readable	1	0
3.3	Input Assistance[13]	N/A	1
4.1	Compatible	27	7
Total		30	18

TABLE XII
ERRORS FOUND IN MANUAL ACCESSIBILITY EVALUATION OF VLC COMPARED TO TESTAR (150 ACTIONS)

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Fuzzy4U: A fuzzy logic system for user interfaces adaptation

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***Abstract*— Adapting User Interfaces to various technological devices is most often than not a part of human-computer interaction requirements. Although many studies addressed this topic some challenges remain, such as context uncertainty and combination of adaptation rules. This article represents an attempt at tackling these challenges, using fuzzy logic to handle adaptation. It proposes an architecture where an adaptation engine is supported by both fuzzy logic and Boolean logic, and illustrated by a prototype. The relevance of such approach has been studied through a theoretical comparison and an experiment including eight experts.**

Keywords—HCI adaptation, context of use, fuzzy logic, uncertainty, rules

I. INTRODUCTION

Adapting user interfaces (UI) based on their context of use, characterized by the triplet <user, platform and environment> [1], is a well-known requirement in Human Computer Interaction (HCI) design processes. It involves dynamically modifying an interface so that it responds more precisely and specifically to each and every user's needs and expectations. Nevertheless, this change ought to consider the constraints given by the device used for this interaction (i.e. the platform) and the environment in which this interaction ought to take place.

Nowadays, many studies on adaptive user interfaces can be found in the literature [2, 3, 4, 5, 6]. However, several scientific challenges remain, especially when the ability to *adapt* includes user considerations as well as the platform and environment [7, 8, 9]. This implies 1) the identification of the diverse users' characteristics and 2) the definition of how to integrate them in the calculation of the solution. Difficulties exist concerning both facets.

First of all, providing fine-grain adaptation requires to have a fine-grain vision of the context and therefore to consider a large number of characteristics. Focusing on the user, the cluster Virtual User Modeling and Simulation (VUMS) has identified more than 250 useful characteristics to model a human user [10]. However, this model does not cover all requirements, since it focuses mainly on physical abilities [1, 11].

A second challenge relies upon the uncertainty on characteristics values, in particular for those related to users. Every value, whether they are captured (e.g. due to a potential lack of accuracy of sensors or in the inference) or declared (e.g. because of different perceptions by various users, personal estimation of the values) may not be certain. This uncertainty is usually disregarded [1, 11, 12, 13, 14].

Once the context has been modeled, the adaptive system still has to calculate the necessary UI adaptations according to the current context. Classically, this calculation is performed by the way of *rules*. There are different approaches to express these adaptation rules, such as models transformations in model-driven engineering [15], design patterns [11] or the development of precomputed solutions where one of these solutions is chosen according to logical rules [16].

The potentially huge amount of context characteristics may lead to the definition of complex and competitive rules that, in turn, can induce a combinatorial issue. Rules might indeed need to be combined. For instance, several of them can impact the font rendering (font type, spaces between characters and words according to dyslexia, font color according to color perception, and so on). They can also compete with each other (e.g. increasing the font size when the user has poor visual acuity while decreasing it when the display surface is small). Classic methods to choose a rule among a set of possible rules exist, such as weights [17].

A more interesting method would be to reach a compromise between all the rules. The large number of potential solutions for this approach opens a new issue: the combinatorial explosion [18], i.e. the difficulty to handle the multiplicity of possible compromises and make a choice among them. This combination may lead to performance issues [19].

This article proposes a solution based on fuzzy logic in the calculation of UI adaptations. It suggests expressing the UI adaptation rules in this formalism. It presents a comparative analysis of the results obtained from a fuzzy logic engine as well as from a more traditional approach in Boolean logic, accompanied by expert opinions. This article represents an extension of previous works [20] published in French. Which focused more on a comparison between Boolean and fuzzy logics and gave less details on the experimental part of the work (prototype and experts' feedback).

This article is structured as follows. Section II presents the current state of the art in UI adaptation. Section III introduces the basic concepts of fuzzy logic. Section IV shows the architecture of the demonstrator and its extension to fuzzy logic with the expected benefits. Section V describes the fuzzy rules used, their comparison with the pre-existing Boolean rules and presents the opinion of experts on this subject. The article ends with a summary of the work and perspectives.

II. STATE OF THE ART

A. Related Work

The state-of-the-art is based on the study of two kinds of studies: articles dealing with UI adaptation and those using fuzzy logic. There are many studies dealing with adaptation to the context of use. Only the most representative will be discussed here.

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Cameleon [1] is a reference in model-based approaches. It promotes the dynamic generation of UIs adapted from models to their context of use. It is based on a process of reification within four levels of abstractions: tasks model, abstract UI, concrete UI and final UI. Theoretically, all contextual characteristics may be considered. However, in reality, just a few are presented. The uncertainty of their values is not mentioned. The adaptation rules represent model transformations applied conditionally depending on the context of use. Rules should be mutually exclusive, which is particularly complex to achieve, for example when two characteristics should induce antagonistic adaptations.

"Adaptation Integration System" [7] is a first example based on Cameleon. It aims to integrate requirements of accessibility for people with disabilities and includes the adaptation rules in the development process. Nonetheless it uses few and predefined characteristics.

Maria [12] is a model-based user interface description language that allows for dynamic UI generation adapted to the different platforms used by each user during a migration process. The article focuses on the platform aspect of the context of use.

Cedar [13] provides an architecture that facilitates the development of adaptive UI within an enterprise resource planning (ERP), built on role-based simplifications. Cedar creates effective adaptations, but in a controlled environment.

[14] defines a 3-layer architecture for the conception of adaptive UI. Adaptation targets *smart environments* and is based on the context of use. The data used are directly read from sensors (e.g. localization systems, temperature sensors, e-health devices) without managing uncertainty. These sensors mainly focus on the environment and the adaptation process is limited to a certain scope defined at the design time.

MyUI [11] is a UI development infrastructure to improve accessibility through the adaptation of users' needs. The adaptation rules are managed thanks to design patterns and their combinations are handled manually during conception. MyUI lists a large number of user characteristics (e.g. contacts information, personality, emotional/physiological/mental states, nutrition, facial expression). However, these characteristics are mainly declared, and MyUI defines the different states of a characteristic through fixed thresholds. In terms of rules, MyUI focuses on improving accessibility for specific disabilities.

Supple [21] supports the automatic generation of UI tailored to the user's abilities, devices, tasks, and preferences. Visual and motor abilities represent the main user characteristics supported during the adaptation. Forty user interface factors (e.g. font size) are endorsed to optimize the layout of the UI elements. While slightly outside our research space, it has been noted in [11] that the performance of Supple proves problematic because it exceeds a reasonable calculation time; this would be even truer in the case of a complex combination of rules.

[19] examines the use of Machine Learning to adapt UI to the context of use, mainly in order to optimize user interactions and limit their errors. Machine learning makes it possible to manage complex and uncertain data, and to calculate complex inferences from them. However, such an algorithm also requires gathering a substantial knowledge dataset before it can offer adaptations that can improve the user experience. In addition, while the article presents potential applications, none were implemented.

A selection of studies relying on fuzzy logic to support adaptive systems can also be gathered from the literature:

FSAM [22] is a tool based on fuzzy logic allowing choosing the service that is most suited to a user according to one's context of use. This study is however limited to a choice between predefined services and does not address any HCI issues.

[23] proposes a fuzzy logic approach for the development of adaptive mobile applications, supporting the diversity of mobile platforms (hardware, OS, API, etc.) and the performance capabilities of each platform. The user is not considered, limiting the number of characteristics and their uncertainty factor.

[24] presents a tool making it possible for car drivers and passengers to develop applications thanks to a vocal interface. Fuzzy logic is used to calculate the level of expertise and concentration of the user: beginner, intermediate, or advanced. Each level leads to a higher or lower level of options and information provided. The system relies on 7 fuzzy rules that consider 10 characteristics (number of applications created, number of requests for help, number of oaths, …) to calculate a single output: the level of expertise. This use of fuzzy logic does not correspond to our requirements in terms of adaptation rules because of the small number of characteristics used in input, their lack of uncertainty (e.g.: the amount of help requests is increased when the user asks for help), and the manual handling of the rules' combination.

[25] presents another approach in fuzzy logic that addresses webpage adaptation to improve user experience. This work is based on use cases, presenting seven of them (e.g. Place an order, Perform a search, ...). Data are inferred from the users' behaviors, thus limiting the size of the user model and the set of adaptation rules possible. It does not address the question of rules combination that seems central to UI adaptation.

[26] proposes a fuzzy logic-based HCI adaptation mechanism that considers three cognitive user factors defined by [27]: "Verbal / Imager" dimension, "Analyst / Wholist" dimension, and working memory capacity. Each of these aspects has specific implications in terms of design. As a result, this work only manages a small number of characteristics. The approach also includes manual management of the composition of rules, which limits the power of the system and its ability to handle unexpected situations.

Finally, [28] presents an approach for HMI customization using fuzzy logic based on semantic relationships between UI components and user preferences to select the most suitable components. The case study presented gives only one rule - having two inputs and one output - and the combination between the entries has been handled manually within the rule. This work does not consider aspects that seem important to us, such as the extent of the context of use and the combination of rules.

B. Analysis

Our analysis of existing studies was based on criteria relating to the difficulties identified to achieve an adaptation engine. Thus they concerned: 1) the extent of the context of

use considered in terms of coverage of the three aspects (user, platform, environment), 2) the number of users' characteristics addressed to give clues about the management of a few or numerous uncertainty characteristics, 3) the management of uncertainty within the values of the characteristics of the context of use, 4) the complexity and 5) the combination of adaptation rules.

Table 1 presents the experimental aspects of the previously mentioned studies, with Harvey's balls.

Based on said criteria, the works going from Cameleon to Supple can be organized (cf. beginning of Table 1). Indeed, all of them deal with dynamic adaptation according to a context of use of varying size (thus including a greater or lower number of characteristics). However, none of these studies address the rest of our criteria: uncertainty, rules complexity, or combination.

Papers [22, 23, 24, 25, 26, 28] use fuzzy logic and consider values uncertainty. In [22, 23], the composition of rules was managed by fuzzy logic, but the lack of an extensive context of use limited the contribution. None of these pieces of work clearly addressed the issue of rules combination.

Finally, the paper from Genaro Motti [19] had the best overall ratings, with 4 of our 5 criteria fulfilled. However, the use of Machine Learning required an important knowledge - difficult to acquire and maintain - before offering adaptations that effectively meet users' needs.

In order to overcome the limits of existing studies and to propose a solution that makes it possible to manage context uncertainty, many characteristics and adaptation rules at the same time, we investigated the possibilities offered by a UI adaptation system based on fuzzy logic. This solution goes beyond existing proposals in fuzzy logic by taking an interest in the complexity of rules and their combinations.

TABLE 1: COMPARISON OF STATE OF THE ART WORKS ACCORDING TO TARGETED CRITERIA

Approaches	Scope of the context of use	Quantity of user characteristics	Uncertainty	Complexity	Combination of rules
Cameleon [1]a	●	◐	○	○	◐
Minon [7]	●	◐	○	○	◐
MyUI [11]	●	●	○	○	◐
Maria [12]	◐	○	○	○	○
Cedar [13]	◐	◐	○	○	○
3-layer architect. [14]	●	○	○	○	○
Supple [21]	◐	◐	○	○	○
FSAM [22]	◐	◐	●	○	◐
Desruelle [23]	○	○	●	○	◐
Cueva-Fernandez [24]	○	○	●	○	○
Nyongesa [25]	◐	◐	●	○	○
Papatheocharous [26]	○	◐	●	○	○
Soui [28]	○	○	●	○	○
Genaro Motti [19]	●	●	●	○	●

●: treated, ◐: partially treated, ○: not treated

III. FUZZY LOGIC

In order to understand the use of fuzzy logic for UI adaptation, this section details its principles and inferring process.

A. *Fuzzy Expert Systems*

Fuzzy expert systems are expert systems based on fuzzy logic. Fuzzy logic can be viewed as an extension of classical logic, which allows to handle uncertainty: whereas classical logic deals only with two values (true and false), fuzzy logic considers an infinite number of real values between 0 and 1. This type of logic was introduced by Zadeh [29] in order to get closer to the human reasoning and to avoid the threshold effects pertaining to classical logic approaches. The particularity of fuzzy expert systems is that rules can be written in a syntax close to natural language.

B. *Concept of Fuzzy set and Linguistic Variable*

Fuzzy logic is based on the concept of fuzzy sets. Let X be the universe of discourse, i.e. a collection of objects denoted x. A fuzzy set A of X is totally characterized by a function μ_A:X→[0;1], called *membership function*. This function indicates how much an object x belongs to X. In crisp sets, an object does or does not belong to the set. Fuzzy sets are useful to describe imprecision or uncertainty. Fig. 1 represents a fuzzy set defines on [0;10] with a triangular membership function and which can symbolize "approximately 5". Membership functions can have different shapes (e.g. instance triangular, trapezoidal, Gaussian, or Bell functions).

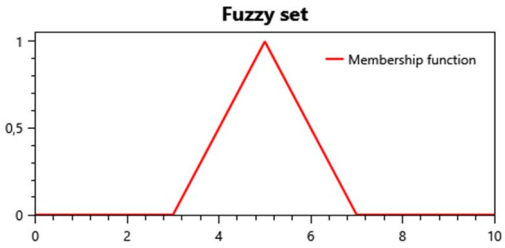


Fig. 1: Example of fuzzy set

The next concept in fuzzy logic, called linguistic variable [30], It corresponds to a triplet (V, X, T_V) where:

- V is the name of the linguistic variable,
- X is the domain on which it is defined (e.g. $\mathbb{R}$ or [0,10]),
- $T_V = \{T_1, T_2, \dots\}$ is a finite collection of fuzzy sets called terms which qualify V (e.g.: "cold", "hot").

Each fuzzy set T_i of T_V is associated with a name and is called linguistic term. Fig. 2 shows a linguistic variable called "temperature" with three terms ("cold", "medium", "hot") and their membership functions, defined on [-20, 50].

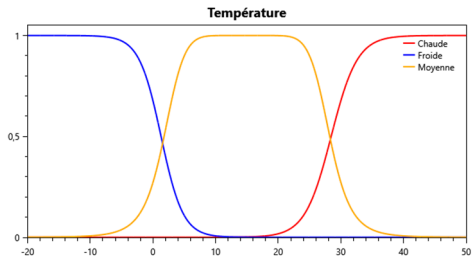


Fig. 2: Example of a linguistic variable "temperature"

C. *Fuzzy Rules to Model Expert Knowledge*

Previous definitions were used to formalize human reasoning through a set of rules. These rules depend on a combination of elementary fuzzy propositions. An elementary fuzzy proposition is the definition of "V is A" from a linguistic variable (V, X_V, T_V) where A is a term of T_V. For instance, if one used the linguistic variable "temperature" of Fig. 2, a fuzzy proposition could be "temperature is cold". It is evaluated from its membership function μ_{cold}: for a particular temperature t, the truth-value of the proposition "temperature is cold" is given by $\mu_{cold}(t)$. The truth-value of a fuzzy proposition belongs to the interval [0, 1] in $\mathbb{R}$ unlike classical logic where the truth-value of a proposition would be either 0 (false) or 1 (true).

A fuzzy expression stands for a composition of a set of elementary fuzzy propositions or other fuzzy expressions. The composition is created by selecting logical operators: negation (not), conjunction (and) and disjunction (or). The exclusive or (xor) is not usable.

Fuzzy propositions can be viewed as a special case of fuzzy expressions. For instance, let two fuzzy propositions be "V is A" using (V, X_X, T_X) and "W is B" using (W, X_W, T_W). Thus, "V is A and W is B", "V is A or not W is B" are fuzzy expressions. The truth-value of a fuzzy expression is given by the application of all the operator functions on the values of their operands.

There are different formulations of conjunction and disjunction operators, but they all have to fulfill the properties of respectively triangular norms and triangular co-norms. A triangular norm (t-norm) is a commutative, associative, monotonic function $\top: [0;1] \times [0;1] \rightarrow [0;1]$ which accepts 1 as neutral element. A triangular co-norm (t-co-norm) is a commutative, associative, monotonic function $\perp: [0;1] \times [0;1] \rightarrow [0;1]$, which accepts 0 as neutral element. For instance, Zadeh's norm is the minimum function and Zadeh's co-norm is the maximum function.

The negation operator is a function $N: [0;1] \rightarrow [0;1]$, which generally associates to a fuzzy value n the value 1-n.

The expressions are used to express the knowledge of an expert as fuzzy rules. A fuzzy rule is composed of a premise (also called antecedent) and a conclusion (also called consequent) in the form "IF premise THEN conclusion".

A premise is a fuzzy expression and a conclusion is a fuzzy statement which value can be of different nature. There are two different types of rule conclusions and fuzzy rules: 1) A conclusion can be a fuzzy proposition. Then, the template of a fuzzy rule becomes "IF temperature is low THEN sweating is low". 2) A conclusion can be a mathematical function of the inputs of the premise. These rules are called Takagi-Sugeno fuzzy rules and their template is "IF temperature is low THEN sweating=f(temperature)."

The rules are mapping the inputs to the outputs of the system regarding a fuzzy implication function.

The THEN part of fuzzy rule denotes a fuzzy implication function I such as $I: [0;1] \rightarrow [0;1]$ that performs on two fuzzy values. It verifies the properties of the implication operator in classical logic when the two operands equal 0 or 1.

The implication operator in classical logic states that either we do not have the antecedent or we have the consequent. There are different formulations of fuzzy implication function inspired from multi-valued logic. Some conjunctive functions, which make it possible to use both inputs and outputs, can be used instead of the implicative functions. That is the case for the well-established Mamdani fuzzy rules that make use of the minimum function.

D. *Fuzzy Inference*

Now that the basics of fuzzy logic have been introduced, we can focus on the process of inference in fuzzy expert systems. In the previous section, we introduced how rules work on their own. In this section, we present how rules work together to compute the outputs and thus process the inference. In the remainder of this paper, we will use Mamdani inference process [31], summarized in Fig. 3.

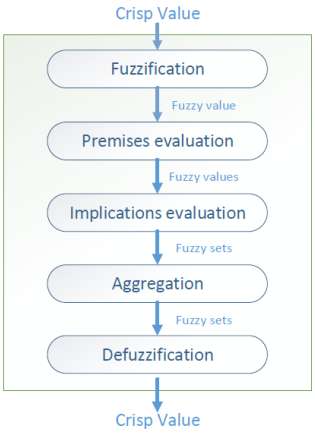


Fig. 3: Overview of Mamdani fuzzy inference.

The first step consists in the evaluation of each elementary fuzzy proposition in the premise of the rules: this step is called *Fuzzification*. It takes a crisp value (the value of the input in the real world) and associates a fuzzy value to it regarding the membership function of the term of the linguistic variable involved in the fuzzy proposition. For instance, with the linguistic variable "temperature" of Fig. 2 and its term "cold", for a temperature of -10°C, "temperature is cold" is evaluated at 1 (i.e. -10°C is really a cold temperature). For a temperature of 1°C, both "temperature is cold" and "temperature is medium" equal 0.5 (approximately).

The premises are then computed with the application of the t-norms, t-co-norms, negation function and other operators according to the rules involved. The value of each premise is a fuzzy value also called *rule activation*. For instance, considering Zadeh's t-co-norm (i.e. the max function) and a temperature of 15°C, the value of the premise "temperature is cold or temperature is medium" equals max(1,0)=1.

The implication function is then applied on the conclusion of each rule. The result is a fuzzy set describing the output. For instance, if the premise of the rule has been evaluated at 0.75, with the implication method being the minimum function, the output's fuzzy set is as shown in Fig. 4.

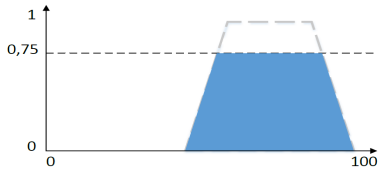


Fig. 4: Result of the implication

The diverse resulting fuzzy sets of a same output are aggregated by an aggregation function, often the max function

for Mamdani systems, resulting in a fuzzy set for each output. For instance, Fig. 5 illustrates the process of aggregation of two fuzzy sets with the max aggregation function.

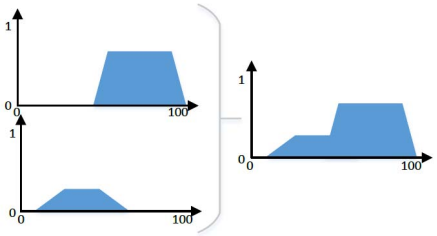


Fig. 5: Application of the max aggregation on two fuzzy sets

Each output's fuzzy set is changed into a crisp value: this process is called *Defuzzification*. There are several defuzzification methods; the best-known defuzzification method computes the centroid of the area under the membership function (the blue area of the aggregated fuzzy set in Fig. 5).

IV. The Fuzzy4U System

This section describes a system named Fuzzy4U, which uses fuzzy logic for UI adaptation. The architecture of this system will first be explored, followed by discussions on the integration of fuzzy logic into its adaptation engine.

A. Architecture Presentation

The Fuzzy4U system is based on [32]'s architecture, proposed by our team for HCI adaptation proposed by our team for HCI adaptation (Fig. 6), illustrated by a prototype. It consists mainly of three components: an inference engine, an adaptation engine and the interactive system.

The inference engine is in charge of dynamically deducing the values of the context of use from captured data. Data can be provided by sensors (e.g. ambient light API in JavaScript) or ad hoc modules (e.g. the number of 'valid clicks' – clicks done on appropriate interactors – and 'invalid clicks' – clicks done on empty spaces – computed). Thanks to a meta-UI, the user can also state the values and even override the values deduced by the inference engine. The user can, for example, declare one's visual acuity or override the detected ambient light. From all those data, the inference engine infers a representation of the context of use. For instance, the user's hand accuracy is deduced from the numbers of "valid" and "invalid" clicks.

As we already mentioned, data can also be declared by the user through a meta-UI. Here, the user can select one of two states within the interface. First, the meta UI presents the characteristics of the context of use (user's dyslexia, color blindness, visual acuity, etc.) making it possible for the user to refine one's context model and thus indirectly control the adaptation. Secondly, the meta-UI exhibits the characteristics of the interfaces (font size, word spacing, etc.): when modifying their values, the user can overpass the system's decisions.

Inferred and declared data are sent to the adaptation engine. When both inferred and declared data related to the same characteristic are available, only the value declared by the user is considered. The engine then uses these data and adaptation rules to select an appropriate version of the interface (named a variant) on which presentation parameters (colors, font, ...) will be applied. For example, if the precision level of the user's hand is low, the adaptation engine can increase the space considered for the click on the interactors to improve the UI usability for this specific user.

The inference engine is distinct from the adaptation engine to ensure the separation of concerns: the first one is responsible for transforming raw values (e.g. 130 clicks on an interactor and 212 in an empty area) into values usable by the second one (e.g. "very low" hand accuracy).

In line with our research aims, the adaptation engine was initially based on rules in Boolean logic only. In this former version, characteristics had textual values (e.g. visual acuity could be 'normal', 'low', 'veryLow' or 'extraLow') and rules were coded thanks to a series of conditions (simple or combined), where the index of the characteristics value in its set of possible values was considered for expressing ranges of possibilities. For instance, a rule in Boolean logic calculating font size based on visual acuity was:

```
If      visualAcuity <= 1 then fontSize = 12 ;
elseif  visualAcuity <= 2 then fontSize = 14 ;
elseif  visualAcuity <= 3 then fontSize = 16 ;
else    fontSize = 18 ;
```

In this rule, 1, 2 and 3 were respectively the indices of 'normal', 'low' and 'veryLow' in the set ('normal', 'low', 'veryLow', 'extraLow'). In this approach, uncertainty was not considered, neither in the values of the characteristics nor in the adaptation rules. Moreover, the approach did not make it possible to deal with rules that would have required complex

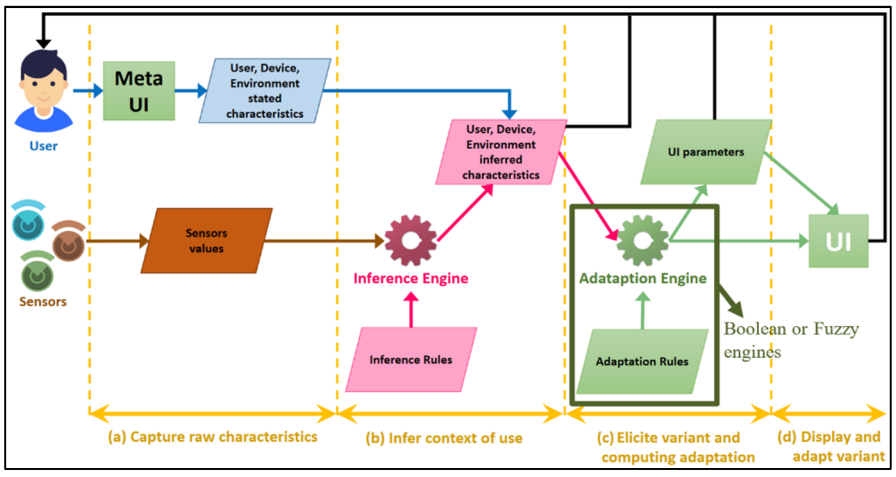


Fig. 6: Logical architecture used by the team for HCI adaptation

or subtle reasoning. In our example with four values for visual acuity, only four font sizes can be computed as a result, leading to poor adaptation granularity and threshold effects during adaptations. Finally, when results depend on several characteristics, the condition can only be written by embedding several *if… then… else* structures and thus leads to redundant sub-conditions. This makes for poor use and maintainability in complex cases. In other words, this approach supported no uncertainty, poor complexity and poor combination possibilities.

The adaptation engine aims at (a) choosing an adapted UI variant and (b) computing the adaptations required for enhancing the rendering. A variant represents a version of one UI dedicated to some spatial organization. For instance, the homepage of a website could have two variants: one for a computer screen and the other for a Smartphone. Using different versions of a UI avoids the complex calculation of their specific spatial organization. This choice is done thanks to distance calculation: each variant is associated to an expected context of use (e.g. a display surface of 900x600 pixels and a visual acuity at least "normal"). A UI is thus associated to various variants (usually two or three), each of them in turn associated to an expected context of use. The current context of use is then compared to all the expected contexts of use of the UI variants. The variant whose characteristics are, in average, the closest to the current situation, is elicited.

The architecture is generic and has been implemented with Web technologies and is based on NodeJS, allowing the execution of JavaScript on both the server and client sides. The objects used respect similar structures on both sides and are stored in text files in JSON format on the server. Therefore, the common structure is kept with manual modifications. The context model and the user model were made according to these characteristics. The module in Boolean logic is executed internally in NodeJS, and the rules are stored in JSON. The full architecture is available as a patent in [32].

B. *Integration of Fuzzy Logic*

The originality of this paper lies in the choice of adaptation engine in fuzzy logic in addition to an already existing Boolean logic engine. Technically, the fuzzy logic engine uses the ExpressIF tool developed by CEA Tech, called through a Web Service via an HTTP request. To allow comparison and add some flexibility a parameter was added by developers for them to call either approach at the touch of a button (in Fig. 6, the "Adaptation engine" and "Adaptation rules" exist in both approaches).

In the following subsections, we will see how adaptation rules can be expressed in fuzzy logic. We will highlight how fuzzy logic has the potential to help breach the barriers of uncertainty of the context of use, the complexity of rules and their combination.

1) *Uncertainty*

All characteristics have a degree of uncertainty, whether they are inferred by the engine (e.g. accuracy of the calculation of the hand precision thanks to a ratio between valid clicks and invalid clicks) or declared by the user (e.g. two users with identical visual acuity evaluating it differently).

Uncertainty of the different characteristics' values can be expressed thanks to membership functions of the variables in fuzzy logic. For example, Fig. 7 shows the definition of the visual acuity variable: the value is defined on the abscissa (here from 0 to 4), and the certainty of the four different states ('normal', 'low', 'veryLow' and 'extraLow') is specified on the ordinates. The 'normal' state is thus certain when the visual acuity varies from 0 to 0.5. From 0.5 and up to 1.5, the certainty of the 'normal' state decreases in favor of the 'low' state, which gains in certainty. At 1.5, the 'low' state is therefore at 100% certainty while the 'normal' state is at 0%. The crossing of two curves (at abscissas 1, 2 and 3) thus indicates a probability of 50% for each of the two states.

The introduction of uncertainty in variable definition makes it possible to limit the effects of thresholds (see rule in section IV.A) that induce a sudden change from one context value to another one. It is particularly useful in the management of rules for which several input variables affect the same output variable, as in section IV.B.3.

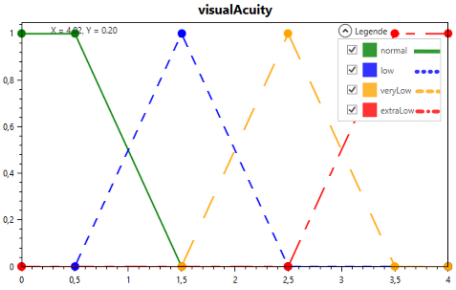


Fig. 7: Definition of the visualAcuity linguistic variable

2) *Complexity*

Next to uncertainty, the expression of adaptation rules represents another of our problem: rules with many thresholds can become complex quickly in Boolean logic. For example, let us consider the rule based on the user's visual acuity level to adapt the font size. As mentioned above, several thresholds are used (1, 2, 3 and 4) and the final granularity of the output variable is relatively small (4 possible values: 12, 14, 16, 18). While this granularity can be improved it remains at the expense of the number of thresholds. For such cases, the implementation of this rule in fuzzy logic would be to define the input and output linguistic variables with only two membership functions each (see Fig. 8 and details below) and to create the rules in fuzzy logic (Fig. 9).

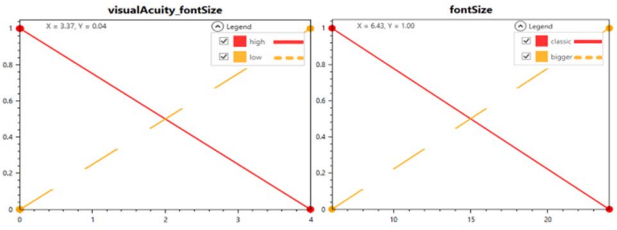


Fig. 8: Definition of the visualAcuity and fontSize linguistic variables

```
If visualAcuity_fontSize is high then fontSize is classic
If visualAcuity_fontSize is low then fontSize is bigger
```

Fig. 9: Fuzzy rules defined for adapting font size based on visual acuity

Given the definitions of the domain variable, the fuzzy logic set of rules becomes simpler, with only two cases.

Using the defuzzification method of weighted centers of gravity, the fontSize output value will be between 12 and 18 points. Its principle is to compute the centers of gravity of the output fuzzy subset for each of the rules, and to calculate a sum weighted by the area under the curve. Considering all

rules with the same output, the defuzzified value can be written as:

$$d(output) = \sum_i C_i \times A_i \; iAi$$

where Ci is the value of the center of gravity and Ai the area under the curve for the i^{th} rule concerning this output.

Defuzzification is usable on continuous linguistic variables. It was adapted here to discrete variables. As discrete domains are ordered, it gives more sense to the center of gravity. In this case, the area under the curve is replaced by the corresponding value in the histogram that serves as the membership function.

Two examples for this method are illustrated in figures 10 and 11. Fig. 10 shows that for a visual acuity of 0 in input, the term "high" is activated at 100% and the term "low" at 0%. According to the first rule, the activation of the "classic" output term is also done at 100%, represented by the red area. The center of gravity of this square triangle is located at the first third of its base, which is a value of 12 for the fontSize output variable with a domain between 6 and 24.

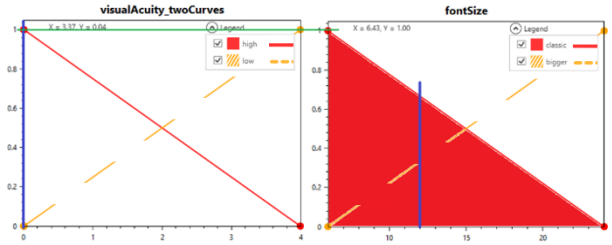


Fig. 10: Diagram of the weighted centers of gravity's defuzzification method for an input value of 0

For a visual acuity's input at 1 (Fig.), the term "high" is activated this time at 75% and the term "low" at 25%. This is represented by the two green lines and the activation of the "classic" output term at 75%, represented by the red area and the activation of the "bigger" output term at 25%, represented by the orange area. The centers of gravity of these two quadrilaterals are then calculated (12.3 for the barycenter bound to "classic" and 10.071 for the second one, related to "bigger"), then weighted according to their areas (respectively 84.375 and 39.375), in order to obtain the result of 13.5 points for the fontSize variable. We thus have the "bigger" state, taking slightly more weight when compared to the "classic" state, with a font size of 13.5 instead of the value 12 in the previous case. These results are therefore continuous and follow a function "fontSize = 12 + visualAcuity * 1.5".

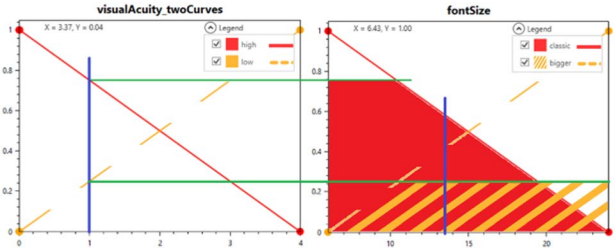


Fig. 11: Diagram of the weighted centers of gravity's defuzzification method for an input value of 1

This example shows how fuzzy logic avoids threshold effects completely. It enables the simplification of the expression of adaptation rules while obtaining more precise output values.

3) Combination of rules

The last challenge to address is the combination of rules that can occur when multiple input variables can affect the same output variable [18]. For example, it may be necessary to increase the clickable space around the interactors either when the visual acuity is weak, or when the accuracy of the clicks (and thus, of the hands) is weak. A problem arises when one input variable is high while the other is low.

Boolean logic does not provide easy answers to this problem. It is possible to choose one input value or the other, but, in which case, it is necessary to establish a system of weighting or prioritization of rules in order to give a result.

Fuzzy logic has the advantage of creating the combination of rules in an intrinsic way, especially through the management of uncertainty: without having a different weight, a greater certainty has more impact.

Consider the example of the size of the interactor click areas, named here clickCorrection. It is based on the user's visual acuity (Fig. 7) and hand precision (whose graph shape is identical to Fig. 7). To define a more or less important correction level of the size, the output language variable - clickCorrection - is composed of four discrete values representing four degrees of correction ranging from 'noCorrection' to 'highCorrection'. These rules in fuzzy logic are listed in Fig. 12.

```
If handPrecision is normal then clickCorrection is noCorrection
If handPrecision is low then clickCorrection is lowCorrection
If handPrecision is veryLow then clickCorrection is mediumCorrection
If handPrecision is extraLow then clickCorrection is highCorrection
If visualAcuity is normal then clickCorrection is noCorrection
If visualAcuity is low then clickCorrection is lowCorrection
If visualAcuity is veryLow then clickCorrection is mediumCorrection
If visualAcuity is extraLow then clickCorrection is highCorrection
```

Fig. 12: Fuzzy rules defined for calculating clickCorrection based on hand precision and visual acuity

The first four rules are based on the state of the handPrecision variable – 'normal', 'low', 'veryLow', 'extraLow'- and provide an output value for clickCorrection - from 'noCorrection' to 'highCorrection', respectively. The last four rules are the same except for the input variable, which is visualAcuity. It may be noted that it is not necessary in the expression of these rules to worry about their possible contradiction or their combination; in fuzzy logic, the output value is determined during the defuzzification.

In the example regarding the correction of the interactor click area size, to obtain a smooth transition from one value to the next, we have opted for the weighted centers of gravity defuzzification method (see subsection IV.B.2). Thus, with a visual acuity of 0 and a hand precision of 4 in input, the result is defined as 'lowCorrection'. Similarly, a visual acuity of 1 and a hand precision of 4 in input shows a 'mediumCorrection' output.

Fuzzy logic therefore manages the combination of adaptation rules thanks to the defuzzification without setting up a specific prioritization algorithm.

V. COMPARATIVE ANALYSIS

Fuzzy logic adaptation rules seem to have advantages over a classical Boolean logic approach. In order to test this hypothesis, we conducted a comparative analysis between the

two types of rules, first on a theoretical point of view then with HCI experts' opinions gathered during interviews.

A. *Analysis method*

The comparative analysis of the two types of rules is based on the expression and the analysis of the results of rules coming both from the literature [11, 33, 34, 35, 36, 37], and our own experience as HCI designers (e.g. clickCorrection).

The rules were implemented in the two adaptation engines (in Boolean and fuzzy logics), and both integrated in the architecture described in section IV.A. The context of use was manually manipulated as a dependent variable in input to test the differences in the rules produced by the two engines.

In input, we use 14 *user characteristics* and 4 *other characteristics* to describe the environment. The user characteristics described the user's age, hands precision, visual acuity, language comprehension, abstract signs understanding, attention level, tremor, the possibility of dyslexia or color blindness ('protanopia', 'deuteranopia', 'tritanopia' or 'total color blindness'), IT experience, and website experience. The four environmental inputs expressed the room's brightness, as well as the hardware used in terms of orientation and display surface (window's height and width). These values were assumed to come either through sensors or by the user's input. These entries were then linked through adaptation rules to 17 output parameters acting on the interface: spacing between letters, words or lines, font and font size, text alignment, text quantity, the presence or absence of animations or purely decorative elements, interactors click size area, contrast, colors changes, using hypertext links or replacing them with buttons, display modes of menu (icon/text), ordering bulleted lists, guidance and confirmation levels. There were 34 adaptation rules in Boolean logic, and 81 in fuzzy logic. This difference was explained by the choice to implement the rules in fuzzy logic. In Fig. 12, the 8 rules in fuzzy logic can be grouped into 2 rules in Boolean logic in the *if… then… else if…* structures.



Fig. 15: Homepage of the hotel website

B. *Rules*

To illustrate these rules, we will use the example of a hotel website, illustrated in Fig. 15 (default homepage interface, with no adaptation).

Five groups of rules - for which the results differed between Boolean and fuzzy logic - were selected for this experiment. The rules mainly depended on multiple inputs.

1) *Display Mode*

The first group of rules was responsible for calculating the "display mode" variable, which corresponds to the use of icons, in addition to the text, within the menus (Fig. 13 and Fig. 14). The calculation was based on three characteristics: 'website experience', 'abstract signs understanding' and 'language reception' which respectively represent the level of user's knowledge about the current website, one's ability to understand symbols/icons, and one's ability to understand written language.



Fig. 13: Menus with text and icons



Fig. 14: Menus with text only

2) *Verbose*

The second group of rules was used to calculate the 'verbose' level of the website (i.e. the amount of text shown to the user). By default, the text was in its complete/standard version (Fig. 16), and it could be more or less summarized depending on the user's characteristics (Fig. 17). These rules depend on two characteristics: 'Language reception' (ability to understand the written language, see V.B.1) and the user's level of 'attention' (i.e. concentration level).

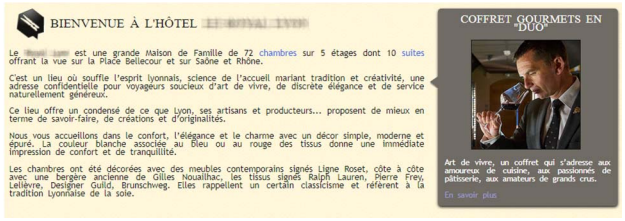


Fig. 16: Standard and complete presentation (default verbose)

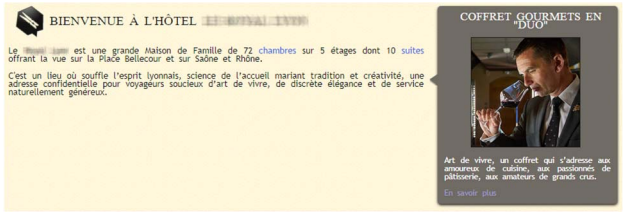


Fig. 17: Shortened presentation (concise verbose)

3) *Guidance Level*

The following group of rules calculated the 'Guidance level' to be implemented within the interface (standard or high) from two input characteristics: the 'IT experience' (with computers and web in general), and 'website experience' (with this particular website). Fig. 18 shows an example of a high guidance level in menus.

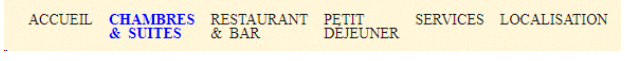


Fig. 18: Menus with high guidance level

4) Click correction

This fourth group was in charge of calculating a variable named 'Click correction', used to enlarge the clicks area of the interactors (Fig. 19; i.e. the size of the area around an interactor within which a click is associated to the interactor). This variable was calculated from the 'visual acuity' of the user, as well as from his 'hands precision' (movement of the mouse and clicks). This group of rules was used to avoid clicks made by mistake right next to an interactor.

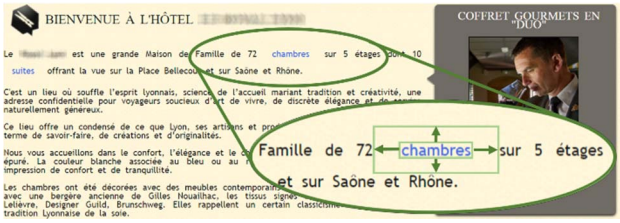


Fig. 19: Interactors click size area extended (High click correction)

5) Font size

The final rule regulated the increase of the font size, based on the visual acuity of the user.

C. Results

Table 2 summarizes the adaptation results of the rules presented in the section V.B. The table can be read as follows: the first column of the table (input situations) is subdivided into two sub-columns. The first sub-column details a set of several characteristics impacting the same output variable. The second sub-column defines examples of values corresponding respectively to each of the input variables. For example, the first input situation of the table is a user having a value of 1, 2 and 2 (1/2/2 in the table) for the listed input variables: websiteExperience (value of 1), abstractSignsUnderstanding (2), and languageReception (2). The next two columns specify the results in Boolean and fuzzy logics.

The differences of results in Boolean logic and in fuzzy logic, for the same input situation, make it possible to highlight two points:

a) For rules defined with a similar complexity between Boolean and fuzzy logic (i.e. rules written the same way in both logics), it seems to us that fuzzy logic makes it possible to obtain more relevant results with regard to the input situations, without having to define and use a system of weights between rules, as this is the case for Boolean logic. For example, the calculated value of the displayMode is identical in Boolean and fuzzy logic for the first and fourth situations, that is to say when the three input values are either all 'low' or all 'high'. However, when the input values provided are heterogeneous, the fuzzy logic returns a mean value, which is more precise. This is especially noticeable for the results of the second group of input situations (adaptation of verbose depending on languageReception and attention), where the verbose output variable can take four states ('thorough', 'summarized', 'concise' and 'laconic'). Indeed, when the value of one of the input variables varies from one extreme to the other, the results from fuzzy logic show that the final value is smoothed, passing through all the intermediate values, which is not necessarily the case in Boolean logic.

b) As this is the case with the font size adaptation according to visual acuity (last line of the table), the fuzzy logic makes it possible to easily obtain an extremely finer granularity than the Boolean logic. The latter could make it possible to achieve such granularity, but this would be to the detriment of the number of thresholds to be managed within the rule: our rules give only four possible font sizes (12, 14, 16 or 18) and we wanted more precise results we would need to pre-define all the values and include several conditions in the rules. Furthermore, it is important to note that in fuzzy logic, this granularity is not limited to the examples in the table: a visualAcuity value of 0.25 will have a fontSize output of 12.375, and so on.

This comparative analysis confirms that fuzzy logic makes it possible to obtain more consistent results with finer granularity without having to manage the combination of multiple rules.

TABLE 2: SYNTHESIS OF THE COMPARATIVE ANALYSIS RESULTS BETWEEN BOOLEAN AND FUZZY LOGICS

N°	Input situations		Results in boolean logic	Results in fuzzy logic
	Input variables	*Values*		
1	websiteExperience abstractSignsUnderstanding languageReception	1/2/2	displayMode = textOnly	
		1/2/3	displayMode = textOnly	displayMode = textAndGraphics
		1/4/4	displayMode = textOnly	displayMode = textAndGraphics
		3/3/3	displayMode = textAndGraphics	
2	languageReception attention	1/1	verbose = thorough	
		1/2	verbose = thorough	verbose = summarized
		1/3	verbose = thorough	verbose = concise
		3/4	verbose = concise	verbose = laconic
3	itExperience websiteExperience	1/1	guidanceLevel = medium	
		1/3	guidanceLevel = medium	guidanceLevel = high
		3/3	guidanceLevel = high	
4	visualAcuity handPrecision	1/1	clickCorrection = noCorrection	
		0/1.49	clickCorrection = noCorrection	
		1/2.99	clickCorrection = noCorrection	clickCorrection = lowCorrection
		0/3.49	clickCorrection = noCorrection	clickCorrection = lowCorrection
		2/3	clickCorrection = lowCorrection	clickCorrection = mediumCorrection
		3/3	clickCorrection = mediumCorrection	
		2.5/4	clickCorrection = mediumCorrection	clickCorrection = highCorrection
5	visualAcuity	0	fontSize = 12	
		0.5	fontSize = 12	fontSize =12.75
		1	fontSize = 12	fontSize =13.5
		1.5	fontSize = 14	fontSize = 14.25
		…	…	…

D. Experts

1) Experimental setup

Our hypothesis is that fuzzy logic has the potential to create more relevant adaptations than Boolean logic for certain HCI adaptation rules. We tested this hypothesis by conducting interviews with HCI experts on this matter. These interviews also served as an idea generation workshop about rules improvement or fuzzy logic practical uses.

Our evaluation was conducted with eight experts, six men and two women, aged 37-57 years. They were all assistant professors or professors in HCI, working in France (Paris, Nice, Grenoble, Valenciennes) for more than ten years. The interviews lasted an average of 40 minutes.

The different input situations of the table were presented to the experts, as well as an example-based definition of the variables (to avoid misinterpretation). The example presented to the experts was the hotel website introduced in section V.B, along with screenshots of different adaptations pertaining to the rules. They were then asked to specify what they would recommend as an adaptation result for each input situation listed in Table 2, in the form of a list of choices corresponding to the possible values of the exit. Finally, they were asked to explain this choice during a free expression phase. Once the answers were given for the 5 proposed situations of Table 2, global feedback was gathered in the form of an open-discussion on the rules and logics tested.

The experts' opinions about the five groups of rules (see section V.B) are detailed below, with a summary in Table 3.

2) Group of rules n°1: DisplayMode

Six of the eight experts recommended the permanent use of icons in addition to the text in the menus (textAndGraphics), in contradiction to the recommendations made by MyUI [11, 35, 36], from which the rule was established. These recommendations propose rather to keep only the text when the user does not possess a major weakness for the various input variables (with an input value between 0 and 2) and to add the icons when he does (input values between 2 and 4). This result can hardly be interpreted from the point of view of the comparison between the two logics since it questions the rule itself. A seventh expert also disagreed with the rule at the level of the input variables, indicating that it would only take into account the "abstractSignsUnderstanding". The last expert agreed with the rule and his results join the fuzzy logic results.

TABLE 3: SYNTHESIS OF THE EXPERTS AGREEMENTS FOR BOOLEAN AND FUZZY LOGICS

N°	Input variables	Output variable	Experts agreement with	
			fuzzy logic	*boolean logic*
1	websiteExperience abstractSignsUnderst. languageReception	displayMode	○	○
2	languageReception attention	verbose	●	○
3	itExperience websiteExperience	guidanceLevel	◐	◐
4	visualAcuity handPrecision	clickCorrect.	◐	◐
5	visualAcuity	fontSize	●	○

Expert agreement: ● High, ◐ Partial, ○ Low

3) Group of rules n°2: Verbose

Seven out of eight experts proposed results that combined the two input variables to provide a more linear adaptation. The results here tend towards fuzzy logic, which allows more linearity and a simplified consideration of the different input values. The last expert advised to rely only on the variable with the best value to perform the adaptation, in order to "rely on a strength".

4) Group of rules n°3: GuidanceLevel

Seven of the eight experts proposed a 'medium' guidance level for the first input situation (e.g. a user with both input characteristics at a relatively good level), and a 'high' guidance for the last one (e.g. a user with both input characteristics at a relatively low level). For the intermediate entry situation (e.g. a user with one good value and one bad for the two inputs characteristics), the results varied between 'medium' and 'high'. The eighth expert stated that "he would promote guidance in relation to the need" and therefore providing a high level of guidance in all situations. These results do not allow to put forward either the Boolean logic or the fuzzy logic, this group of rules having only two inputs and a two-state output, the differences remaining insignificant.

5) Group of rules n°4: ClickCorrection

Four of the experts stated that, in this case, they would use the maximum value between the two inputs to calculate the output, not an intermediate value calculated from the two inputs. In other words, this would result in a maximum weight for one of the inputs (the one with the best level), and zero weight for the second characteristic. This rather joins the operation of Boolean logic, although it remains possible to perform in fuzzy logic. The four remaining experts were inclined towards the use of a mean value between the two inputs, and therefore their results were more linear, closer to the fuzzy logic.

6) Group of rules n°5: FontSize

Six of the experts recommended "precise", "linear" font size calculations in order to avoid threshold effects, an inconvenient for users, which is consistent with fuzzy logic. The two remaining experts advocated the use of thresholds, as in classical Boolean logic, which also remains possible in fuzzy logic.

7) Open discussion with the experts

Two experts stated that the fuzzy logic way of handling uncertainty was particularly adapted for the values declared by users. Three experts also indicated that the rule combination management of the fuzzy logic was a good thing, although it may sometimes be necessary to maintain a weighting system for certain rules (e.g. a higher consideration of the websiteExperience than itExperience, when calculating the guidance level - see Group of rules n°3).

E. DISCUSSION

According to the results obtained during our evaluation, the fuzzy logic seems to answer the needs of a UI adaptation engine, while meeting our criteria: the uncertainty of values, the complexity of rules and their combination, without restricting the context of use. However, the experimental setup and the rules implementation are discussed further in this section.

1) Threats to Validity

The interviews were realized with a small number of experts. Nielsen & Mack [38] showed that eight general

practitioner non-novices experts were enough to detect more than 90% of usability problems. But enlarging the panel to international experts could be interesting as it would provide a wider range in backgrounds. For instance, none of the experts tested was either an Ergonomist or an expert in fuzzy logic. It would be meaningful to interview such experts to get more feedback during the final open discussion. However, an expert evaluation cannot fully replace end-users' feedback. So conducting an end-user evaluation could complete our current work.

Another validity issue is related to the chosen example. As mentioned in section V.A, the input data used for the comparison analysis were manually selected by the authors to highlight the differences of the two logics, but the results were calculated solely by their respective engine. Other data could be considered in a similar experiment. Moreover, the rules were illustrated with the example of a hotel website. Other websites domain could be used to strengthen the results.

2) Fuzzification, Defuzzification and Membership Function

As presented in section III.D, fuzzy logic requires phases of fuzzification and defuzzification, as well as the definition of membership functions for each of the linguistic variable states. These phases are critical to obtain relevant results.

Fuzzification consists in associating a fuzzy value to an input value, according to the membership function of the linguistic variable term involved in the fuzzy proposition (e.g. the different membership functions for each term for visual acuity - Fig. 7 - or for the hand precision). The difficulty is that their definition remains subjective as the literature does not generally provides us with fixed values. However, it is possible to modify them after the fact.

In terms of defuzzification, several solutions are possible: first or last maximum, average maxima or a calculation of weighted center of gravity. The choice of the defuzzification method is defined for each output linguistic variable, and it will depend on both the type of the latter (continuous or discrete values) and the desired logic of the rule. In our work, the rules were all defined with a weighted centers of gravity, in order to calculate an average of the results for the rules that affect the same output variable instead of using only one of the results (which is the case with the maxima or minima defuzzification method). However, the calculation of the weighted centers of gravity is not perfect: for example, it was necessary to define the value domain of the font size (fontSize, Fig. 8) between 6 and 24 to obtain relevant results between 12 and 18 because of the way fuzzy logic and the membership functions work (see section IV.B.2). Nevertheless, it has always allowed us to obtain results that seem relevant to us.

Finally, the membership functions can be created in different manners: continuous piecewise functions, rectangular or triangular broken lines, Gaussian lines... Some types of curves reached beyond our research domain. For example, piecewise continuous functions would result in threshold effects at discontinuities and would not be the most suitable for representing users' characteristics. Similarly, broken lines with rectangular shapes would mean that there is no management of the uncertainty and therefore fall back into an operation similar to the Boolean logic. In our work, we used triangular broken lines because, on one hand, they allow simpler calculations, and on the other hand, they are easier to be apprehended by experts. Gaussians can also be used, but are preferred when rules are learned automatically.

3) Types of Variables Used

In this work, we used quantitative variables (e.g. visualAcuity), ordinal variables (e.g. clickCorrection) and nominal variables (e.g. types of color blindness). Compared to Boolean logic, the contributions of fuzzy logic in this paper were about quantitative or ordinal variables. The nominal variables are used in the same way in the two logics, without contribution from fuzzy logic. There may be an interest in using fuzzy logic for this last type of variable, but no example has been found yet.

4) Rules Relevance

According to our study, fuzzy logic seems adequate to support a UI adaptation engine. Nevertheless, there is always the question of the relevance and coverage of the rules we have expressed. These may be considered limited or arbitrarily chosen. To overcome these shortcomings, we have used rules mostly derived from the HCI adaptation literature [11, 33, 34, 35, 36, 37]. There were three rules in Boolean logic (six in fuzzy logic) relative to the devices (window's size and orientation), one rule (four in fuzzy logic) relative to the environment (brightness), and 30 rules (71 in logic fuzzy) related to the user. As far as the user is concerned, 23 of the 30 rules come from the literature [11, 33, 34, 35, 36, 37], including 11 rules taken from the European project MyUI [11, 39, 40].

We faced an issue regarding rule validation by the experts: Some did not agree with the rules themselves (most notably the group of rules n°1, for the displayMode output). So the problem was more related to a lack of consensus about rules in the HCI community than the rule itself.

VI. CONCLUSION

This article proposes a UI adaptation system based on a fuzzy logic adaptation engine. We showed the potential interest of using fuzzy logic in terms of uncertainty of the input values and combination of adaptation rules. The fuzzy logic and the Boolean logic solutions were compared first, theoretically, then through eight experts' interviews. This comparison enlightens the benefits of fuzzy logic.

We can also note that the greater the number of characteristics and rules, the more useful fuzzy logic can be compared to Boolean logic. This was explained by fuzzy logic bringing advantages when an output variable depends on several inputs (see section IV.B.3). Should advances be made in the characterization of uncertainty, adaptation using fuzzy logic would benefit from them.

The question of the difficulty to handle the specific aspects of fuzzy logic remains, that is, fuzzification and defuzzification. Experiments with computer engineers could prove this point to be immaterial.

Finally, it is possible to consider an extension of the adaptation engine, which is not limited to logic but also proposes automatic learning techniques for the personal preferences of users such as those related to aesthetics.

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A Unifying Reference Framework and Model for Adaptive Distributed Hybrid User Interfaces

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***Abstract*—Over the last decade, research on adaptive and distributed user interfaces (DUIs) has increased. We also witness a growing number of Internet of Things (IoT) devices, allowing digital user interfaces (UIs) to communicate with physical objects and vice versa through so-called hybrid user interfaces. There exist various solutions to manage adaptive, distributed or hybrid UIs. However, none of them covers all three aspects and users have to deal with multiple applications and configurations when developing adaptive distributed hybrid user interfaces. We introduce the eSPACE reference framework and conceptual model unifying the domains of adaptive, distributed and hybrid interfaces. While our reference framework has been inspired by the CAMELEON reference framework, the conceptual model is based on the Resource-Selector-Link (RSL) hypermedia metamodel. We propose an approach for adaptive distributed hybrid user interfaces where users can author their user interfaces based on the different levels of abstraction introduced by our reference framework. We further present a use case illustrating the extensibility, flexibility and reusability offered by our unified approach and discuss potential future work.**

***Index Terms*—Adaptive user interfaces, distributed user interfaces, hybrid user interfaces, internet of things, end-user development, model-based approach**

I. Introduction

User interface design and development is a difficult and time-consuming task [1]. With the rise of new kinds of devices, input and output capabilities as well as user needs, the task has become even more complex. While the *Design for All* approach [2] might fit a majority of users in a traditional context, it does not adapt to recent use cases and often leads to a bad user experience [3].

Further, with the rise of smart objects or *things*, the scope of user interfaces (UIs) has grown from digital UIs to physical UIs. We refer to the combination of digital and physical UIs as *hybrid UIs*. Given that we are living in an era where UIs for smart environments (including IoT and tangible systems) are gaining in popularity, physical UIs should be integrated into our UI models. For this reason, we promote the *unification*, *creation* and *customisation* of adaptive, distributed and hybrid UIs via a model-based approach and aim to reduce the effort required to develop such interfaces by following an authoring rather than programming approach.

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II. Background

In the late 1980s an emerging number of modelling languages to create rich and accurate interface models led to *model-based user interface development (MBUID)* [4], reducing UI development and maintenance costs based on a layered architecture [5]. Szekely [6] introduced a generic MBUID architecture with the typical components of model-based interface development environments (MB-IDE), including modelling tools, the model, automated design tools and implementation tools. The model organises information on three levels, including the *task and domain model*, the *abstract user interface* specification and the *concrete user interface (CUI)* level. A CUI can further be translated into an executable representation (linked to some application logic) on the *final user interface (FUI)* [7] abstraction level.

Even though modelling languages became more expressive, due to the continuous evolution of UIs, model-based user interface development remains a challenge [4]. Two decades ago, Szekely [6] stated a number of challenges, including *task-centred interfaces*, *multi-platform support* and *interface tailoring*, which are still valid today. Another challenge is the support for *multimodal interfaces* to develop richer UIs.

By taking Szekely's challenges into account, we focus on MBUID in the domain of adaptive and adaptable UIs, distributed UIs (DUIs) as well as hybrid UIs. Adaptive and adaptable UIs address the first and third challenge, while DUIs tackle the second challenge. The third domain has been chosen since we think that an additional important challenge for MBUID are hybrid UIs in order to deal with IoT solutions that were not yet present when Szekely introduced his challenges.

Model-based adaptive and adaptable user interfaces aim to improve the user experience by adapting to a user's context of use at runtime [3]. Hereby, the context of use is defined by a triple consisting of the *user*, *platform* and *environment* entities [8]. While adaptive UIs automatically react to changes in context, adaptable UIs are tailored according to predefined options but usually require explicit human intervention. A key goal of adaptive UIs is *plasticity*, meaning that a UI preserves its usability across multiple contexts of use [7].

The first multi-context reference framework applying a model-based approach was introduced by Calvary et al. [7].

An extended version later gave rise to the CAMELEON reference framework (CRF) [8]. CRF structures the development life cycle into four levels of abstraction and supports UI plasticity. Following these abstraction levels, approaches to develop adaptive UIs such as Akiki et al.'s IDE [9], Paternò et al.'s tools [10] and research based on UsiXML [11] emerged. Inspired by CRF and multiple research domains, the Multi-Access Service Platform (MASP) [12] addresses the deployment and runtime issues when developing adaptable, distributed and multimodal UIs for smart environments. While adaptive and adaptable UIs may adapt to a platform, they do not support the creation of UIs over a set of heterogeneous cooperating devices. Further, the majority of existing solutions is less flexible in terms of the UI granularity since it is impossible to show only parts of a UI on a device.

With the growing amount of devices, research on *model-based distributed UIs (DUIs)* tries to take advantage of these cross-device ecosystems. Elmqvist [13] defined a DUI as *"a user interface whose components are distributed across one or more of the dimensions input, output, platform, space, and time"*. Balme et al. [14] presented CAMELEON-RT, an architecture reference model for DUIs which can be used to compare and reason about existing as well as to create new runtime infrastructures for distributed, migratable and plastic UIs. Some adaptive UI approaches evolved towards systems that include DUI support, such as the distributed MARIA language [15]. Melchior et al. [16] proposed DUI support at different levels of granularity, including action/service, widget, windows and application level. In contrast to Manca and Paternò [15], Melchior et al. focus on GUIs and do not provide support for other modalities such as voice. MASP provides support for UI distribution with limited multi-user interaction and no control of the distribution granularity.

The rise of smart devices such as smart power plugs, light bulbs or thermostats led to dedicated applications to control these devices. Further, the idea of adding physical objects to interactive environments shows many benefits, such as intuitiveness, ease of learning and naturalness. Therefore, smart things should be considered in the UI development process via *model-based hybrid user interfaces*. Reference architectures defining a set of building blocks and addressing requirements for IoT environments have been proposed. Essential requirements are interoperability, device management, dynamic discovery, context-awareness, scalability, large volume data management, data security, integrity and privacy as well as dynamic adaptation [17].

While most existing approaches omitted support for runtime IoT adaptation, it is addressed by Hussein et al.'s [18] work on adaptive IoT systems and by the MDE4IoT framework [19]. The integration of physical objects is supported in a development framework for physical UIs by Varela et al. [20]. Further, Coyette and Vanderdonckt [21] focussed on the prototyping of UIs combining the digital and physical worlds.

Various systems have been developed to support model-based user interface development. Some approaches cover parts of the UI development process by providing tools to support specific abstraction levels of the CRF, while others, such as Cedar Studio IDE [9], CAMELEON-RT or MASP focus on the whole development cycle. Most of the presented solutions focus either on adaptive, distributed or physical UIs, with some exceptions such as MASP, distributed MARIA and Dandelion [20] spanning over multiple domains; namely adaptive and DUIs for the first two and DUIs and physical UIs for the latter. Nevertheless, none of the existing systems covers *all three* closely-related domains and provides support for adaptive, distributed and hybrid UIs. In addition, the *extensibility* of adaptive and distributed behaviour is limited or completely absent and most systems provide a fixed set of distributable elements. Only Cedar Studio [9] fully supports the extensibility of adaptive behaviour. Most approaches also lack *flexibility* with respect to adaptation and distribution rules, distribution granularity in DUI systems and dynamic adaptation in IoT systems [17]. The *reusability* of model components, rules, UI parts and distributed settings is often not supported. One of the few systems providing a fine distribution granularity and high reusability has been presented by Melchior [22] but it is limited to GUIs only. Last but not least, existing solutions mainly address designers and developers, with less support for *end-user development*.

III. Use Case

In order to illustrate the potential of our unified approach for adaptive distributed hybrid UIs, we present a use case which is currently not supported by existing MBUID solutions. Lucas wakes up around 7:30 a.m. every morning. For supporting his daily morning routine, he developed a *leaving home application* running on a smartwatch as shown in the mock-ups in Figure III.1. Once Lucas leaves and locks the front door, the application checks whether the clothes iron, lights and TV are turned off and—if one of them is still on—sends a message to Lucas, who can turn the device off via the smartwatch user interface consisting of the three parts shown in Figure III.1.

Lucas' second application is the *cats application*. He has two cats for whom he bought a smart feeder, a pet Wi-Fi camera, and a customised food storage box with LEDs, a weight sensor and a push button. The food storage box glows green when full and red when almost empty to remind Lucas when to buy food. When pressing the push button, cat food is added to his grocery list. With his self-made application shown in Figure III.1, he can control the feeding time and see his cats when he is not at home via the video stream, which also contains a record/snapshot button to record a video or take a picture. He also added a button to access the image gallery containing the captured images and videos.

Further, Lucas installed a motion sensor behind the couch to get notified when the cats potentially scratch the couch in order that he can activate a water spray to stop them. A temperature GUI component can be used to set the temperature in the apartment. Once the temperature drops to 16 degrees Celsius, Lucas gets a notification. An *administration panel* is used to edit the applications, manage their rules and distribution properties as well as the user rights.



Fig. III.1: Mock-up of Lucy's *cats application* (smartphone), Lucas' version (tablet), his *leaving home application* (smartwatch) and the administration panel

Today Lucas is heading to work and normally his *leaving home application* would notify him that he forgot to turn off the lights. However, since Lucas' girlfriend Lucy moved in, they made some changes to Lucas' applications so that Lucy can use them as well. She created a profile with her preferences and adapted some of his applications to her needs via the administration panel. Given that Lucy leaves for work later, Lucas' *leaving home application* did not check whether the appliances are turned off. Later Lucy leaves and gets notified that the TV is still on. She opens the *leaving home application* on her phone—which adapts to the new device as well as to her preferences—and turns off the TV. Note that Lucy is colour blind and therefore her application shows blue and orange buttons instead of the green and red buttons.

During the day, Lucas receives a notification that the cats are scratching the couch. After a quick look at the video stream of the *cats application*, he realises that the cats are just playing near the couch and presses the `funny` button. The `funny` button has been added by the couple to notify each other about funny content and is shown in the tablet and phone mock-ups in Figure III.1 (smiling cat image). Whenever Lucas presses this button, Lucy receives a notification. As illustrated in the smartphone mock-up, Lucy's UI of the *cats application* only contains the video stream and the `funny` as well as a `gallery` button. Further, Lucy shared the video stream UI element with her best friend and whenever she presses the `funny` button, she notifies Lucas as well as her best friend.

Once home, Lucas fills the feeder with cat food and recognises that the food box is glowing red. Therefore, he presses the button on the box to add "cat food" to his grocery list. Later, the couple shows each other pictures by displaying them on the TV by using a *touch-throw* gesture on their phone.

IV. eSPACE Reference Framework

In the following we present our multi-layered *end-user Smart PlACE (eSPACE)* reference framework shown in Figure IV.1, which unifies adaptive, distributed and hybrid user interfaces. The different layers of the CAMELEON reference framework have been used as inspiration to divide and structure our reference framework into similar abstraction layers. Unlike CRF, we are not aiming for a purely MBUID process but want to make the most of both worlds by combining manual and model-based techniques. To promote flexibility, extensibility and reusability of the different components of

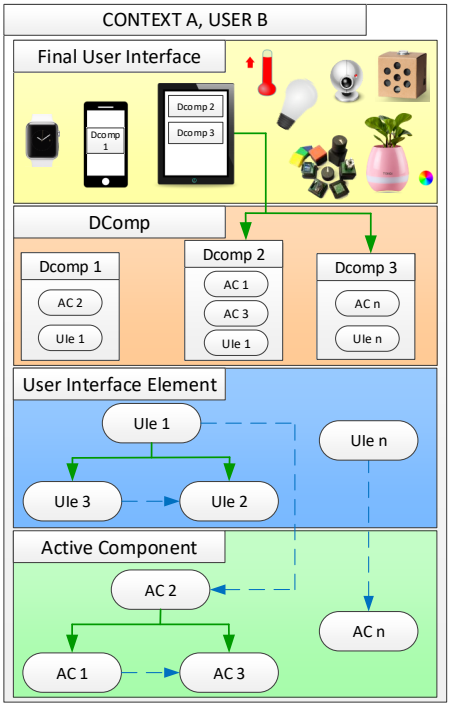


Fig. IV.1: eSPACE reference framework

a UI, we provide a loose coupling between UI elements and their tasks by placing them in separate layers. The layer containing the "tasks" is called the *active component* layer. Tasks are represented as active components (ACs), a concept introduced by Signer and Norrie [23]. Each AC represents a piece of program code that executes an action, such as *turning on the light*. ACs can be linked to each other to execute more complex interactions, as shown by the blue dashed arrow in Figure IV.1. `AC 1` could, for example, be a scratching detector AC linked to an AC that sends notifications so that Lucas is notified when a cat might be scratching his couch. To reuse this functionality, a new AC can be created composed out of these two ACs, as shown with `AC 2` that is composed of `AC 1` and `AC 3`. If Lucas wants to reuse this scratching notifier in other applications, he can just refer to it as `AC 2`. The `notifier` AC is a generic notifier that is reusable in other applications with different configurations.

The next layer containing UI elements (UIes) such as text fields, buttons, video frames or a combination of different ele-

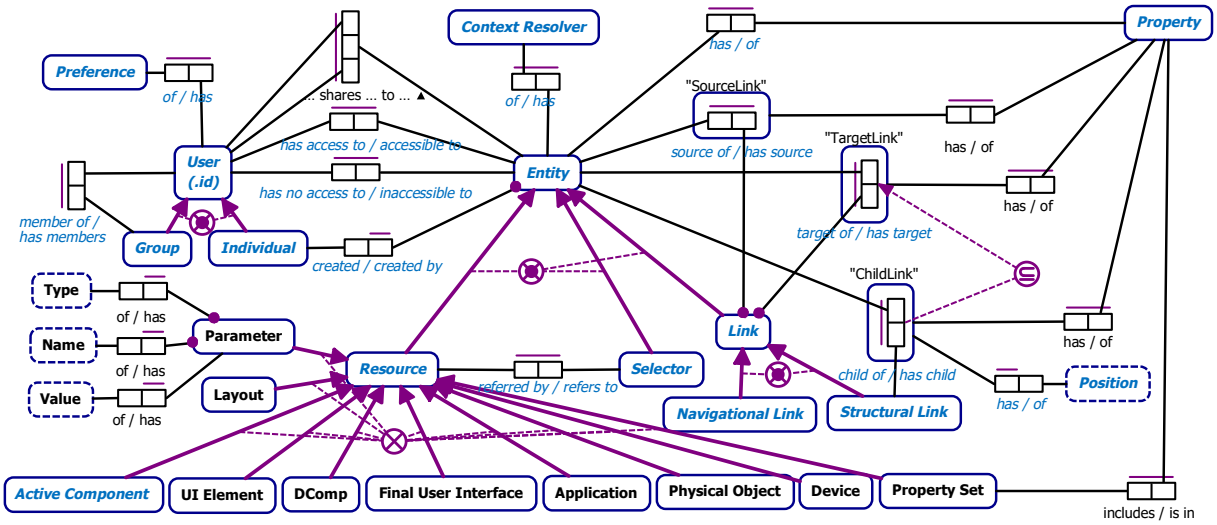


Fig. V.1: Conceptual model based on RSL

ments is called the *user interface element* layer. A UIe can also be a physical UI, such as a light switch, a physical button or a slider. Similar to the previous layer, different UI elements can be linked together to form more complex UIes. One can use links to navigate between different UI views, such as in Lucas' cats application where when he presses the `gallery` button, a link is followed to the `photo gallery` view. Links can also be used to arrange UI elements in one view. For example, a video player can be created by linking a `video frame` UI element with a `button` UI element. This composition can be saved as a `video player` UIe, which can be reused in different applications. Compositions are represented by green solid arrows. Figure IV.1 illustrates `UIe 1` as a composition of `UIe 2` and `UIe 3`. Last but not least, links can be used to bind some functionality to UI elements by linking them to ACs. For example, linking a `button` UIe to an AC that turns on the light, will enable the button to act as a light switch.

The third layer is the *DComp* layer consisting of *distributed components (DComps)*. These DComps consist of the "models" created by linking ACs and UI elements, together with the configuration (metadata) for the corresponding ACs and UI elements. Each DComp holds at least one AC or UI element and is distributable in real time. Lucas' cat application consists of multiple DComps, one of them for the live stream component used to watch his cats. This DComp holds a `video player` UIe that is linked to a `show stream` AC. Note that the DComp can be distributed to any another device, such as a smartphone, in order to see the video stream. Distribution can happen at different levels of granularity. For instance, Lucas could distribute the `capture/record` button to his smartwatch for recording the cats by using his watch. Since DComps are device independent, this layer can be compared to the CUI layer of the CRF, with the difference that DComps do not have to include any layout information.

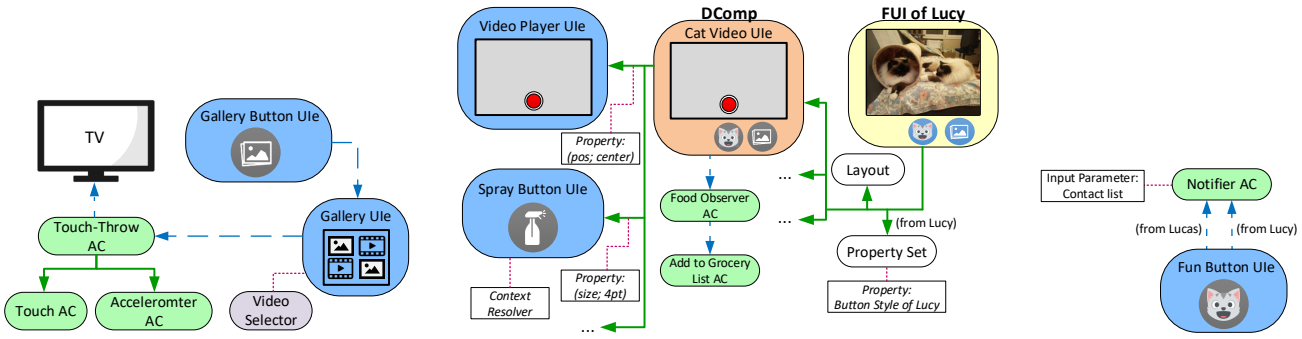
The last layer represents the *final user interface* which, similarly to the CRF, contains the final user interfaces. Once a DComp is attached to a device, it will get its look and feel depending on this device and become part of the final user interface (FUI). Multiple DComps can be placed on a device with a certain layout and be saved in one FUI. For example, the leaving home application FUI contains three simple DComps to control the lights, the TV and the clothes iron. A FUI can still be adapted depending on the context of use. If Lucy uses Lucas' smartwatch (she has to be logged in), the buttons of the *leaving home application* adapt to her colour preferences.

Our framework supports the *reusability* of its components over multiple applications and endorses *flexibility* and *extendibility* by allowing these components to be linked together for navigation and to create new compositions. We further promote end-user development by allowing UIes to be created and customised by simply linking different components.

V. Conceptual Model

Our conceptual model for adaptive distributed hybrid user interfaces is based on the Resource-Selector-Link (RSL) hypermedia metamodel [24] and its concept of active components [23]. RSL was chosen due to its support for the loose coupling of resources via different types of links and offers features for user and context management. The main components of the RSL metamodel are the `Resource`, `Selector` and `Link` entities which are subtypes of the `Entity` type as shown in Figure V.1 (original RSL components are coloured in blue). Note that while we use the ORM modelling language [25] for our conceptual model, the original RSL metamodel is based on the OM data model [24].

In the previous section we expressed the need to compose ACs and UI elements as well as to navigate between them. This is achieved by using `Structural Links` and `Navigational Links` (solid green and dashed blue arrows in Figure IV.1). For example, we can link ACs via navigational links to execute multiple actions after each other or UIs can be linked to navigate between views, as shown for the `gallery` button and `gallery` view in Figure V.2a. Further, navigational links can be used to link UI elements



(a) AC Composition and Image Selector (b) Lucy's FUI composition (c) Notifier AC

Fig. V.2: Examples of conceptual model instantiations

to ACs. By using structural links, one can create structures as illustrated in Figure V.2a. They can be used to compose UIs containing multiple UI elements, such as the `video player` UIe that is composed of a `button` UIe and a `video frame` UIe. New ACs with combined functionality can be created as well (e.g. linking a `touch` AC with a `accelerometer` AC to create a `touch-throw` AC used to move pictures to the smart TV). RSL `Selectors` can be used to refer to a piece of a resource. A `video` selector can, for example, be used to transfer parts of a video rather than the entire video from the `gallery` view and thus enables video excerpts to be distributed to the TV, as shown in Figure V.2a. Note that, instead of using multiple links to structure ACs and UIs, we use RSL's multi-targeted links. The children of a structural link are ordered via a position attribute and the `child of` relationship is a subset of the `target of` relationship (via a pair-subset constraint in the ORM scheme).

Structural links are further used to structure `DComps` and `FUIs` as illustrated in Figure V.2b. Depending on the context of use, the composition of the `DComps` and `FUIs` might be different. Context can be modelled by using the `Context Resolvers` provided by RSL, which act as gateways. The `water spray` button has a context resolver which verifies at run-time who is using the application. If Lucy is using the application, her `FUI` will not contain this button. Context resolvers can also be used on links, to set conditions on when a link needs to be followed.

Entities in RSL can have multiple `Properties`, which are key-value pairs. They might, for example, be attached to a UI element to define its size. In addition, RSL offers user management, where users have preferences and can be part of a group. Each group or individual user can be granted or denied access to specific entities.

In order to define properties over the individual sources or targets of a link, we objectified these relationships and added a `has` relationship. This is useful to have distinct properties on the link to every source or target of many-to-many links, as shown on the structural link with as targets the `video player` UIe and `spray` button. There the property is used to set the position of the UI elements for this specific composition. In addition, we added a `sharing` relationship between `User` and `Entity` to enable users to share their entities with each other. This enables extensibility via a growing shared entity set as users add their self-created `ACs`, `UI Elements` and `DComps`.

Based on our reference framework, we differentiate between different types of resources in our model. As shown in Figure V.1, we have the `Application`, `DComp`, `Active Component`, `Final User Interface`, `UI Element`, `Parameter`, `Property Set`, `Layout`, `Device` and `Physical Object` resources. An `Application` consists of one or more `FUIs`, which in turn are composed of at least one `DComp` that contains at least one `AC` or `UI Element`. ACs can be used to verify information, such as *"is the door locked?"* or to perform an action on a `Device` or `Physical Object`, such as *"turn the light off"*.

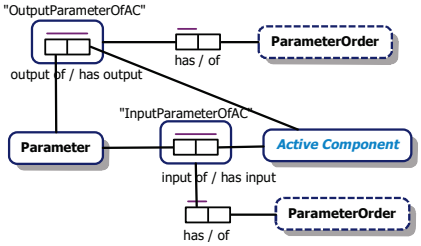


Fig. V.3: AC parameters model

The `Parameter` resource is used to represent the input and output parameters of `ACs` and `UI Elements` as illustrated in Figure V.3 for the model ofs `AC` parameters. Each `Parameter` contains a name, type and value. The `notifier` AC has a `contact list` as input parameter as shown in Figure V.2c. When Lucy logs in, the navigational link is triggered, instantiating the AC with her contacts as input parameter. Further, the `Layout` resource is used to set the layout style, such as grid or column layout and the `Property Set` is used to group properties. These are mainly used to hold styling properties as shown in Figure V.2b, where the `FUI` is composed of `DComps` with a certain `Layout` and user-specific `Property Set`.

With our conceptual model we show how *reusability*, *flexibility* and *extensibility* can be provided using the RSL link service, the introduced resources and concepts. In contrast to

existing systems, we do not distinguish between physical and digital UIs in our core model. Finally, we want to promote end-user development by allowing users to create UIs by simply linking components.

VI. Discussion and Future Work

We have proposed a new unifying approach for the development of user-defined adaptive distributed hybrid UIs where users can create smart UIs based on the strengths of both model-based and manual techniques. A major issue of MBUID is the complexity of the models and notations which makes the tools hard to learn and use [5]. Therefore, we reduced the modelling to a single expressive model where users can link ACs and UIes to form a user interface. However, this is still complex for end users and more work is needed to investigate the appropriate metaphors for hiding the complexity of the underlying model. Our goal is to include end users in the UI development process. For this reason we plan to create an end user authoring tool based on the concepts introduced in this paper.

From related work we have seen many existing systems for adaptive, distributed or hybrid UIs. However, none of them supports the creation of UIs that are adaptive, distributed as well as hybrid and we would have to use a combination of the existing systems with different models, setups and configurations for each of them. In order to simplify this process, we introduced a *unified approach* supporting *all* three aspects. Therefore, as a first contribution, we proposed the eSPACE *reference framework*, which helps structuring the development process of smart UIs and supports runtime adaptation and distribution as well as physical UIs. Further, we have seen that most of the existing systems are limited in terms of *flexibility*, *customisation*, *extensibility*, *distribution granularity* and *reusability*. We tackle *all* these limitations with our *conceptual model* that is based on the RSL hypermedia metamodel. The potential of our model has been illustrated with some examples. Our model can adapt to evolving user needs, technologies and environments by introducing new `Preferences`, `ACs`, `Devices` and `Physical Objects`, which shows the flexibility and extensibility of our approach. Based on our conceptual model, adaptive distributed hybrid UIs which support distribution at a fine level of granularity can be created by using `DComps` and `Selectors`. In addition, our model supports runtime adaptation based on `Context Resolvers` and a user's `Preferences`. By using an RSL-based link service, our components can easily be reused by simply linking to them. This allows for new compositions and hereby promotes extendibility and reuse of adaptation and distribution rules which is not offered by most existing work. While we have a functional implementation based on the presented model, in future work we plan to provide a development framework and end-user authoring tool as well as a proof-of-concept application. Finally, with our reference framework and conceptual model, we want to support the community in providing a new way of thinking about user interface development for adaptive distributed hybrid UIs.

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Executing IoT Processes in BPMN 2.0: Current Support and Remaining Challenges

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***Abstract*—The Internet of Things (IoT) has seen a vast surge in recent years, both in academia and in industry. Business processes are starting to take advantage of IoT to interact with the increasingly connected and dynamic physical environment. Recent literature has focused on analysing how this interaction between processes and IoT devices can be modelled, i.e. how the process can be described for discussion purposes. However, little attention is given to configuring the execution of these IoT-based processes. IoT-enhanced processes should indeed be able to incorporate IoT devices in the endeavour of process execution. This paper discusses research challenges in IoT process configuration and execution using the executable Business Process Model and Notation 2.0 (BPMN 2.0) standard. As such, we constitute an agenda for future research.**

Keywords. Internet-of-Things, IoT, Internet-of-Things Processes, IoT Processes, Process Execution, IoT Process Execution, Process Automation, IoT Process Automation.

I. Introduction

The network of interconnected devices that constitute the IoT keeps growing. A plethora of devices are used to facilitate both businesses and individuals in their daily endeavours. The application areas are both vast and diverse, ranging from smart home environments [1] to medical monitoring systems [2]. Usually, a single device does not suffice to encapsulate the physical complexity and therefore multiple devices are combined to render a system that accommodates the reality. Business processes can benefit from IoT by interacting with these devices to steer their behaviour. Ideally, the business process is in turn capable of adapting to its execution environment by tailoring the process to case-specific needs as demanded by the context. This integration of IoT and business processes has enjoyed significant attention in literature, and in particular when it comes to the integrated modelling of processes and IoT devices [3]. This interaction between IoT devices and the business process remains of paramount importance during the execution of the process as well. However, very few researchers have investigated this topic, while only providing partial solutions. In this paper, we approach that gap by contributing an incomplete yet indispensable set of research challenges that need to be tackled to achieve IoT process execution using the Business Process Model and Notation 2.0 (BPMN 2.0) standard [4]. We focus on BPMN 2.0 since it is an executable and widely accepted standard in industry and academia. Furthermore, BPMN 2.0 adheres to the model-driven development (MDD) paradigm, which recognises that models rather than computer programs are the primary focus and drive of software development. As such, models need to be detailed enough to be executable. Though detailed, models should be abstract of the technology used, as the technology should be made explicit during the execution of the system.

This paper is structured as follows. Section II provides background information on process execution, the Internet of Things, the link between IoT and business processes, and the related work on the execution of IoT processes. Section III provides a real-life IoT healthcare running example which will be used to illustrate the challenges. Section IV discusses which elements of BPMN 2.0 are suitable for IoT process execution. In Section V we identify a set of challenges that need to be tackled to guarantee the correct execution of IoT-enhanced processes, and we identify works that partially address these challenges. Finally, Section VI concludes and provides directions for future research.

II. Background and Related Work

In this section, we give an overview of concepts and research areas that are relevant for the execution of IoT-enabled business processes.

A. The IoT paradigm

IoT refers to the ever-growing network of interconnected devices. Generally speaking, an IoT environment is populated by two kinds of devices: sensors and actuators. Sensors serve as a mechanism to capture reality and are therefore the source of IoT data towards the system. Actuators on the other hand operate in the reverse direction, i.e. they change the reality by activating a physical reaction that is initiated by the system. Typical sensors are for example humidity sensors, light sensors, camera sensors, or heart rhythm sensors. On the other hand, typical actuators can be an electric motor, a heating actuator, a sprinkler system, or a speaker. Data collected by IoT devices is considered to be part of the context information [5], [6], i.e. the information describing the conditions under which the system operates. Relevant context information might for instance include the location of an object, the humidity level, and the temperature. Thus, IoT devices aid in digitising the context that manifests itself in the physical environment.

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B. Business processes and their execution

The field of Business Process Management (BPM) is concerned with defining and executing business activities within an organisation. The more context-intensive the environment in which the processes takes place, the more challenges arise regarding the modelling and execution of said processes. A process can be specified and executed using the BPMN 2.0 standard. The models expressed in BPMN 2.0 and saved in XMI [7], are interpreted by a process engine, like Camunda [8], to execute the corresponding tasks as specified in the models.

C. IoT business processes

Recent literature has focused on incorporating IoT into BPM [3], [9]. IoT and business process integration can be twofold. By definition, IoT business processes are enacted in a dynamic and highly connected physical environment. Since IoT is a technology that can be used to digitalise the context of a system, the process is granted the capability of both understanding its context and of changing it through IoT devices. This was also firmly stressed in [3], indicating that IoT technology can help concretising abstract process models and help the processes deal with new situations. Therefore, on one side IoT devices can be used to digitalise the context of a business process and consequently to incorporate the context into the process execution. That way, an abstract process model can be made concrete for context-aware execution [3]. On another side, IoT devices can be used to automate tasks. This can be a physical task, such as opening the curtains in a smart home, or a digital task, such as sending a message or notification to a system or a human user.

Most papers on the cross section of IoT and process management mainly deal with the integrated modelling of IoT devices in business process models. Examples can be found in [10]. Few works, however, do touch on the subject of configuring IoT processes for execution, e.g. [1]. Most of them rely on code generation, such as [11]. Others use existing process engines for model interpretation, while resorting to code generation for the concepts not supported by the process engine [12]. Another approach is to avoid code generation and to extend an existing process engine to support the newly introduced constructs [13], or to develop an entirely new custom process engine [14].

III. Running Example of an IoT Process

Consider a patient health monitoring system for a person diagnosed with the Chronic Obstructive Pulmonary Disease (COPD). COPD is a disease that obstructs the lungs and obstructs the airflow and breathing of the patient. Acute attacks of the disease can happen. In that case the patient can experience uncomfortable complications such as fast breathing, a fast heart rate, hyperactive use of muscles, and a cold skin [2]. In scientific literature it has been recognised as well that an IoT-based patient monitoring process can help increase the life quality of the patient and decrease the risks that are inherent to the disease [2]. Multiple sensors and wearable technologies exist that can collect patient data relevant for the patient monitoring process [2]:

- Electrocardiogram (ECG) sensors monitor the heart.
- Respiratory sensors check the breathing rate.
- Skin temperature sensors monitor the skin temperature.
- Muscular Electromyography (EMG) sensors monitor the muscle activity.
- Blood pressure sensors measure the blood pressure.

All these sensors collect measurements on the patient's health. IoT settings are often data- and decision-intensive. Note that a single sensor or even a few sensors combined are not enough to capture the COPD. For instance, the patient might take a walk outside in the winter and a sensor registers a low skin temperature. In that case, the patient is not necessarily suffering from COPD at that moment. However, an expert can build patient-specific decision rules to capture COPD in such a monitoring system. For instance, if the sensors register a low skin temperature, a short and fast breathing rate, together with high blood pressure, the monitoring process might decide that the patient is suffering an attack and running out of oxygen. In such a situation the process can trigger the administration of an oxygen mask to the patient. An illustrative COPD monitoring IoT process is given in Figure 1. First the heart rhythm of the patient is checked and the emergency alarm is activated if needed. Afterwards, the severeness of the COPD is assessed, and given the assessment, the process ends or treatments with oxygen masks or inhalers are carried out.

IV. BPMN 2.0 Support for IoT Process Execution

To achieve IoT process execution, IoT devices must be linked to process elements as described in Section II-C. The BPMN 2.0 standard offers different mechanisms that could be used to establish this link. We can group these mechanisms as follows:

1) **Tasks**. The latest BPMN standard defines three types of automated tasks:
   a) Script tasks have scripts attached to them that are written in a language that the process engine can parse and consequently execute in an automatic fashion.
   b) Service tasks are tasks that invoke an application or service to automatically complete the task. Since IoT devices can be managed by IoT services that are invocable by other systems, the service tasks are a suitable mechanism to link the IoT infrastructure to the executable business process. The service task can forward a method call to, for instance, a Java delegate class, which in turn implements an IoT service. That way, communication and data propagation between IoT devices and the business process can be implemented.
   c) Business rule tasks can be used to incorporate IoT resources into the business process. IoT data collected by the IoT devices can have the role of input data to the decision logic hidden behind a business rule task. The business rule task can possibly invoke a separate decision model that encapsulates the logic [15], [16].

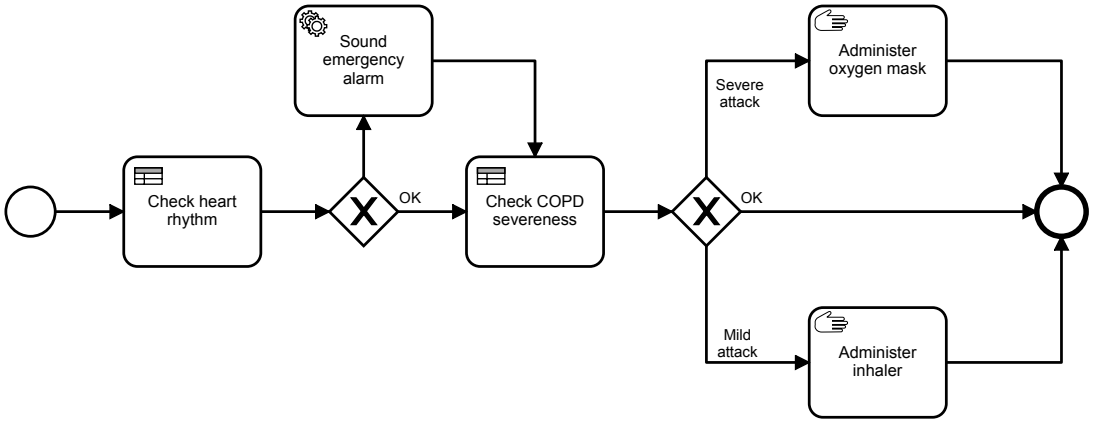


Figure 1: A process model for a COPD monitoring IoT process.

Figure 2 depicts the task types that are suitable for modelling IoT processes, i.e. a script, service, and business rule task according to the BPMN 2.0 standard [4].

2) **Events**. Another way to establish communication between IoT devices and the business process is the use of events that are triggered by an IoT device. If an IoT device registers an action in the physical world, this is reflected in the process by triggering an event. The execution of the event can subsequently trigger a part of the process. Similarly, the process can trigger an IoT device if a certain event manifests itself.
3) **Resources**. Note that the IoT devices can be viewed as resources of an IoT process. According to the BPMN 2.0 standard specification [4], the resource class in the meta model is used to specify resources that can be referenced by activities. These Resources can be human resources, but also any other resource assigned to activities during process execution. Furthermore, the standard defines resources as abstract, i.e. it only defines the resources without specifying which specific resource is allocated to the process element. Actual resource allocation is resolved at runtime. Given that IoT devices can be viewed as resources, the integration of IoT technology and business processes can be approached in a BPMN 2.0 compliant manner. Consider IoT devices as resources which can be invoked from the process model. Since the standard specification considers abstract resources, this can be achieved without administering changes or extensions to the standard BPMN specification. Furthermore, the existing BPMN 2.0 elements with automation properties, such as service tasks and business rule tasks, can be used to execute the IoT process.
4) **Data**. Notice that the data interchange between the IoT devices on the one hand and the IoT process on the other is of paramount importance in a highly interconnected and dynamic setting where the IoT data drives the decisions made in the process. Such a setting was illustrated in the running example in Section III, where the decisions in the process are driven by a data collected from multiple IoT devices. The IoT infrastructure produces plenty of data that can be relevant for the process. This data needs to be interpreted and correctly utilised by the IoT process. Thus, IoT processes are strongly data-intensive as the data perspective of IoT processes revolves around data elements being consumed, produced and exchanged during process execution. This emphasises that a critical resource for an IoT process is the IoT data itself.

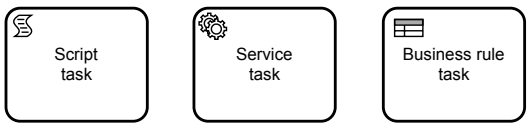


Figure 2: BPMN 2.0 script, service, and business rule tasks.

V. Challenges

Although the BPMN 2.0 standard already offers good support for different aspects of IoT process execution, some challenges still remain. Here, we enumerate a set of research challenges that need to be addressed to guarantee a sound IoT process execution, relying on the BPMN 2.0 standard. For each challenge we follow the same structure: we briefly describe the challenge, provide an illustration based on the running example in Section III, and describe relevant literature that tries to approach the research gap described in the challenge. An overview of the challenges is provided in Table I.

A. Resource allocation challenges

Inherent in IoT processes is the use of IoT devices as resources for task automation and context adaptation. In what follows, we point out challenges for IoT resource awareness in processes.

Challenge 1 (C1): IoT resource-awareness in tasks

1) Challenge description: In the previous section, we discussed the current support of the BPMN language towards incorporating IoT devices in the business process from a modelling perspective. The challenge is to configure the IoT

process in a technology-independent way, yet with a sufficient level of detail to interact with the available resources at execution time.

2) Example: Take for instance the *sound emergency alarm* service task of the running example in Figure 1. The service task is linked to the *alarm* device in the connected reality. The execution of the *alarm* device corresponds to the execution of the *sound emergency alarm* service task. Here it is clear that the business process is guiding the use of the IoT technology in the physical world. However, as previously mentioned, the other direction of integrating IoT devices and the business process is a possibility as well. Namely, the IoT devices can be used to digitalise the context in which the business process is executed. This can for instance happen through the *check heart rhythm* and *check COPD severeness* business rule tasks in the process model in Figure 1. The logic hidden behind the business rule tasks is dependent on data collected from the IoT resources.

3) Possible solutions: Researchers have argued that BPMN 2.0 is capable of modelling IoT processes without necessarily extending the existing standard specification. For instance, [11] shows how BPMN elements can be used to model Wireless Sensor Network Applications. The devices and actions performed with the devices are not represented in the model. Thus, no discrimination between regular automated tasks and IoT tasks is present in these models, both when it comes to process modelling as well as process execution. The service tasks simply call upon a service responsible for managing an IoT device. Others, however, have indicated the need to distinguish between regular automated tasks and IoT tasks in the design phase. They propose a visual discrimination between regular automated tasks and IoT tasks, as well as between regular events and IoT events [9]. They link IoT resources to the process by adding a new symbol indicating that an activity or event is linked to an IoT resource, and they also extend the meta model to include the newly proposed types of IoT tasks and events. These newly defined process elements can be made executable through code generation, by extending existing process engines to incorporate the new elements, or by developing a custom process engine. Note that such an approach deviates from the standard BPMN 2.0 support as described in Section IV. Hence, a trade off exists between conforming to the standard specification or extending it for IoT purposes. The former guarantees that the IoT process remains executable according to BPMN 2.0, while the latter explicitly models IoT devices in the process.

Approaches modelling the IoT device within the business process are straightforward as they resort to a one-to-one mapping between process elements and IoT devices. However, a one-to-one mapping between an IoT device and a process element is not necessarily satisfactory. Furthermore, IoT processes can rely on multiple IoT devices, even within the same process element. Therefore, rule-based IoT resource allocation should be investigated, in analogy with works on regular resource allocation and scheduling in business processes [17].

Challenge 2 (C2): IoT resource binding at runtime

1) Challenge description: In an IoT infrastructure, multiple devices that monitor or execute the same physical reality can be put in place. In such a setting, rather than a straightforward one-to-one mapping of IoT resources and process elements, as described in the previous challenge, a selection of the proper resource at runtime is necessary. This link between the process model and the IoT devices should be established depending on certain criteria, such as device availability, accuracy, malfunctioning, and so on.

2) Example: Take for instance the *sound emergency alarm* service task of the running example in Figure 1 which is linked to an *alarm* device in the connected reality. The most relevant *alarm* device can be selected for execution, e.g. the speakers present on the floor of the hospital where the patient is, or the smart phone of the physician that monitors the patient if the physician is currently not on the same floor.

3) Possible solutions: Optimised resource allocation is considered an important challenge in the merger of IoT technologies and business processes [3]. Among other solutions, the logic on which device to select at runtime can be modelled in a decision model. A standard suitable for such decision modelling is the Decision Model and Notation (DMN) [18] provided by the Object Management Group. This model can be invoked at runtime to dynamically bind an IoT device to the relevant process element. That way, a more efficient IoT resource utilisation can be achieved and process execution can be safeguarded. A similar approach that aims at resolving IoT resource conflicts in business processes is suggested in [19]. Here, the authors define event condition action (ECA) statements indicating when and under which conditions an already allocated resource should be substituted with an equivalent resource.

Challenge 3 (C3): IoT resource malfunction event handling

1) Challenge description: Once IoT resources have been allocated to a process element, be it by a simple one-to-one mapping as discussed in *C1* or by dynamic resource binding at runtime as considered in *C2*, the IoT resource may still be deficient or inaccessible during the enactment of the relevant process elements. These unexpected events should be captured in the process. In case an allocated IoT device is not responding or failing, the IoT process might not be able to continue its execution. Such failures should be noticed and captured in the process. Resource failure monitoring is crucial for the quality of task execution [3].

2) Example: In the running example of Figure 1, such a safeguard should be foreseen at service task *sound emergency alarm*. If the *alarm* device fails during execution, the consequences for the patient being monitored are potentially severe.

3) Possible solutions: In the case described in the example, opting for process termination is not an option. Therefore, a routine should be put in place to select a different alarm device or to convey the message to the physician in some other manner, e.g. by sending a text message or smart notification to the physician's smart phone or by initiating an automated call.

In case of multiple alarm devices, by re-invoking the service task responsible for the operation of the failing device, an alternative device can be dynamically bound to the service task. A modelling pattern should be foreseen in the process model to capture failures and to call upon another IoT device to perform the execution. Remedying resource malfunction complications can be done by for instance setting up error event handling modelling patterns to assure that processes can continue, terminate, restart, or that they can be partially rolled back to reiterate the failed activities with other available resources. In [11], some error handling patterns for wireless sensor networks (WSN) have been introduced. The patterns rely on events that capture undesirable behaviour. Another interesting line of research are self-healing business processes. Here, the idea is to replace at runtime services that fail during process execution. An example is provided in [20], where the authors define monitoring and recovery actvities to ensure process resilience.

Challenge 4 (C4): IoT data retrieval: push vs. pull

1) Challenge description: Another important challenge to consider is understanding the context situation in which the process is being executed. This can be done by pushing the data to the process from the IoT devices or by the process pulling the data from the devices on demand. In the former case a sensor performs a data push to the process. However, given that IoT devices often provide a stream of data, the data pushes are likely to happen frequently.

2) Example: In the running example of Figure 1, the data necessary for invoking the business rule activities *check heart rhythm* and *check COPD severeness* can be pulled from the IoT sensors described in the running example in Section III. Notice however, that a data push from the IoT devices to the process might be required as well in certain situations. If the heart rhythm sensor notices a steep increase of the heart rhythm which is followed by a quick decrease in a short period of time, this might point towards heart arrhythmia. If the heart rhythm sensor captures such behaviour, the IoT device should push a notification to the process. A data push from the IoT device to the process can for instance be captured in the process through an event, which in turn can trigger activities that update the patient's medical file and that automatically warn a responsible physician.

3) Possible solutions: As the example illustrates, a trade off between pushing IoT data to the process and providing the process with IoT data on demand should be made when setting up the system to guarantee effective process enactment. The data can be captured in the process by, for instance, events that are triggered when the IoT device pushes data to the process. Another possibility is for the process to pull the data captured by the devices on demand. The devices register data and store it into a database or knowledge base, if the most current data update by the devices is considered relevant. In such a way, the data stored in the database or knowledge base is the most recent relevant data. The process can then pull necessary data from the database whenever it is needed in the process. This can for instance be done by using a service task which queries the database and retrieves the necessary data. This data can subsequently be used in the following stages of the process. Additionally, a combination of push and pull is possible as well, i.e. some IoT devices store data in the database such that the process can pull data on demand. Other IoT devices immediately notify the process by for instance triggering an event in the process that captures the sent data and provides it to the process for further interpretation.

Existing work on the integration of ontologies and task models [21], [22] in IoT environments, as well as the integration of ontologies and Petri Nets [1] can provide inspiration towards solving the data retrieval challenge. Furthermore, relevant works also include those that provide possibilities to retrieve data based on semantic queries over ontologies [23].

B. Communication challenges

Introducing IoT resources to the business process invokes additional questions regarding the communication between the business process and said resources. We elaborate further below.

Challenge 5 (C5): IoT and human resource communication

1) Challenge description: Regular non-automated processes tasks are usually performed by human actors. Whenever users finish a task that has been assigned to them, they indicate this by sending a confirmation to the system. This way, the next task in line becomes enabled and the human resource responsible for the enactment of that task can start with the execution. Notice, however, that in an IoT setting task automation is a commonplace pattern. Hence, certain tasks will not be executed by human resources, but rather by the system itself. This contributes to the co-existence of different types of resources in an IoT process [3]. In such a setting, the system needs to notify the process that the automated task has been executed successfully such that subsequent tasks, be they human tasks or automated system tasks, become enabled. If the subsequent tasks are driven by human resources, the system should notify the users about system task completion and it should indicate that the tasks the human resources are responsible for are permitted to be executed. Thus, a message notification system should be put in place to facilitate the interaction between automated IoT tasks and human user-dependent tasks. Furthermore, these message notifications should be organised in such a way that they maximise effectiveness, i.e. that they do not needlessly bother the receivers of the notifications and that they do not produce non-value adding overhead tasks for the human users.

2) Example: In the running example of Figure 1, the *sound emergency alarm* activity might be executed for a patient and a nurse responsible for the manual activity *administer oxygen mask* starts a shift after the alarm, or the nurse was not able to hear the alarm at the time. In that case the nurse should be notified to indeed administer the oxygen mask to the patient, but to be careful not to move the patient into a bad position given the abnormal heart rhythm as established in the *check heart rhythm* decision activity.

1) Possible solutions: In [24] simple message flows in BPMN between IoT tasks and human tasks have been proposed to facilitate co-existent resource communication. A more advanced approach can be found in [25], where the authors propose considerate notifications which interact with users in a way that is not disturbing for the user. They provide a possibility to personalise and adjust the level of obtrusiveness of the notifications.

Research challenges in BPMN 2.0 IoT process execution
Resource allocation challenges
C1: IoT resource-awareness in tasks
C2: IoT resource binding at runtime
C3: IoT resource malfunction event handling
C4: IoT data retrieval: push vs. pull
Communication challenges
C5: IoT tasks and human resources communication

Table I: Research challenges in IoT process execution.

VI. Conclusion and Future Work

This paper discusses the configuration and execution of IoT-enhanced processes. More specifically, we investigated to which extent the latest BPMN standard supports IoT process execution. To manage this, we consulted existing works on the integration of IoT and processes and we concluded that most research revolves around the modelling of IoT devices in processes. Only a select group of researchers also touch on the subject of configuring and executing the IoT-enhanced process models by either relying on already existing process engines, custom process engines, or by utilising code generation. As most researchers rely on BPMN 2.0 for the modelling effort, we argue that sticking to the core of the standard is beneficial for IoT process execution as well. However, we identified a set of challenges regarding IoT process configuration and execution according to BPMN 2.0. Furthermore, we analysed the literature to identify approaches that address these challenges. However, the approaches presented in literature are either not standardised or not sufficient to tackle the challenges. Therefore, we appeal that these challenges need to be fully remedied to obtain a clear view on IoT process execution.

The identified challenges should be addressed in the future with the aim to solidify the integration of IoT and business processes for execution. Particular attention will be given to alleviate the burdens specified in the research challenges in this paper. More specifically, we will focus on dynamic IoT resource binding at runtime. Additionally, we will study change patterns for IoT process evolution at runtime.

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Towards an integrated methodology for the development of blockchain-based solutions supporting cross-organizational processes

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***Abstract*—Blockchain technology is argued to have the potential to facilitate the development and improvement of cross-organizational business processes, on various aspects of the business process management discipline. In this paper, we review existing work on the use of blockchain technology to support business processes with a focus on cross-organizational settings. Based on this, we suggest to view blockchain as a software connector helping organizations to integrate the IT systems they use to support business processes. In addition, this paper suggests to use a model-driven engineering approach for the development of such connectors. By doing so, the need to develop a methodology helping to model and implement blockchain-based software connectors supporting cross-organizational business processes is highlighted. By adopting such an approach, organizations would be able to facilitate and speed up the development of blockchain-based solutions. This in turn would facilitate experimentations with this technology, which is considered as an important phase for organizations to derive value from it.**

Keywords—cross-organizational business processes, business process management, BPM, blockchain, model-driven engineering, MDE, methodology, software connector

I. INTRODUCTION

Organizations offering services as well as research on this topic has traditionally focused on the relationship between the organizations themselves and their customers. More recently, this view has expanded to consider the various service providers that are contributing to the delivery of what is called a customer journey [1]. In this context, service providers can take a leading or subordinate role in the organization of the customer journey, or leave the integration function up to the customer [1]. In that latter case, she will have to assemble and coordinate interrelated services herself to achieve a particular goal [1]. There are many cases where the journey followed by a customer involves interactions with multiple organizations. By looking into that set of interactions instead of looking at individual interactions alone, different insights can be gained [1]. The network of providers that are responsible for the delivery of services that, in the mind of the customer, are seen as one overall, integrated service can be considered as a unit of analysis for services [1]. Although the idea of optimizing customer journeys may seem focused on business-to-consumer (B2C) interactions, integrating Business Processes (BPs) across organizations is also valuable in business-to-business (B2B) interactions. A typical example is the integration of BPs along a supply chain, which can help improving the operational and the business performance [2].

Considering this, it is important for organizations to further develop collaborations and integrate their BPs. This is particularly relevant nowadays, considering that the majority of BPs are going beyond the organizational boundaries [3], [4], and hence are characterized as cross-organizational.

Services can be considered as a type of processes [5] and can be approached from a Business Process Management (BPM) perspective. BPM includes methods, techniques and tools aiming at supporting the design, the enactment, the management and the analysis of BPs [6]. Using this perspective, organizations can attempt to increase the added value they deliver to their customers, the value they are able to capture and to make coordination with partners more efficient. This remains valid regardless of whether customers are consumers or other organizations.

To innovate and/or improve their BPs, organizations need to use certain tools. Information Technology (IT) is one of them and was considered by many as the most powerful one, already in the 90s [7, Ch. 1]. Nowadays, IT can be used for a variety of BPM activities, including the execution of existing BPs and their reengineering in the light of the new capabilities offered by IT. Different types of IT systems can be used to do so, including Workflow Management Systems (WfMSs), Business Process Management Systems (BPMSs) and Process-Aware Information Systems (PAISs). More details on the distinctions between these are available in [8]. Such systems have been well adopted by organizations in order to effectively and efficiently support the execution of their BPs, but they are often confined within organizational boundaries [9]. In order to go beyond such boundaries, there is a need for organizations to integrate the IT systems they use to support their BPs. Doing so can yield a number of benefits including more transparency, increased integration, faster communication and higher throughput [10]. Although not all processes rely on IT to support them, only such processes are considered in the scope of this paper. Furthermore, we focus on the integration of IT systems to foster the development of cross-organizational business processes but it is important to underline that other (complementary) solutions can be considered to achieve this goal.

A central requirement to be met for organizations to collaborate together and integrate their processes revolves around trust. For instance, collaborating organizations integrating their systems need to have a solution that provides trustworthy monitoring information about the execution of the process. In this context, trustworthy means that it has to reflect reality and ensure that this history has not been tampered with. Further details on such matters are discussed in the next sections of this paper. Such a trust requirement is particularly critical considering that the lack of trust between

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organizations can hamper the innovation and development of cross-organizational BPs [11].

In this context, blockchain technology is argued to be a potential solution to solve the issue of trust between organizations, and thereby facilitate the development and innovation of cross-organizational BPs. However, as it is still considered as a new technology, research on the use of blockchain for BPM activities is still scarce and many related questions remain unanswered [8].

The remainder of this paper is organized as follows. First, section II provides a generic introduction to blockchain technology. After that, section III discusses the role of blockchain as a software connector and suggests the use of Model-Driven Engineering (MDE) approaches for the development of blockchain-based artefacts. Then, section IV presents opportunities and challenges of blockchain technology to support BPM activities with a focus on IT systems supporting these. After that, section V discusses existing work with regards to these challenges and opportunities. Furthermore, it motivates the interest of a software connector view in order to design blockchain-based systems aiming at facilitating the integration of IT systems supporting cross-organizational BPs. In the same section, the need for a methodology helping to build blockchain-based software connectors using a MDE approach is underlined. Finally, section VI closes this paper with a conclusion.

II. Introduction to Blockchain

A. Origin and potential impact

In 2008, a person or group under the pseudonym of Satoshi Nakamoto published a white paper describing an alternative, digital and distributed currency called Bitcoin [12]. This currency relies on a distributed ledger technology that is used to record transactions and is referred to as blockchain technology (or simply blockchain in the rest of this paper). With the developments of this underlying technology, a much broader range of applications was made possible. Blockchain is argued to have the potential to disrupt many industries, and may have brought us at the dawn of a new revolution [13]. The industries and activities that can potentially be impacted by this technology include but are not limited to financial services [14, Ch. 3], healthcare [15], governmental services [13, pp. 44–52], energy [16], insurance [17] and supply chain management [18], attracting the attention of both researchers and practitioners.

The expectations and promises related to this technology are numerous. They range from more efficient operations for organizations to the possibility for entities to interact directly with one another without the need of a Trusted Third Party (TTP) or other intermediary. In turn, blockchain can help reduce costs and delays while giving entities more control over whatever is managed using this technology (money, creative content, data, etc.).

B. Characteristics

Blockchain can first be described as being a distributed database (or ledger, since it records transactions) that is shared among and agreed upon a peer-to-peer network [19]. In a blockchain network, the peers (also called nodes) are maintaining a copy of the ledger and validating the transactions that are to be recorded. This is managed by the network of peers, and not by a central authority having the possibility to accept, reject or even modify transactions.

In order to be recorded in the ledger, the transactions (which are timestamped) are grouped into blocks. Whenever a new block is added on a blockchain network, it includes a hash of the previous block that was added. In doing so, blocks are linked together and form a chain of blocks, hence the name of blockchain. Whenever a new block is created, it has to be verified and added to the blockchain. In order to do so, particular nodes are selected to validate the block and then publish their version of the blockchain which contains the new block for the rest of the network. The fact that blocks are linked together using hashes of previous blocks makes it easy for a participant to verify whether or not the history of transactions as published by a given node has been tampered with. Indeed, changing the details of a transaction changes the content of a block. Changing the content of a block in turn changes its hash and therefore breaks the chain of blocks, which means that past transactions have been tampered with. Assuming that a transaction has been validated by the relevant nodes, it will get propagated to all the other nodes (as part of a block) and cannot be deleted or changed.

Finally, transactions need to be cryptographically signed by their initiator (e.g. a person willing to make a payment on the Bitcoin blockchain), preventing entities to write transactions on behalf of others without having their cryptographic keys.

As a result of these characteristics, blockchain can be defined as "[…] a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions that are secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity" [19, p. 3].

Since the development of the Bitcoin blockchain, other blockchains started to appear, offering different characteristic and being more (or less) suitable for different types of use. The Bitcoin (initial) blockchain is focused on currencies and payments [13, Ch. 1]. Although such a blockchain is capable of handling transactions of various types (including non-financial), more recent implementations such as Ethereum [20] added an additional layer focusing on the development of programming code that can be deployed and executed on a blockchain [13, Ch. 2]. Such a code is referred to as a smart contract and their development makes blockchain not only a shared database but also a shared execution environment.

C. Challenges

As a new technology, blockchain faces many challenges anchored in various disciplines. In [21], a research framework around blockchain is proposed, and identifies a number of questions that still need to be answered. Among these are included the following:

- *Q1*: How can interfaces between smart contracts and existing [IT] systems be designed to increase interoperability?
- *Q2*: How can firms utilize blockchain features for their own business processes?
- *Q3*: How does blockchain provide added value for companies to conduct transactions […] with customers, other companies [and] stakeholders […]?

As this paper focuses on the use of blockchain to support BPM activities, such questions are addressed in the different sections that follow. The reader can refer to [21] for more details about the broader challenges faced by blockchain.

III. Blockchain as a Software Connector and Model-Driven Engineering Approach

A. Blockchain as a software connector

As discussed in the previous section (c.f. *Q1*), one of the challenges of blockchain is to integrate smart contracts with existing IT systems. As suggested by [22], this can be achieved by having dedicated integration components on top of a blockchain. Indeed, a blockchain by default only has access to what is on the blockchain. However, smart contracts can emit events that can be captured by external systems, and the different functions that they provide can be called from these. This can happen in a direct way (i.e. by adapting existing systems to make use of blockchain) or using dedicated integration components, as suggested by [22]. With such possibilities and considering blockchain as a shared database and execution environment, it can be used to integrate different systems. In the light of its distinctive characteristics, [23] suggests that blockchain can be seen as a type of software connector.

According to [23], software connectors offer a number of interaction services, defined as:

- *Communication services* focused on transferring data among different components.
- *Coordination services* managing the transfer of control towards different components.
- *Conversion services* adjusting interactions between components and ensuring that each component can process the received information even though it was not initially in the expected format.
- *Facilitation services* support and optimize interactions between the different components (e.g. clearing payments, transactions validation and permissions management).

Seeing blockchain as a software connector provides a number of advantages. First, it helps making explicit the necessity to make a number of architectural choices impacting performance and quality attributes of the systems such as security, privacy, scalability and sustainability [23]. Although such attributes are not deeply discussed in this paper, they are very important to consider when designing blockchain-based solutions. A second advantage claimed by the authors of [23] after applying this view on a number of cases is that it helps improve information transparency and traceability. Both of these are important in the context of cross-organizational BPs. Although not explicitly mentioned, some organizations involved in the development of blockchain technologies also share (at least partly) this view [24]. On top of that, it can be argued that the software connector terminology fits well with the needs of blockchain-based solutions supporting cross-organizational BPs. Such a fit is discussed in more details in section IV.

The proposition of the present paper is to adopt the view of blockchain as a software connector in a context where this technology is used to facilitate the integration of IT systems supporting a number of BPM activities across organizations.

B. Model-driven engineering approach

Other challenges related to the use of blockchain include the development and implementation of blockchain-based artefacts. Assuming that blockchain is used as a software connector, the question to know how to develop these remains open. As with any technology, an organization willing to investigate, experiment or implement blockchain-based solutions requires people with knowledge and skills around it. However, people meeting such requirements are still scarce and the development of blockchain-based solutions remains difficult due to the steep learning curve [25] and lack of adequate tooling for developers [8]. This difficulty to find appropriate people is a challenge that organizations investigating blockchain currently have to face. Another challenge involved in the development of smart contracts results from their immutable character. Once a contract is deployed, it is not possible to change it or to remove it. Therefore, programming or logic errors in their code can have costly consequences. In addition to that, executing smart contracts on certain platforms induces costs based on the computing resources that are required for the execution. Therefore, producing optimized and high-quality smart contracts is a critical issue that has to be considered. Finally, there are a lot of different blockchain implementations that are available, and it is an ecosystem evolving quite rapidly. Therefore, it would be valuable for organizations to have the ability to implement blockchain-based solutions on different implementations without having to re-develop their artefacts for each platform.

One of the solutions that can facilitate the development of blockchain-based artefacts in such a context is the use of MDE approaches [25]. Such approaches consist in transforming a (set of) model(s) into code that can be executed. The code that is generated is typically based on best practices, is expected to be of high quality and is generated consistently. This helps mitigating the issues mentioned in the previous paragraph. MDE approaches also allow domain experts to be more closely involved in the development of the software, potentially allowing them to generate working prototypes on their own, and without the (direct) need of computer scientists or more technical people.

Our suggestion in the present paper is to make use of MDE to design and implement blockchain-based solutions as software connectors. Such connectors could then be actually implemented on different blockchains using the same models as initial input while providing more flexibility to domain specialists, reducing the need of blockchain specialists and providing high-quality smart contracts.

In the section that follows, opportunities and challenges of using blockchain for BPM activities across organizations are summarized, using [8] as a framework to structure the discussion. While discussing this, the present paper highlights the implications of adopting a software connector view of blockchain in this particular context and the implications of the use of MDE to design and implement such connectors.

IV. Blockchain and Business Process Management

As stated before, blockchain represents a number of opportunities and challenges for BPM. In [8], a review of these is proposed and structured along two dimensions. The first one is made of the stages of the traditional BPM lifecycle: process identification, discovery, analysis, redesign, implementation, execution, monitoring and adaptation and

evolution. The present paper focuses on IT-related aspects of the implementation, execution and monitoring phases of BPs that are supported by IT. The second dimension used to structure the review of [8] is made of BPM capability areas: strategy, information technology and people. In this paper, only human and strategic aspects are discussed. The first one is only briefly discussed in section III.B while the second is further developed in the present section. Through the discussions in this section, partial answers to questions *Q1, Q2* and *Q3* (c.f. section II.C) are provided.

A. Cross-organizational business process monitoring

When organizations integrate their processes, there is typically an underlying contract specifying the terms of the collaboration with regards to the different participants (obligations, rights, rules, etc.) [26]. As part of such contracts, rules may specify Service Level Agreements (SLAs) and compensation mechanisms to be applied in case SLAs are not met or in case of non-compliance with the agreed upon process. Considering this, records about the execution of the process represent the basis information to verify whether or not the terms of the contract are respected, and to support the enforcement of the contract (e.g. enforce a compensation mechanism) [26]. Therefore, this information needs to be indisputable and recognized by all the participants [26].

When different organizations integrate their IT systems supporting the execution of BPs, different options can be considered. One of them is to implement a Service-Oriented Architecture (SOA). In such an architecture, different system components interact through messages that can be captured and that represent monitoring information about the execution of BPs. Although such a history of messages could be stored and managed in many different ways, the characteristics of blockchain make it a particularly interesting candidate. Indeed, message exchanges can be stored on a blockchain and inherit its characteristics (a.o. the immutable and tamper-proof character), ensuring that records cannot be tampered with and are not under the control of a given participant or TTP [8], [22], thanks to the distributed and peer-to-peer nature of the technology. This contributes to the creation of an indisputable basis of information to enforce the contract underlying the collaboration. Assuming that a given entity has access to that history of messages, independent monitoring of the BP is possible [8].

Having a history of message exchanges that can be trusted and accessed to prove the (non-)compliance with agreed upon aspects of a collaboration contract can reduce the risk faced by organizations involved in such collaborations. Thereby, it can facilitate the development and innovation of cross-organizational BPs. With such ideas in mind, a number of platforms (including [25], [22], [26] and [27]) relying on blockchain to (among others) monitor the execution of BPs have been developed.

Although not initially classified in the monitoring stage of the BPM lifecycle, having access to trustworthy records about the execution of BPs can also yield interesting opportunities related to process discovery. Indeed, it could be analyzed by an organization (e.g. using process mining techniques) to establish trust in the way a (prospective) partner operates [8]. Although this can be qualified as an opportunity, it can equally be qualified as being a risk since other organizations could apply the same idea and reverse-engineer internal BPs [8].

Assuming that blockchain is used to create a shared repository of trusted records about the execution of BPs, it can be considered as providing communication and conversion services, as defined in section III.A. The communication service here would be used to send data about process execution from the systems used within one organization towards the blockchain. It can then be reused by a given software component whose goal is to display or manage monitoring information about the BP. The data that are transferred can be converted into a format different from the one in which they are initially sent. Doing so using smart contracts consists in building a conversion service.

B. Business process implementation and execution

While some existing platforms supporting BPM activities and relying on blockchain focus on monitoring aspects (e.g. [26]), others (e.g. [22], [25] and [27]) propose to include the actual implementation and execution of BP (choreographies) on blockchain. Indeed, smart contracts can be used to enforce a sequence of activities, require particular inputs for particular tasks, produce outputs, etc. and different instantiations of a given smart contract can be used to represent different instances of a BP.

While it is possible to implement fully-fledged BPMSs relying on blockchain, another possibility is to integrate smart contracts with existing IT systems used by organizations to support their BPs.

Considering that blockchain is used to manage the implementation and execution of BPs, it can be considered as providing communication and coordination services as defined in section III.A. The communication service is here mainly about communicating the state of the process execution along with data that are required for the execution itself. Depending upon the state of the process and the process itself, blockchain could define what activity needs to be executed next and by which participant. Assuming that only certain participants can conduct certain activities, the blockchain would be responsible for managing the control of the process. It can therefore be seen as a coordination service in a software connector terminology.

When implementing and executing BPs on a blockchain, the advantage of using smart contracts also lies in their immutable character. For instance, if the sequence of activities defined in a process is implemented as a smart contract, participants can be sure that it won't be possible not to follow the agreed upon sequence [22]. In a similar idea, particular activities can be executed directly using a smart contract and without the need of additional systems. Doing so, blockchain provides a number of facilitation services. For more details about the challenges and opportunities of blockchain for BP improvement and reengineering, the reader can refer to [8].

C. Strategic considerations

After having summarized the challenges and opportunities of blockchain for BPM based on the different stages of the traditional BPM lifecycle, this section continues with strategic considerations. Strategic alignment consists in actively managing connections between organizational priorities and BPs, and is typically conducted in a top-down manner [8]. As blockchain represents a potential threat (but also opportunity) for a number of (core) BPs, there is a need for certain organizations to work the other way around. Indeed, they should investigate how they should define/adapt their strategy in the light of the implications of blockchain [8]. It is therefore

crucial for organizations to understand the strategic value that they can derive from this technology.

Although blockchain has the potential to enable new types of business models, its initial impact is considered as being an increase in operational efficiency through the removal of intermediaries and/or efforts related to record keeping and transaction reconciliation [28]. For organizations to reap benefits out of blockchain, [29] suggests a four-step process which includes a prototyping phase. That phase will include a number of adjustments to the prototypes that can later on be validated and scaled appropriately. Starting from the perspective of an organization's business model, [30] identifies two groups of drivers for innovation in business models: internal and external drivers. While external drivers include technological changes (such as the availability of blockchain), internal drivers include the outcomes of the organizational learning process [30]. This process implies conducting and evaluating small experiments (in this context) with blockchain [30].

In order to launch experiments with blockchain, it will be required to create a team or set of teams working on this, potentially with help from external companies [29]. In a context where people having sufficient knowledge and skills are scarce and where development follows a steep learning curve, using MDE can yield a number of benefits. Indeed, it can help create prototypes faster, prototypes of higher quality than what humans would do when developing smart contract code manually, and targeting multiple platforms using a pre-defined set of models. Regardless of the speed and quality of prototyping, it remains important for organizations to select well-appropriated use cases since blockchain is not expected to provide benefits for all types of processes, but this question is not in the scope of the present paper.

D. Research directions

In the previous sub-sections, a review of the challenges and opportunities of blockchain for BPM was presented. It was based on the review suggested in [8], focused on particular aspects, complemented with additional research and analyzed adopting a software connector view. In their review, authors of [8] propose a number of directions for future research, including:

- *FRD1*: The development of a set of blockchain-based solutions for the execution and monitoring of business processes.
- *FRD2*: The development of methods for the analysis and engineering of business processes relying on blockchain technology. The underlying goal is to find ways to efficiently specify and deploy such business processes.

The sub-section that follows provides an overview of the work that has already been conducted and that can be considered as an answer to the future research directions suggested by [8]. Such answers are then analyzed in the light of the suggestions of this paper i.e. to use blockchain as a software connector to support cross-organizational BPs implemented as workflows and to develop these using MDE.

V. Discussion

A. Blockchain-based platforms supporting business process monitoring, implementation and execution

Following the research direction *FRD1*, a number of platforms already propose to support the monitoring and/or implementation and execution of BPs on a blockchain ([22], [25], [26] and [27]). Although they have distinctive characteristics, a common element to three of these solutions ([22], [25] and [27]) is that they use MDE to generate smart contracts based on Business Process Model and Notation (BPMN) models. They also typically make use of dedicated integration components (e.g. [22]) that are used to integrate smart contracts with existing systems, as discussed in section III.A. Other authors also propose to use MDE to manage decisions on blockchain, transforming Decision Model and Notation (DMN) models into smart contracts [31].

Most of the platforms discussed above seem to adopt a BPMSs vision. Although such platforms can be very useful and do provide interesting insights, we believe that an alternative vision of the use of blockchain for BPM can yield different advantages. Instead of seeing blockchain as a platform on top of which fully-fledged BPMSs can be implemented, we believe that seeing blockchain explicitly as a software connector (as suggested by [23]) can be a good way of facilitating the development of cross-organizational BPs. One of the reasons behind this idea is that organizations having invested significant efforts and amounts of money into the development of PAISs (e.g. Enterprise Resource Planning (ERP) systems) are unlikely to replace these by systems relying entirely on blockchain. Indeed, integrating such software so that they can interact with blockchain for different purposes seems to be a more realistic approach. However, the solutions discussed above would make more sense for organizations already using BPMSs instead of PAISs to support their processes.

B. Analysis and engineering of business processes relying on blockchain

After briefly presenting existing platforms supporting the monitoring and/or implementation and execution of BPs using blockchain, the focus is now on research direction *FRD2*.

As stated before, MDE approaches offer a promising avenue for the engineering of systems relying on blockchain to support cross-organizational BPs. In order to use MDE, there is a need to define what needs to be modeled (e.g. roles, access rights, SLAs, activity sequence, data structures, etc.) and what types of models should be used to represent different complementary aspects of the system which is being designed. Existing work so far has mainly relied on BPMN and focuses on the control-flow perspective of BPs, with one of the contributions suggesting to manage decisions on the blockchain based on smart contracts generated from DMN models. Hence, there is a need to further investigate the other perspectives and elements to be incorporated in the system to be designed.

Existing solutions focusing on BPMN and on a control-flow perspective provide useful insights to answer such questions. In addition to that, other work has for instance suggested to adopt an artefact-centric perspective for the modeling of BPs relying on blockchain [32]. Another example of existing work that can provide useful insights is the WSLA framework [33] that can be used to formalize and

operationalize SLAs monitoring and compensation mechanisms in SOAs.

Although existing work can provide insights to answer the questions discussed in this sub-section, to the best of our knowledge there are no methodology proposing an integrated and consistent set of models that can be combined together to design and implement software connectors relying on blockchain to support the integration of IT systems used for cross-organizational BPs.

VI. CONCLUSION

In this paper, we review existing work on the use of blockchain technology to support BPM activities, with a focus on IT-related aspects. One of the prominent interests of this technology in that context is to be used as a platform for monitoring and/or implementing and executing cross-organizational BPs. Existing platforms doing so seem to have the vision of blockchain as a technology underlying new kinds of BPMSs. We suggest to adopt a different view and to consider blockchain as a software connector, as argued by other authors, as it can yield a number of benefits and fits well in the context of cross-organizational BPs to integrate across organizations. In the light of the difficulties to face when designing and developing blockchain-based solutions, relying on MDE techniques offers a promising avenue. In this context, we call for the definition of a methodology allowing to design complementary models that together would offer a complete and consistent picture of the system to be developed, and that could be transformed into code executed on blockchain technology. Such an approach could then be used to implement either production-ready or, at least, experiments using blockchain in the context of cross-organizational BPs. As suggested by different reports, such an activity is crucial in order for organizations to clearly identify and capture the strategic value that blockchain has to offer.

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Value Expression in Design Science Research

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***Abstract*—Design science research has grown into a major research approach in Information System (IS). Most current DSR approaches take a positivist approach that downplays human agency. An alternative framework is transformational design research (TDR), inspired by pragmatism and Rosenstock-Huessy's view on language. This paper's aim is to contribute to TDR by focusing on the expression of values, with a particular interest in values that are embodied in the technology. After a critical review of the traditional Requirement Engineering methods and of the so-called value-sensitive design approaches, we propose a new value expression approach that builds on and extends traditional value modelling. The method is illustrated with a literature example of process mining.**

Keywords— Design science research, value-sensitive design, value modeling

I. Introduction

The role of design in IS research has been a subject of debate for many years. In their seminal article, Hevner et al [24] argued for a full recognition of "design science research" (DSR) in IS, while at the same time providing a set of guidelines on how to sort out the good IS design research from the bad. The core of DSR is summarized as "build and evaluate" a well-described artifact. However, the discussion about design science research in IS so far has at least two major shortcomings. First of all, the DSR formulations such as [24], but also more elaborate ones such as [56] suffer from a positivist "Cartesian" world view that downplays human agency. There is an urgent need to enrich the DSR discussion with alternative world views used in the IS field, such as Heidegger's phenomenology [23,60] and pragmatics [19] – even if these alternatives are not unquestioned themselves. A second gap is that the focus has been mainly on what DSR can contribute to IS, rather than the other way round: what is design, from an informational perspective?

Transformational Design Research (TDR) is being developed as an alternative DSR framework that takes an informational approach, in line with the Language/Action Perspective (LAP – [59,56]). The TDR framework extends LAP by means of the language philosophy of Rosenstock-Huessy, a contemporary of Heidegger. For one thing, TDR views artefacts as bearers of value, and so value expression is one important activity in a TDR project. The objective of this paper is to contribute to TDR by developing an innovative value expression method, building on how values are dealt with in current Design Research methods but also on other sources, in particular, the value-sensitive design tradition.

Apart from the theoretical value – extension of the current DSR toolbox – the results are also relevant in the context of the current need for more comprehensive ethics in Computer Science. In particular, I want to mention Responsible Data Science [2] and Responsible AI [14]. In both cases it is felt that ethics is not something that should be left to the user, the technology itself being neutral. On the contrary, it is stated that there is also a responsibility of the designer/researcher at design time. A value expression method can be a tool to support the systematic exploration of value issues in these domains.

The structure of this paper is as follows. Section 2 gives a summary of TDR and illustrates it with a literature case. Section 3 is a literature review on the role of stakeholder analysis and the treatment of values in design, including value-sensitive design. In Section 4, we present a TDR value expression method and illustrate it by applying it to two IS cases. We finish in Section 5 with general conclusions.

II. Transformational Design Research

Rosenstock-Huessy asked himself the question: how does human language differ from the language of animals? His answer was that speech is a responsive and creative act in which we discover things about ourselves, each other, and the world itself which we would never have chanced upon had we not the power to reframe the universe through speech [9]. So speech changes the world, specifically by revealing what is implicit or not yet realized. In this section, we briefly introduce Rosenstock's view on language and the Transformational Design Research approach derived from it.

A. The Cross of Reality

In [42], essential language is positioned by Rosenstock-Huessy on the "cross of reality", consisting of an axis of time (from past to future) and an axis of space (from inner world to outer world). In his own words:

- When we speak we are connected to the past and the history of mankind because we try to use the *right* words
- At the same time, we look forward to the future by giving a *creative response* to the legacy of the past
- We *express* our inner world - not just putting thoughts into words, but expressing and completing our inner world as we talk
- We *clarify* the outer world as it appears to our senses

What has this to do with design? On the basis of the linguistic character of design [56], it makes sense to see design as a special case of speech act in the Rosenstock sense. Designing is then something that stands at the center of a cross of reality and inherits the creative and dynamic character of speech. This design view is independent of the object of design but I restrict myself in this paper to IS design and IS artefacts, where IS stands for the Information System – briefly said, the way the information and communication processes in/across organizations are set up, including the IT tools that support these processes [56]. Fig. 1 puts design in the center

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of the cross of reality. Designing is extending the given, exploring the possible, disclosing alternatives and expressing the tacit. Note that we have slightly changed Rosenstock's space dimension. The outer world takes the form of the technical world (rather than the physical object world), although this includes the given physical world in its potential for technical use. The inner world takes the form of the tacit intersubjective world, as explained below. The subject world of the designer as a person is less relevant.

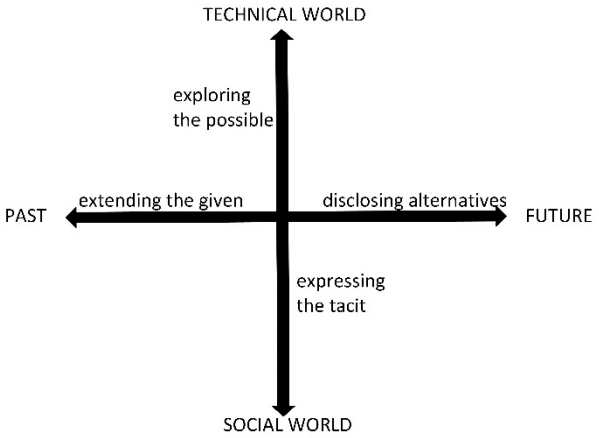


Fig. 1 Transformational design research (TDR) – a four world perspective

Designing from a transformational point of view means:

- **Extending the given**. Design typically starts not in a vacuum, but in a problem situation, with its legacy and running practices; with stakeholders and designers all bound by prejudices. There can also be time pressure to act. The given cannot be ignored, but it can be transformed. For TDR it is important to stress that design is positioned *in time* and that in the concrete historical reality, the subject and the object, or the social and the material, do not exist independently, but are interwoven in many ways.
- **Disclosing alternatives**. The result of a transformation of the current situation (the past) is a new situation, the "to be" state. There is more to design than just solving a problem. Proper designing implies looking forward and therefore disclosing a new world, or, better said, new worlds [48] because the future is not fixed and there are always alternatives from which a choice has to be made. This future orientation has always been important in pragmatics [19] and critical theory [21,22]. Disclosure of new possibilities that contrast with actual conditions is, according to Dewey, the most penetrating 'criticism' that can be made [12:349] and therefore should be at the core of critical theory, according to Kompridis [30]. At this point, the TDR approach sides with the pragmatist concern with social progress and distances itself from the extremely past-oriented view of Heidegger.
- **Exploring the possible**. Designing not only transforms the current situation, but also the available technology in the current situation. The designer wants to *find out what is possible* but not yet realized. The available technology (including the given physical world) is optimized, combined, translated from one field to another, specialized etc., to arrive at something that was not possible before. Knowledge about this potential is then laid down in technological rules that are subject to validation and further development. The interest in the *potential* of artefacts and things, rather than on their observable properties, distinguishes TDR fundamentally from positivist research[1].
- **Expressing the tacit**. An often neglected dimension in design is the transformation of the social world. Designing involves expressing the tacit/implicit, from the personal but more in general, from the intersubjective. This transformation implies a growth in self-understanding, but also a rationalization [23]. Implicit norms become explicit rules. Values get embodied in tools [18]. Knowledge is 'captured' and standardized, desires become goals. The expression *in the form of technical design* is a special case of what Habermas [21:22-23] calls self-reflection which, according to him, is more important than theoretical reconstructions: "Self-reflection leads to insight due to the fact that what has previously been unconscious is made conscious in a manner rich in practical consequences".

In line with Rosenstock-Huessy, but deviating from the Speech Act theories of Searle and Habermas, 'expression' is taken in an intersubjective sense, that is, not restricted to the individual 'subject world'. In a design context, we are especially interested in implicit social norms and values that get embodied in the artefact – and these clearly have an intersubjective character[2].

So far we have talked about design, not design science. Designing happens all over human society, not only in a research context. Design science research involves design, at its core, but design in a particular way, as part of a design science project. TDR conceptualizes this situation as a Conversation for Design between the scientific community and the designer/researcher. The Conversation for Design is a variant of the Conversation for Action [59] between customer and agent and that consists of an initiating (commitment) phase and an evaluative phase. In the Conversation for Design, the scientific community comes up with requirements of rigor, and evaluates the design results in the publication process, on the same requirements. The requirements are not foreign to the design activity – any good designer will test his proposal, for instance, but the scientific requirement may impose statistical rigor to the test. Note that by positioning design research in this way TDR includes but also deepens the Hevner [24] guideline that DSR must be published.

[1] Positivist methods can be used e.g. for the evaluation of the technological rules. However, what is missing in positivism is the recognition that there is an implicit and an explicit, where essentially, the transformation of one to the other is a language action. The potential of artefacts cannot be directly observed, only indirectly by a design activity (design + implementation + intervention).

[2] Habermas [22] is a bit ambivalent in his "three" world view: although in his work he stresses the intersubjective character of communication, he talks about the subject world in an individual sense. Habermas' social world, as reference of "rightness" validity claims, is to be placed on the historical axis, in particular the given (past) where the intersubjective/social aspect has been materialized. In the historical world (and so in the social reality) the technical and intersubjective aspects are interwoven. Value expression is the transformation from an implicit intersubjective world into an explicit social world, where in most cases use is made of technical means –text, to start with, but also artefacts like traffic lights, entrance gates and ERP systems.

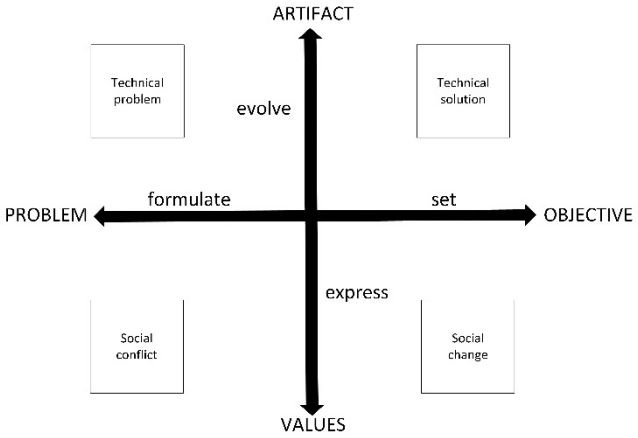


Fig. 2 – Transformational Design Science Research – micro-perspective

B. Micro-perspective

The TDR model in Fig. 1 depicts the four dimensions of design. We can work this out on a macro and a micro-level. The macro-level considers the design research from a long-term perspective: what is the future aimed at? What are the long-term technical issues? What is the body of technical knowledge? The micro-perspective refers to the actual design activities. Fig. 2 depicts a micro-perspective with four concrete activities. First of all, *formulating* the problem. Behind the manifest problem (symptoms), typically two root problematics can be distinguished: technical (the technology is not performing as it should) and social (e.g. established interests). These root problematics are often unaddressed in the designing sec, but do constitute the background – together with the given constraints, such as legal and economic constraints. Secondly, future-oriented *setting* an objective, which is not about what is built, but addresses the ”why?” or ”what for” question in terms of effects. At design time, these are intended effects. At evaluation time, these become hypotheses to be tested. Setting an objective may include describing alternative “to be states”, identifying criteria for evaluation and comparison and selecting. Also relevant is the risk identification, that is, the disclosure of states that become possible by application of the artefact but should be avoided. *Evolving* the artefact means extending the technical world by building or evolving some artefact. According to TDR, the artefact embodies values. *Expressing* the values of various stakeholders is therefore a necessary step. Of course, the problem situation will already include some explicit norms and values, but these are never completely fixed and always need to be reconfirmed. Expressing the values is not easy; there may be resistance: powers may want to hide themselves, rationalization may be felt as dehumanizing. Expression is more than translating thinking into words. Rosenstock talks about expressing *and completing*. The explicit rule differs from the implicit norm, even if their propositional content is the same. Note that all the research activities, on all four dimensions, have a hermeneutic character.

C. Example

TDR can be applied to one of the examples of Hevner [24], the article Anonymity in GDSS - Gavish and Gerdes (1998). GDSS (Group Decision Support Systems) were an important development in the ‘90s and a prominent example of computer-supported collaborative work. GDSS supports brain-storming and group decision making by electronic means, so that it becomes possible, for instance, to brainstorm anonymously. Applied to this case, the TDR research approach would yield the following:

Problem formulation – According to Hevner’s description, the problem is relevant because field studies indicate that people would not use the GDSS or trust its result if there is no anonymity. The lack of trust can be taken as the formulated problem. In fact, the claim is not found explicitly in the Gavish and Gerdes paper itself who just state that anonymity has pros and cons. The problem analysis in the paper does not go very deep. However, from the text we can find *technical* causes for the formulated problem (a GDSS uses network protocols that require message identification, so complete anonymity is hard) and *social* causes (the intimidation problem - people in a group meeting may be afraid that what they say is used against them).

Technical artefact – The researchers state definitions of anonymity and then describe mechanisms to achieve these. So the anonymity mechanism is the technical artefact. The authors do not build new artefacts – which is seemingly deviant from a Hevner perspective, but not so in TDR that is not focused on “building an artefact” but on “evolving the artefact”. The authors compare existing artefacts and analyze their costs. Artefact components include encryption and intermediation, among others.

Effects - The intended *technical* effects are well-defined in the form of the anonymity requirements. The validation is done by formal proof, which is an accepted validation technique in the field of Decision Support Systems (the name of the journal). The evaluation of the artefact *in use* – not performed by the researchers – would validate the hypothesis that the anonymous GDSS is being used and appreciated more than the non-anonymous. The researchers show that they are well aware of the social aspect, and they discuss extensively the possible side-effect problems of anonymity, such as legal liability. From a TDR perspective, we would say that the anonymous GDSS opens up new possibilities for brainstorming, not practically available before; and that, if accepted and implemented in practice, this kind of brainstorming can transform the group culture. If so, the evaluation should not be against the “old norms”, but against the new norms after the group culture has been changed and the change process needs to be addressed.

Values - The article does not include a systematic investigation of the stakeholders (users, managers, technicians …) and their goals, nor of their values. But clearly, values are all over the place in the GDSS domain. Some may see the GDSS as a rationalized process in which participants are depersonalized as much as possible, others see it as a road to equality and democracy. The GDSS conception may depend on the existing level of trust and mistrust in the organization. The value of accountability is compromised in the anonymous case. Interestingly, the Gavish and Gerdes paper does extensively address the problem of convincing groups of the effectiveness of the anonymity, so to some extent it recognizes the need of a transformation of the social world.

III. STAKEHOLDER ANALYSIS: A LITERATURE REVIEW

The value aspect of Design Science Research is typically couched in terms of stakeholder analysis. In this literature review, we first consider the traditional IS development approach and the strategic management perspective, then the stakeholder analysis in the DSR literature, followed by the value-sensitive design tradition in the philosophy of technology that so far has not received much attention in the DSR field but is quite relevant.

A. Requirements Engineering

In the traditional Software Engineering literature, stakeholder identification is an important part of the requirements engineering phase. For instance, the Sommerville textbook [47] describes stakeholders as "a person or group who will be affected by the system, directly or indirectly". It immediately adds that eliciting stakeholder requirements is difficult, for various reasons, the first one being that "stakeholders often don't know what they want from the computer system", and another one "conflicting requirements from different stakeholders". Both reasons are not surprising in the TDR framework that, in contrast to the positivist worldview, makes a distinction between the implicit and the explicit, and that views conflicts in the social world as the rule rather than the exception. Alexander [3] provided a checklist for stakeholder identification, including direct ones, like end users and support staff, but also indirect ones, who can be both positively and negatively involved, as well as agents that are involved in the development process.

In the IS Design Theory of Walls et al [52] a design science research project is similar to a normal software development project, but focused on a group of problems or cases, rather than one particular case or company. Requirement collection then becomes meta-requirement collection. This kind of stakeholder analysis has found its way into the DSR literature, such as [57], where chapter 4 is titled "Stakeholder and Goal Analysis". It emphasizes the implicitness of desires and different levels of awareness of goals. It also notes that desires can conflict and enumerates six conflict types (but does not include social conflicts). It does not make the Walls distinction between requirements and meta-requirements explicitly and allows a stakeholder to be an individual company.

A widely known method for stakeholder analysis is the i* method and its variants [25]. It involves identifying stakeholders in context, their goals, and their inter-actor dependencies. For goals a difference is made between hard goals (conditions that will be met or not), and soft goals that correspond loosely with values (or at least qualities) and are satisfied to some degree. Goals are organized in a goal tree. The i* method uses a graphical notation, whereas GRL offers a formal language for specifying goals and logical reasoning with them.

An often cited example of i* is reproduced in Fig.3. The stakeholders/agents are "kids and youth" that need counselling, an organization that provides this service, and the counsellors themselves. In the example the focus is on a specific way of providing the service by means of digital means (cyber café, text messaging). The organization has capabilities to provide counselling services and aims to extend these capabilities using the cyber café technology.

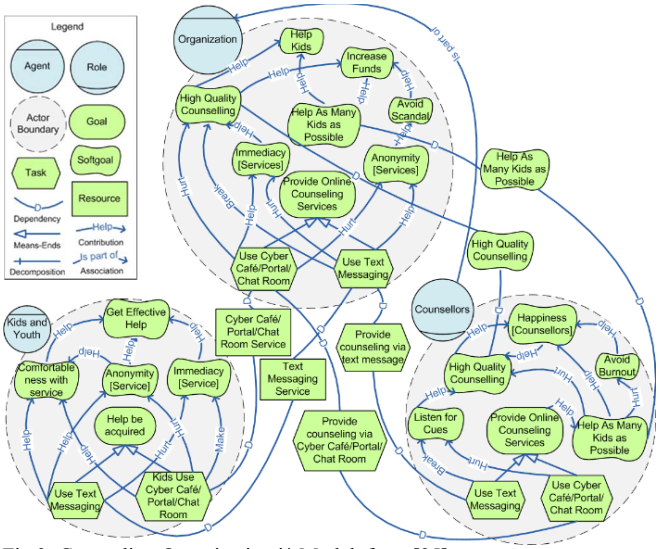


Fig.3. Counseling Organization i* Model, from [25]

One nice property of i* models is that they not just list stakeholder goals but show the dependencies between goals inside and across agents (cf. [31]). Requirement lists only say what the stakeholders wants the system to be, but not why, what values are involved and how they are related. Another positive point of i* is that the artefacts in question – the text message service and cyber café, in this case – reoccur in the model, although strictly speaking it is not the artefact, but the service enabled by the artefact. The text message service being used by the kid helps him to achieve the *goal* of getting help as well as *soft goals* (comfortable, anonymity) that are needed for the help to be effective, but at the expense of immediacy. The cyber café can offer immediacy, but at the expense of anonymity. The i* model also has limitations. The economic aspect is underdeveloped: funds are mentioned, but not their source, and it looks as if counsellors don't get paid. The model does not explicitly link the qualities of the artefacts, such as being anonymous or containing personal information, to the soft goals. What we also see as a limitation is that although the goals are linked to each other, and so their consistency or inconsistency can be determined, there is no further way of analyzing *why* these goals are important.

Value modelling, such as the e3value modelling, bears similarities to i* [20]. It also uses a network structure. However, instead of focusing on actor goals, it puts the economic exchanges between actors in the center. This is explainable from its original motivation to explore (Internet) business models. In [54] e3value has been extended in several ways so as to better support strategic analysis, in particular by: (a) the recognition of *second-order value objects* (qualities) next to the first-order "goods & services" value objects; (b) the recognition of resources and capabilities within actors that are both the source and the target of value exchanges, next to the value activities in which the capabilities and resources are used; (c) value encounter modelling for situations where multiple parties collaborate in creating value, beyond two-party exchanges. The case of Fig.3 lends itself to a value encounter model with three actors/roles mentioned, plus additional parties such as the inspection, government, charity funds, or perhaps parents. Capabilities that are underlying the actor goals are e.g. the professional expertise of the counsellor, the autonomy of the kid (endangered by mental problems), and the social capital of the kid (potentially

threatened by negative publicity). Resources would be e.g. financial resources and technical resources, like the chat app. The cyber café (rich medium, PI content) and the chat app (text medium, no PI information) are two different value propositions that have different effect on the kid's capabilities.

The primary goal of stakeholder analysis in IS development is to collect requirements in order to, in the end, produce useful artefacts. The artefact that is built should meet the *interests* of individuals or groups. A closely related but distinct goal is stakeholder *participation*. Participative/socio-technical design [15] and the Scandinavian tradition of participatory design (e.g. [31]) emphasize that users should participate in the design process from the beginning. Not only to ensure that their diverse interests are expressed (e.g. management and laborers), but also in order to increase the user acceptance and thereby the success of the project. Involving users has become common practice in modern agile development methods and the co-creation approach. What is interesting to note is that by involving end users, participatory design in fact allows and stimulates a transformation of the *social* world in parallel to the *technical* transformation. This is what TDR aims for: not just acceptance, but transformation. For instance, in an Australian Participatory Design case (the case is not about IS), participants described the project as 'a transforming experience as they saw the world through different eyes.' [39:62]. According to [4], Participatory Design includes Technology itself as an agent (not a blind force, but an agent nevertheless) that gets into discussion with, and so also changes, all the project participants ("transforming society") .

B. Stakeholder Analysis in the management literature

The concept of "stakeholder" has also a background in the strategic management literature, especially from the time that it started to look more into the environment of the organization [7,17]. The stakeholder is defined here relative to an organization, rather than a project, although it may also refer to organizational change. Mitchell et al. [34] proposed a classification of stakeholders (QCoS) based on power to influence, the legitimacy of each stakeholder's relationship with the organization, and the urgency of the stakeholder's claim on the organization. QCoS is one approach among many stakeholder mapping approaches that have been developed since the'90s. According to Venable [51], QCoS is interesting, but one-sided, as its focus on power and status leads to a defense of vested interests rather than an advance of emancipation, as is done, for instance, in the Critical System Heuristics (CSH – [50]). [51] explores the use of CSH for Design Science Research, and in particular highlights the CSH role of "witness", which includes the interest of the society at large, including future consumers. How to implement this witness role is a problem. The researcher/designer could take that role, but according to Venable, his "personal interests will likely be narrow and not representative of the breadth of different interests" .

The strategic Stakeholder Analysis is applied by [8] to IS research. It even extends the scope of possible stakeholders to include the natural environment.

C. Stakeholders and values in the DSR literature

The two stakeholder approaches above have found their way into the DSR literature, but not extensively and not with much critical reflection. For instance, Hevner et al [24] mention the word "stakeholder" and they emphasize the problem-solving orientation of DS, but as spelled out by [51], the Hevner problem space is defined rather narrowly in terms of "business needs", consisting of business goals, tasks, problems and opportunities. Other possible stakeholders are not considered, and no guidance is given on how "the" business needs need to be determined. Another much cited DSR paper [36] does include a phase of "problem identification", but does neither mention the word "stakeholder", nor "values." Wieringa [57] devotes a chapter to stakeholder analysis based on the IS development literature, building mainly on Alexander [3]. Possible differences between software development and DSR are not discussed. Stakeholders are analysed in terms of goals and desires only. Johannesson & Perjons [29] have a chapter on requirement definition. They say very little about stakeholders but provide quite detailed information on the different qualities relevant for artefacts: *structural*, such as conciseness; *usage*, e.g. usability, fun; *management*, e.g. maintainability; *environmental*, e.g. interoperability. None of the two books mentions network approaches such as i* or value modelling.

It can be concluded that the DSR approaches currently used, as far as stakeholder analysis is concerned, are either silent about how it is done or build upon basic proven Requirements Engineering methods. There is very little attention for the social environment and its structure in which the artefact is supposed to be used, let alone to ethical values.

The broader DSR literature has repeatedly asked attention for ethical aspects in IS research. Venable's result referred to above has been included in a more general paper on ethical principles in IS research [35]. The first principle is the public interest: "Design science researchers should explicitly identify all stakeholders who may be affected by the artifacts once placed into use and critically consider what benefit or harm may result for/to such stakeholders. Generally, principles of safety, health, democracy, empowerment, and emancipation for all, particularly for the public, should predominate in choices of features and capabilities that an artifact should or should not have". The value expression method proposed in this paper aims to support DSR researchers in this kind of critical stakeholder analysis.

D. Value-sensitive design

In the field of technology research, the role of values has received a lot of attention. Simon [44] already noted that artefacts have a purpose and so presume the existence of norms. In engineering, there is always the hope that when the product is used it will benefit some stakeholders in the domain. A more difficult question is whether these values do exist only in the application context and play a role in the evaluation of the artefact, or whether they also play a role in the design. Are technological objects neutral in themselves, or can artefacts embody values? Friedman [18], Van den Hoven [26] among others, have argued for value-sensitive design that aims at integrating (ethical) values in a systematic way into the design of technical artefacts. Flanegan [16] for instance, describes a case of game design based on the value of gender equity. Latour [32] makes the point, on a philosophical level, that "technology is society made durable": we delegate ethical rules to objects, for instance,

with speed bumps that make cars drive slowly in living areas (interestingly, in UK English they are called "sleeping policemen"). Although it is too strong a statement that technology always embodies values, it has been argued convincingly that in many cases it does [41,58]. If so, this implies that there is more than users' aspired values. Explicitly or implicitly, there are also designers' intended values [49] that can be more or less aligned to but do not coincide with the users' aspired values, as they are influenced by design choices. The designer's intended values can be built into the artefact itself, as Latour's famous example of the hotel key shows, or built into the practices in which the artefact is used (for instance, by means of regulations). Several tools have been developed to support value-sensitive design, such as value hierarchies [40] that roughly distinguish a top level of values, a bottom level of design requirements, and an intermediate level of norms (in the sense of rules for action, that may include goals and constraints). The relationship between the levels is not one of deduction or specialization, but a "for the sake of" relationship.

The systematic approach of value-sensitive design consists of a conceptual investigation (into the values, and trade-offs to be made), the empirical (of the context of use) and the technical investigation (on the design of artefacts that support certain values). The first type corresponds to the value expression that is the subject of this paper. The second type corresponds roughly to the research undertaken for problem analysis (past) and evaluation (future) in TDR, whereas the third one corresponds to the technical exploration in TDR.

One particular value-sensitive design approach follows the capability approach (CA) developed by Sen [43] and Nussbaum [36] in which human capabilities are described as the real opportunities or positive freedoms for a person to do and be what he/she has reason to value. For these philosophers, the goal of justice is not to distribute wealth in an optimal way, but to increase the capabilities, including, (but not exclusively) of those who lag behind. It makes sense to suppose that there is a close link between the nature of technical artifacts and capabilities, as this is what technical artefacts do: enable people to do things that they could not do or less well without the artefact, whether it is flying to the moon, processing bulks of information, remote heart surgery, or whatever. Technology is enabling, no more no less. So a CA perspective on DSR in general and the value modeling in particular, is interesting [37], and urges the designer/ researcher to not only list ethical values but to relate these to them via the concrete increase in capabilities of the users, and so to identify these capabilities to be expanded in the first place[3]. A quite compatible perspective on value experience and value commitment, that stresses both the creative nature of human action and how value commitments and self-formation are intertwined, is provided by Taylor and Joas [28], among others.

Value-sensitive design is not the same as but can be combined with the so-called Responsible Research Innovation (RRI) concept [45]. According to the European Commission, RRI "is an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation." More specifically, it implies that societal actors (researchers, citizens, policy makers, business, third sector organizations, etc.) work together during the *whole* research and innovation process in order to better align both the process and its outcomes with the values, needs and expectations of society". Within Horizon 2020, RRI has a focus on the following issues: a) public engagement, b) open access, c) gender, d) ethics and e) science education. RRI and similar concepts outside Europe can be seen as an important development, but whereas value-sensitive design offers concrete guidelines for researchers, the focus of RRI is on the policy level. One way of conceptualizing RRI is to say that besides the Conversation for Design (II.A) between the research community and the designer/researcher, through which the community ensures scientific rigor, there exists (or is brought to existence) a Conversation between the research community and the society at the policy level, and the commitments the research community makes are pushed forward to the individual researcher in the Conversation for Design.

A strong point of value-sensitive design is that it has reflected more on the nature of technology in relation to society than is usual in the DSR domain, but it also has limitations. Compared to the existing IS development methods, the value-sensitive approach does have some but not many worked-out tools yet. Furthermore, the tendency in the field is to focus on ethical values. This is understandable as these usually play a marginal role in mainstream technological research, but in the end, an integrative approach for all values would be most desirable.

IV. VALUE EXPRESSION IN TDR – A PROPOSAL

A. Design choices

On the basis of the literature review in Section III, and considering the TDR design perspective, we get to the following design choices for value expression in TDR.

(1) generic vs specific, broad vs narrow

According to TDR, the ultimate goal of design research is the development and validation of technological rules that make claims about the effects of using the artefact in some context. As with all scientific knowledge, these rules must be defined on a generic level. So when there are individual stakeholders in a DSR project, like companies, it is not sufficient to render their aspired values: these should be *generalized* into values of stakeholder roles. Furthermore, the stakeholder analysis should not be limited to users that are directly affected, but should be as broad as necessary. One way to do that can be to include the Society as stakeholder, as in Myers and Venable [33].

(2) goals vs values

Goals and values are often taken together. For instance, to address values in i* or Tropos, they have to be represented as soft goals. However, we recognize the following problems with this approach: (a) if we represent values as soft goals, the evaluative aspect ("X is good") and the normative aspect ("X

[3] By stressing the freedom of persons, the CA perspective may be interpreted as being interested in personal well-being only, ignoring that value is often experienced by people in their social functioning and in human interaction (Dewey). This would be a misinterpretation. However, this discussion leads beyond the scope of this article, and is not needed for applying the CA approach in the context of Transformational Design Research.

should be pursued") are lost [11]. A goal only expresses what an agent aspires. Cf. the distinction of Dewey between "desired" and "desirable" [13]. (b) Stakeholder goals are often quite specific, whereas values are not values if they are not recognized in a community (although they can be given different weight by community members, in different contexts). (c) There is also a problem with associating values with actors, as i* does. This may be fine for expressing that the agent assigns a high weight to the value, but cannot express "delivered value", the value that a resource or service has (so connected to the resource, as well as to provider and receiver). (d) If we take human agency seriously, then resources do not contribute directly to goals. Goals are set and achieved by the agents themselves. Resources can enhance the capabilities of agents, and so help them in achieving goals. Given these considerations, we posit that the role of goals in value expression is limited. Of course, a concrete design project does have stakeholders with goals, but goal modelling is not the most appropriate way of doing value modelling.

(3) intrinsic vs instrumental value, causalist vs expressive view

According to the famous philosopher G.E. Moore, not all values are relational, in the sense that they depend on people's desires or appreciation but they can also be intrinsic. For Moore, intrinsic value is not an observable property (he is not an ethical naturalist), but the idea is that "intrinsic value supervenes on intrinsic natural properties that cannot be reduced to these natural properties" [41]. Extrinsic values are relational. They are often but not necessarily instrumental values. Typically, all technological objects have instrumental value, in the sense that they are used to create value. However, as we noted in III.D, there are good reasons for stating that for instance, a speed bump cannot only be *used* for improving the security in a living area, but increases the security by design. While at the same time, other uses (for instance, to make the car jump) are clearly *inappropriate* uses. In contrast, a knife can be used for cutting food and be instrumental in improving human well-being, but it can be used in many other ways. So technology can embody values [41]. There is more than instrumental value.

The philosophical question of whether this embodied value is extrinsic (but not instrumental) or intrinsic is less relevant for the purpose of a value expression method, but let me do a suggestion. As explained in [41], Moore's intrinsic value in fact combines two ideas: that the value is not instrumental (it may be agent-related but not agent-dependent), and that the value is somehow "in" the artefact, rather than only ascribed to it by a moral agent. Now it is good to realize that embodied values can be viewed from two different perspectives [6]. The *causalist* conception looks at the consequences of the artefact in the context of use. The *expressive* view looks at values that the designer tries to impose on the artefact, so the values express or represent the designer's values [16]. In the TDR approach, values can be intrinsic, if we take the expressive view. It does not totally exclude agents, but acknowledges that there is a (designer) agent. In that sense, the value is agent-related. However, before leaving, this agent has embodied the value into the artefact, and so the artefact – as more than the purely physical parts, but with intended capacities – has intrinsic value: in the way the designer has arranged and given form to the components, 'supervening' on natural properties.

DSR should not only consider instrumental value but also the intrinsic ones as such. Inscribing intrinsic value to some artefacts does not necessarily imply technological determinism, as there is still left freedom to the user on whether and how to use the artefact [6]. It is also not necessary that the value is always realized; it is sufficient that it is manifests itself in a wide range of uses. For instance, there are many ways a gas-engine car can be used. One cannot say that killing people is an intrinsic property, although it occasionally happens. However, in most cases (namely, when the car actually drives), there is generation of greenhouse gases, so that is an intrinsic property (disvalue, one would say). Finally, it is also not necessary that the design immediately embodies the intended value in the right way. The artefact is an evolving artefact, and one driver for the evolution is the experimental test of whether the intended value is embodied optimally.

(4) ensembles vs components

Not all artefacts are the same. Simondon [46] made a distinction between technical objects, ensembles and components. A technical *object* is something with over time has acquired a persistent type identity and that can function on its own, for instance, a diesel engine. Its components are tightly integrated but can be replaced, in principle. An *ensemble* is a loosely integrated collection of technical objects that can be separated. For instance, an information system consisting of hardware and software. *Components* are only useful as part of a technical object. The difference between the three types is perhaps not absolute, but nevertheless useful. The DSR literature in the IS field mostly talks about context-specific *ensembles*. On the basis of the application in a use context, it is possible to say something about their effect ("does it solve the problem?"), and from there, the researcher can try to generalize these effects to "similar" ensemble artefacts in "similar" contexts. Often the use context is in business. The DSR literature in the Computer Science field mostly talks about technical objects. For *technical objects*, the evaluation is typically done in contexts (experiments) that are strictly controlled in order to draw conclusions for all contexts that meet the controlled features. The use context is typically in the lab. It seems that extrinsic values are very relevant for ensemble artefacts, but too indeterminate for technical objects. For the latter, intrinsic values are more relevant. In some cases, these intrinsic values are very general, such as "efficiency", "reliability" but they can also be artefact-specific. For *components*, the evaluation context is the technical object(s) in which they participate, and the values are typically intrinsic.

B. Value modeling in TDR

How can we express values in TDR? By that we mean modelling values as part of a process by which stakeholder (implicit) aspired values and societal values in general are identified, analysed and translated into design requirements. As TDR is also interested in the question of inscribing values on the technology, the translation should include a reflection (before, after, or during the design process) on the values that the artefact is actually embodying (from both a causalist and expressive point of view). A first step and key component of the value expression is the value modelling. In the context of this paper, we focus on this part only. The modelling already includes some analysis, but an independent analysis and subsequent translation into design are not considered here.

Value modelling, such as Value Encounter Modeling [55], can be a useful tool. The advantage of value modelling is that

it views users' aspired values not in isolation ("I want anonymity"), but as part of a social-economic context. Key elements of the value model (Fig. 4) to be used in DSR value expression are:

- *Agents and activities* – In line with pragmatism [12,19] TDR assumes that human agency is key. Artefacts are used by agents in order to bring about change. Agency is assumed both in the design of tools and in the use of tools, and both have a transforming effect (on a different scale). Values and actions are interdependent, as the value of objects (or the value ascribed to the object by a stakeholder) is always potential value that is only realized when the object is actually used, so in action. We take the term value creation and value activity as synonyms here.

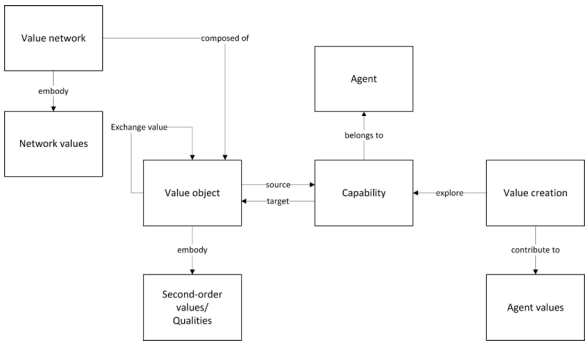


Fig. 4 Value expression conceptual model

- *Capabilities* – Capability is defined as the ability (of an agent) to employ resources to achieve some goal and can be interpreted as a type of disposition [5]. Aspired user values must be linked to capabilities and resources that these users/agents have. In the value modelling tradition, [53] conceptualizes value objects as being provided by some agent to another agent. To call a service a value object means that using his resources and capabilities, the provider adds value to the resources of the receiver – which in turn must be interpreted as saying that it increases the capabilities of the receiver. I suggest to extend the management notion of capability that also has been applied in service modelling to a wider moral context, as in the Capability Approach [37] described in III.D.
- *Value objects* – Value objects are resources or services exchanged between agents. In practice, these resources are mainly artefacts, while many services also involve the use of an artefact. Reversely, artefacts do not just "exist", but are provided by some agents and have impact on capabilities of other agents (the agent may provide the artefact to himself, as an atypical case). Often the value realization is a form of co-creation. For instance, a television is an artefact whose value realization depends on the consumer/TV watcher, the television manufacturer, the network provider and media companies. Importantly, the value object, whether it is a service or a resource, is not a value but only a bearer of value. It has features (second-order values in [55]) that express the inhering values. These values can be intrinsic or extrinsic and they are the cause for the value added to the receiver. For example an ethical value such as "safety" or "gender equality" is not a first-order value (a value object), but can be a second-order value (inhering in the value object) of for instance a computer game.
- *Reciprocity* – taking a social and economic perspective, rather than an individual focus, also recognizes that value exchanges require a certain level of reciprocity. The market *price* or exchange value is almost always relevant for an artefact, but the value exchanges and their network are often more complex than product-for-price.
- *Fairness*- the value network is only sustainable when all agents can survive. In addition, fairness in the distribution of the benefits is a key social value. Conflicts that usually exist between stakeholder goals, according to the Requirement Engineering literature, are often rooted in social conflicts. If so, they should not be treated as inconsistencies in the requirements but should be analysed on the level of the value network and its distribution.

"Value" is a cover term. The constructs of Value Expression allow us to include the following more specific value concepts:

- *Value-in-use* – the value that is realized by agents (one or more in co-creation) in activities that use the artefact, and that is aimed at agent value
- *Humanist (agent) value* – the value of a human life that depends for its experience on the capabilities of the agent and his/her action
- *Delivered value* – the value that is provided by one agent to another. A distinction is to be made between the value object and its qualities (second-order values)
- *Exchange value* – the economic value of a resource
- *Network value* – values embodied in the value network

C. Example

To illustrate the approach and as a first evaluation, we consider the example of process mining in auditing. The advantage of this example is that the technique is already known and discussed for quite some time. We first take an application point of view, and consider the application of process mining in auditing (cf. [27]). In this case, we talk about a process mining tool such as Celonis that combines several technical artefacts including a mining algorithm, an interactive visualization tool, and event log preprocessing. As such it is an *ensemble* object.

Fig. 5 depicts the initial value encounter model. It contains four actors (roles): the auditor, the Process mining (PM) tool provider, the auditee, and society. The PM activity is in the encounter and closely interlinked with the assurance activity. Value objects are rendered with straight lines, second-order values with dashed lines. For instance, the value encounter provides value to society in the form of financial reporting with the values "quality, reliability" – this is an important value for society and the claim is that process mining contributes to this indirectly via the contribution to providing assurance. The interactivity of the process visualization is a value to the auditor in the sense that it helps him better explore his auditing expertise in order to come to a professional judgment (that is needed in the assurance activity). Capabilities are rendered by rounded dotted boxes. Auditing expertise is the capability here, which is not replaced by but

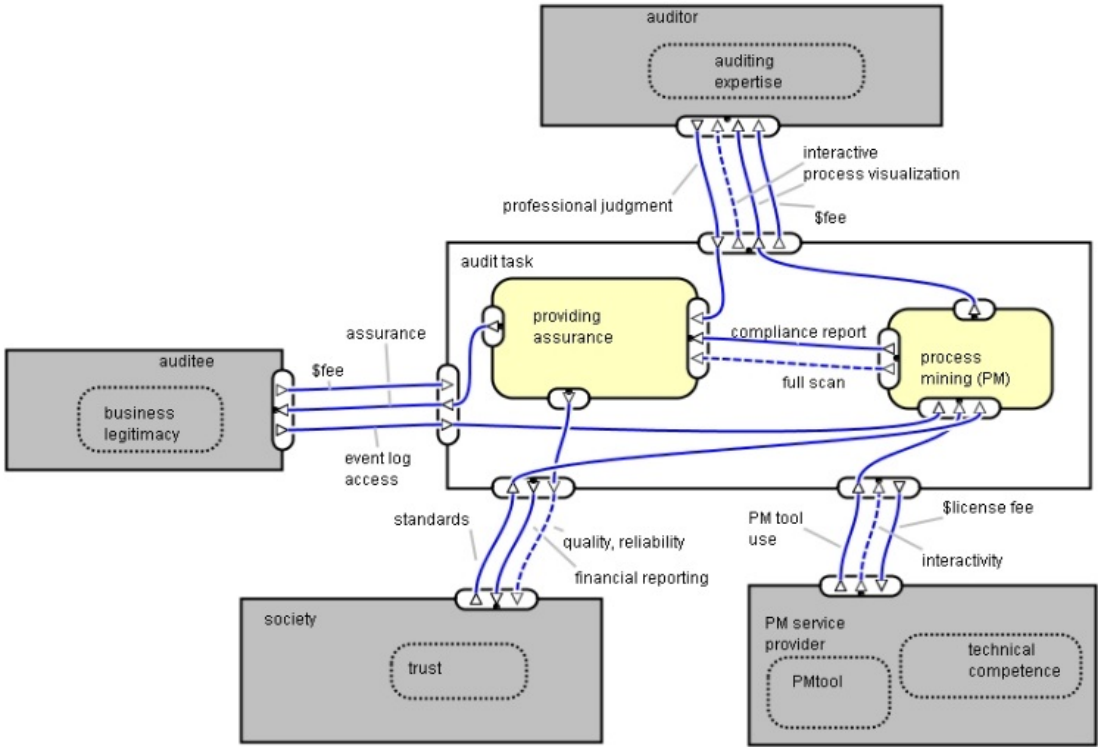


Fig. 5 Value Encounter model Process Mining application

augmented by the use of process mining. For society, trust is a basic capability (social capital) that needs reliable financial reports for being maintained.

The usage scenario sketched can be said to embody values. Although it is not the only available alternative, it is – assuming that the process works well – a means to ensure high-quality reporting.

The example shows that value encounter models can easily grow big and complex, that is also why Fig. 4 is simplified. The graphical representation can help to explore the value model but is probably not sufficient for working out the details.

The process mining algorithm is only part of the PM tool. It can be called a technical object in the sense of Simondon [46] – which means, by the way, that it also a type that is evolving and will evolve over time, without losing its identity. When doing value expression for the algorithm, the context is of course much smaller than in Fig. 5. Let us consider one of the early papers in process mining [1], about workflow mining. Here the primary motivation for process mining is that it allows one to build a process model automatically, rather than by human effort. This is not only more efficient, but also has the nice property that the model corresponds to the event log – it is not normative, but descriptive. From a value expression point of view, the question is what the value is of the process model and what the added value is of a mined model. For the former, we can say that the process model is a resource of a process owner and that a good process model increases his capabilities (to be in control). For the latter question, it can be said that a mined model has some nice qualities, such as completeness and accuracy. However, knowing that event logs are usually not perfect, the mined model may also have the disvalue of passing on the noise, and of providing models that are not accurate. An important part of the paper addresses this value problem. It is devoted to determining what makes up the quality of a process model and to comparing different algorithms on their performance.

Fig.6 depicts a value encounter model around the process mining algorithm. It includes the agents (roles) process owner, process data owner (e.g. the ERP system manager), process miner and platform provider. Another possible agent that is not mentioned in the article and not included in the model is the data *subject* – the user involved in the process whose behavior is made visible and who might be negatively affected by that[4]. Although the model is far from complete, it does highlight the possible conflict between completeness and accuracy, and the (second-order) value of noise filtering. We observe that the values involved in the second model, which is closer to the technology and does not take the use context into the scope, have more to do with functional quality than with ethical or economic values. Still, it does explicate the stakeholders and their capabilities, such as "process control" for the process owner and "modeling expertise" for the process modeler. As such, it does emphasize that the algorithm, as other artefacts, is a tool that does not produce value on its own but indirectly by drawing on and increasing the capabilities of agents. The model also shows the transformation that is brought about in the modeling domain, by the addition of agents that were not involved in traditional process modeling and by the capability extensions, and the critical role of the provider of the process data. Although the model does not claim to be complete, it appears that the reciprocity towards the data owner is missing, and this could

[4] In the Responsible Data Science Initiative https://redasci.org/ , this issue relates to the values of "confidentiality" and "fairness" in the sense of lack of bias.

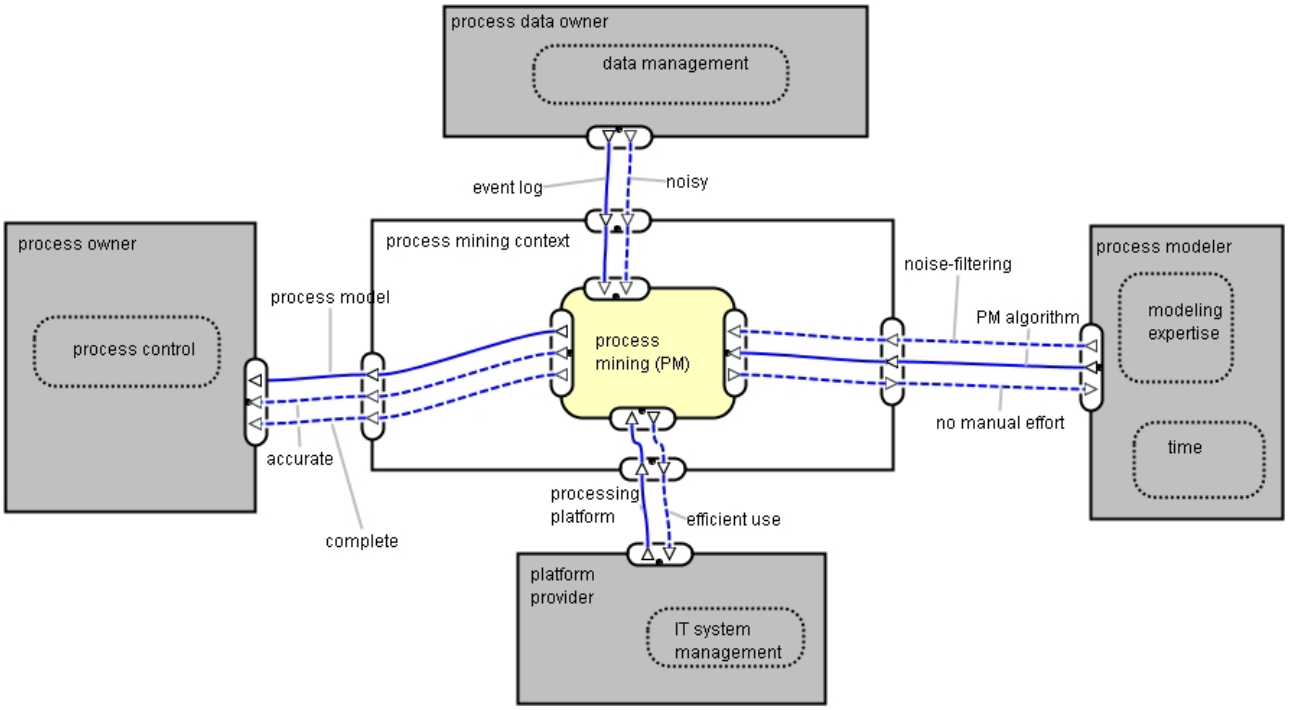


Fig. 6 Value Expression model Process Mining algorithm

hinder the adoption. Indeed, from our experience the acquisition and preparation of the data is often a hard job. It might be a good idea to return value to the data owner in the form of increased data quality, as a result of the process mining, as explored to some degree in [10] .

V. Conclusions

The goal of this paper was to provide a value expression method as part of TDR design research. The literature review has shown that current DSR approaches typically use a requirements engineering approach to stakeholder analysis that has limitations in a research context. Network based approaches, in particular value modeling, prompt for more explication of values and allow more value analysis then the traditional requirement list approach. The value-sensitive design tradition shows that value analysis is relevant for technical design and provides useful concepts. In particular, we have used the Capability Approach, as being one congruent with pragmatist (agency focused) approaches such as TDR.

In section V we have addressed some design decisions that must be made when developing a value expression method. We have proposed value encounter modeling as a tool for modeling values on various levels: the individual agent, the value exchange and the value network. To evaluate the proposal, value encounter modeling has been applied to a literature example. The example shows that it is possible to apply both in application use contexts as in more limited technical use contexts. As the values in both contexts are different, a more worked out value expression method should take this differences into account and come up with different analysis methods. For instance, economic sustainability is an important value to analyze in the application context but not in the technical context.

Value encounter modeling makes use of graphical models. These have advantages but also limitations. They can quickly become too complex. So it seems recommendable to combine a graphical model with a textual format, e.g. in the form of tables. The graphical model can be used well for the overall picture in the explorative stage of value expression. One possible topic for future research is to design tools to support the next stages. However, it should be kept in mind that the goal is not a development method, but to enable the critical reflection on the values that play a role, with two objectives: what values should be embedded in the artefact and which ones not? And: what value transformation is projected in parallel to the technical transformation?

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Comparison of Two Value-Modeling Methods: e^3value and SEAM

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***Abstract*—In the last few decades, several value-modeling methods have emerged in requirements engineering for IS research. We compare two value-modeling methods, e^3value and SEAM. We illustrate their use with an example of the exchange of the Intellectual Property Rights (IPR) on music. In the process, we propose a comparison framework. The results of our study show that e^3value and SEAM are similar value-modeling techniques: both model services in networked systems and focus on value exchanges. They differ, however, in the way value is conceptualized: the market viability of the service system in e^3value versus the subjective value and lack of market profitability analysis in SEAM. e^3value shows how value flows from one actor to another, whereas SEAM shows the relative importance of different value propositions and how they are constructed by the service network. These results can be used by modelers to select a value-modeling method for their purposes by proposing explicit selection criteria. The comparison framework, which is in its early stages of development, can be used to compare other modeling methods.**

***Index Terms*—Value modeling, Services, Conceptual modeling, Comparison framework**

I. Introduction

Value is a widely used concept in the IS field. It is a core concept in industry's good practices for IT, such as ITIL [1], and it is a cornerstone in research areas, such as service science [2], [3] and business theory [4]. The IS research domain is closely related to value-based theories from requirements engineering [5] and software engineering [6]. For many years, the computer-science field has been trying to represent how technology advancements provide value to users. There are different ways to interpret and represent value; the most often used one is to measure economic value. Service science provides another interpretation: value [creation] "is a process of integrating and transforming resources, which requires interaction and implies networks" [3], [7]. Therefore, we compare two modeling methods that show value creation through networks and interactions. For a number of years, the most prominent value-modeling method in the IS research has been e^3value [5]. However, there are other value-modeling methods, e.g., DVD [8], SEAM [9].

The e^3value modeling method has evolved throughout the years to represent the economic viability of a venture. The models capture networked industries of multiple actors who transfer value between each other. At its heart, e^3value draws its inspiration from the classic economics literature, to model the environment of an IS that is sustainable, meaning that it can produce monetary value.

SEAM is a method that helps modelers to represent how a network of suppliers provide value to a network of adopters and to itself, through collaboration, that results in a service system. SEAM is built on foundations that include general systems thinking, philosophy, policy making, service science, strategic thinking, software engineering, and enterprise architecture.

In this paper, we address the questions about (1) the commonalities and differences between e^3value and SEAM are for modeling value exchanges in the form of services, and (2) the modeling method a modeler should choose for their purposes. Considering that education is the primary field of application of both e^3value and SEAM, we seek to systematize and classify the modeling methods we show in our classrooms. We explore the feasibility of using the two methods together in this initial study and, through our comparison, we find that there is a sufficient overlap and some differences that would benefit further research. Students, future collaborators, and the research community could benefit from the different perspectives that these methods present and could be able to choose which method to use in which situation.

This is a joint work between the two research groups that created e^3value and SEAM. It began with the chance encounter of the authors, and then their willingness to compare and use together their methods. Our discussions resulted in reflections on what kind of models are used for value modeling, what choices modelers make when they use a modeling method, and which perspective a modeling method takes. We decided to formalize these reflections and to propose them to the research community.

In order to compare SEAM and e^3value, we model the same example with both methodologies. The example describes the international clearing of Intellectual Property Rights (IPR) for music broadcasting. We selected this case because it has been extensively used in e^3value research.

This paper is structured as follows. In Section II, we introduce an example used to compare both methods. In

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Sections III and IV, we introduce both methodologies and use them to model the example. In Section V, we describe a comparison framework, which we follow in Section VI to compare both methodologies. We discuss the comparison of the methods in Section VII. We present some related work in Section VIII, and we discuss the threats to validity for our study in Section IX. We conclude and give the outlook for future work in Section X.

II. The Running Example

The public broadcasting of music (e.g., in cafes, radio, concerts) brings together four main entities. The rights user who plays the music, the rights owner who makes it available, and typically, two intermediaries. These intermediaries, called Intellectual Property Rights (IPR) societies, collect the fees from the rights users and distribute it to the rights owners. There are typically two IPR societies involved because each IPR society is based in a given country and collects fees for rights owners who reside in that country. If the music is played in a different country, the IPR societies of both countries are needed to perform the exchange of rights for a fee, much like fund exchanges between banks. The amount to be paid depends on the importance of music for the rights user and on the size of the audience. The fee, usually a fixed yearly fee, is paid by the rights users, giving them the right to play the music. IPR societies have a database of their rights owners, music tracks, and relations between rights owners; these relationships represent track ownership. The most important rights users (usually large radio and television stations) are required to report a play list. To understand which music is played where, IPR societies do market research in venues such as restaurants and shops. Based on this, a list of tracks is compiled, with the total number of seconds played and where. This aggregated play list is used to divide the collected money over the rights owners for a fair distribution. This process is called repartitioning. The case of public broadcasting is presented in detail in [10].

III. SEAM

The most important elements of the SEAM ontology are given in the legend of Figure 1. The *business element* represents a service-providing value network. The business element can be seen as a black box or as a white box. If the business element is shown as a black box, the only other element it contains is a *service* (and its *properties*). A *service* is an interface for the value that an element provides where the external elements cannot see how the *service* is implemented internally. For a modeler to depict how the internal organization of a *service* is done (i.e., the transition from black box to white box), the *business element* can be refined through a *refinement* relationship. When the *business element* is shown as a white box, the model includes elements that comprise the value network that delivers the service, for example, business elements and human elements. These other elements participate with their *services*, through an *exchange* relation to the service *process*. SEAM has more provisions for value

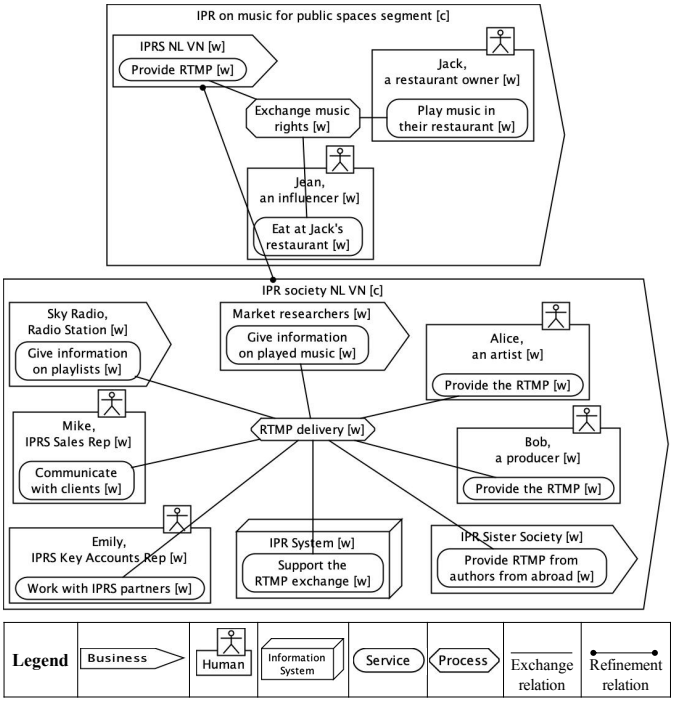


Fig. 1. SEAM service model of the IPR case

modeling: a supplier-adopter relationship model [11] and a motivation model [12]. Due to space limitations, these are not included in this paper. In our comparison, we use the SEAM behavioral model that most resembles e^3value.

Figure 1 depicts the SEAM service model of the case of intellectual-property rights. The model shows how the value network of the IPR society provides the service for the right-to-make-public (RTMP) music to its adopters. The service provider, the IPR-society value network (VN), and the service adopters (*the restaurant owner named Jack*, and *a customer named Jean, who eats at Jack's restaurant*) are shown on the first level. The IPR society participates as a black box (marked by '[w]' for whole) on the first level; the service adopters *Jack* and *Jean* cannot see how the IPR society organizes the delivery of the service of giving rights to make the music public.

On the first level, where the main service provider is modeled, the *exchange* relationship has semantics different than on the refined level. The *exchange* relationship represents a delivery relationship, and the elements on the right-hand side of the *process* element are considered adopters; these elements do not contribute to the *service process* but only consume the *service* of the service provider. The service adopters can be multiple, as shown in the case with *Jack* and *Jean*, and they are also considered when a motivational analysis is done. For example, the choices of *Jack* are going to depend on the preferences of *Jean*.

The second level shows the IPR society as a white box (marked by '[c]' for composite). The IPR society includes various actors who contribute with their services to the process of the RTMP delivery. The IPR society does not appear as a

single business element in its own value network rather as multiple IPRS employees, *Mike* and *Emily*, who contribute to the RTMP process. The white-box element captures the IS that support the exchange of information between the different actors. The *IPR System* can be refined to smaller components, e.g., storage and libraries. The *Banks* are not present in the model because they are only a utility that helps in the transactions between actors but are not a defining feature of the service in making the music public.

IV. e^3*value*

An e^3*value* model shows the *actors* or *market segments* (many actors of the same kind) involved, the *value* adding *activities* they perform, and the objects of economic value (called *value objects* they exchange via *value transfers*). Also, the notion of economic reciprocity is shown by the means of a *value interface*. The value interface contains *value ports* that represent that value object requested from or offered to the environment. The notion of economic reciprocity prescribes that if a value object is transferred via a port in a value interface, *all other* value ports in the same value interface should also transfer a value object, or no object at all. In the interior of an actor or a value activity, *dependency elements* are drawn. Various kinds of dependency elements exist: (1) the *customer need* represents that someone has a state of perceived deprivation [13], which can be satisfied by exchanging value objects with others. In other words, customer needs are satisfied by obtaining value objects from others. There are also *boundary elements*. These elements show that we are not interested in modeling additional value transfers. Customer needs, boundary elements, and value interfaces could be connected by three types of dependencies: (1) *straight* dependencies, (2) *AND* dependencies (all connected dependencies should occur), and (3) *OR* dependencies (some dependencies should occur). The e^3*value* is described in detail in [14] and is validated in many industries.

Figure 2 shows the e^3*value* model for the music case. A rights user (a restaurant) play a music track for their visitors. There are many restaurants, hence the use of the modeling construct 'market segment'. The restaurant needs to obtain the RTMP for the music. The restaurant pays a (yearly) fee, based on the function of the music (usually background music) and the size of the venue. The collection of the fees is done by the 'value activity' called *clearing*. All collected fees, minus a fee for the IPR society, are paid to another 'value activity' called *distribution*. The purpose of the distribution is to pay individual rights owners for their music. In practice, many tracks that are played have international rights owners. The fees collected for these tracks are paid to the international sister society who, in turn, pays the money to the rights owners. This is depicted by the transfers to the international sister societies and the transfers to the local distributing activity (annotated #1), thus separating the music played into national and international repertoires. There are two sources of revenue for the distribution activity: the fees collected by the national rights society and the fees collected by international

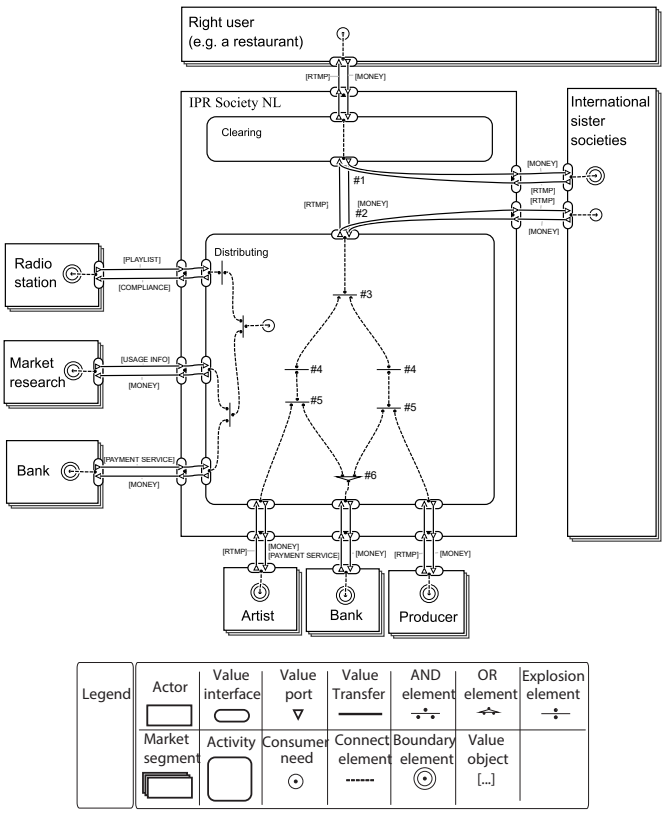


Fig. 2. e^3*value* model of the IPR case based on [10]

sister societies for the repertoires that the national society clears. These sources of revenue are summed, indicated by the OR join (annotated #2). The national rights society, in this case, clears the fees and distributes them for two types of rights owners: artists and producers. The fact that two types of rights owners must be paid is represented by an AND fork (annotated #3). A music track has multiple artists who are rights owners. This is modeled by an explosion element (annotated #4) that indicates that, for one track, *m* artists should be paid. The same construct is used to represent that a track can have multiple producers. In order to pay for both the artists and producers, the IPRS uses a payment service is represented by an AND fork (#5). The payment to either an artist or a producer triggers a flow to the bank, modelled by an OR join (annotated #6).

V. The Comparison Framework

The comparison we propose is qualitative. We base it on the differences and similarities that we saw through the application of e^3*value* and SEAM to the example. The comparison framework is shown in Table I. We base the comparison attributes (*Users, Purpose, Language, Mapping, Origins, Application*) on the works of Thalheim [15], Gregor [16], and Gordijn [17].

Thalheim describes four main dimensions of conceptual modeling [15]: (1) *Purpose*: the relationship between the artifact (a model) and the primary reason for creating it, based on the work of Gregor on the nature of artifacts in IS [16]. We

TABLE I
COMPARISON FRAMEWORK BASED ON [15]–[17]

Attribute	Choice	Description
User	Author (modeler)	Who is the modeler (active participant, observer)? Is it only one or many? How much knowledge specific to the modeling method do they need?
	Addressee	The models are created for a particular audience. Who are they? What is their purpose and motivation?
Purpose	Purpose based on Gregor's classification [16]	• Analyze: Creates a description of *what is*. No causal relationship or explanatory interpretations are given. • Explain: Explains *what is, how, why, when, and where*. It relies on presenting multiple views of causality and of methods for argumentation. • Predict: Not only describes *what is* but to also predicts *what will be*. • Explain & predict: *Explains* in detail the phenomena and predicts what will happen. Provides testable hypotheses. Gives testable hypotheses about the future without thorough justifications or causality. • Design: Gives guidance on how to build an artifact.
	Context analysis	Does it provide analysis tools for capturing not only the IS requirements but also the environment, e.g., stakeholders, their expectations, roles, economic situation? How does the modeling method present the context of the IS system?
	Individual / Group	Can the modeling method be used for creating a shared understanding between different people? How does the method present different perspectives?
	Type of analysis	What kind of analysis can be conducted with the modeling method: IS specifications, motivational analysis, socio-technical components and their interactions, and economic viability?
Language	Ontology	What information can be presented with the model, i.e., qualitative, quantitative, graphical, textual? What are the concepts in the ontology of the method?
	Other models	Are there more than one models in the modeling method? Are they connected and how?
Mapping	Reality to model	The modeling notation provides a way to map the relationship between the universe of discourse (an observed portion of reality) and the model. This is the epistemology of the modeling method. Epistemology provides the *User* with a means to express how they know what they know. A modeler has their own experience and value system that influence what they would represent in a model (captured by ethics).
	Model to reality	The model, or a part of it, serves as a basis for implementation of an artifact. How does the modeling method map the model to the reality to be created?
	Model to model	Different models have different elements that might not exist in other ontologies, or the same elements might exist but they might have different meanings. How are these model transformations handled in the modeling method? Are there already model-to-model mappings?
Origin	Known theories	Modeling methods use existing theories and knowledge from different domains. Hence, the modeling methods express a different world view distinctive for the domain it emerges from.
	Axiology	What are the choices that the modeling method adheres to? What are its aesthetics and ethics ?
Application	Tools	Is there a computer-aided tool to support the modeling process? Is it readily available?
	Adoption	Is the modeling method adopted in academic or industry communities?
	Value from using	How well does the modeling method model what it claims it can? How well does it achieve the purpose of its use?

added three additional aspects about whether to and how to conduct a *context analysis*, whether the method could be used to achieve *individual or group understanding*, and what *type of analysis* can be carried out. These additional criteria were added based on our discussions and on the need to express our arguments for the reason of using the modeling methods. (2) *Language*: the ontology of the modeling methods can be used to discern what kind of concepts (entities and relationship) can be expressed with the modeling language. (3) *Mapping*: the relationship between the objects in the observed reality, the concepts of the observer, and the expressed representation (in the form of models) is based on the Ullmann's triangle of conceptualization [18]. (4) *Value* is evaluated based on the purpose and how well the models and the modeling method fulfill it.

We included also the *user* secondary attribute from [15]. Our reasoning was that the *user* dimension shows the targeted audience of a modeling method and how a modeling method accounts for the subjective dimensions of modeling. In addition, we chose two attributes, *origin* and *application*, to compare modeling methods from the work of Gordijn [17]. In the work of Gordijn et al., the authors are also the creators of the modeling ontologies and used these two attributes to present the differences and similarities, based on their own understanding of the modeling methods. We included the *value* dimension of Thalheim [15] under the *application* attribute because it reflects how well the modeling method fulfills the *purpose*, or how well the models describe the situation under observation.

VI. COMPARISON

A. Users

1) SEAM: SEAM requires the modeler to understand the relationships between groups of people in different contexts. In the example, the SEAM diagram shows together the restaurant owner and the person who eats at the restaurant. The modeler needs to understand the environment of the service, often the modeler has the role of a business analyst, an RE practitioner, or a consultant. Also, modeling with SEAM requires some specialized knowledge of its *language*. An addressee of a model can be the modeler(s), someone who is engaged in the service exchange under modeling, or someone external. Most often, the modeler uses the model to understand the context and to be able to find ways to integrate an IS that fits in this context. In this sense, the immediate addressee is the modeler

but, at the end, it is the stakeholders who benefit from the results of the modeling.

2) e^{3}value *:* The general purpose of *e^{3}value* is to understand the context of service systems and, especially, their *raison d'être*. The intended user of the *e^{3}value* method is first the business developer, the analyst, or the consultant. These users need to have good conceptual modeling skills and be educated in the methodology. Other users are members of the board of directors, people responsible for innovation in a company, and the marketers. Usually, these people read and comment on the *e^{3}value* model but are not directly involved in technically constructing the models. In this case, we played the role of model builders, where people at the management level (of the IPR society) commented on the models so that we could improve them.

3) Commonalities: Both methods focus on the *context* of service (information) systems. Although we agree it is important to understand the IS requirements, it is also critical to understand *contextual requirements*. In our experience, misunderstanding the context could hinder requirements engineering process. Our experience is that modeling is perceived as *difficult* by users, and that they need coaching. There are method that are easier to understand, e.g., the Business Model Canvas [19]. As they favor simplicity, such methods lack rigorous analysis support.

4) Differences: The *e^{3}value* has a focus on the notion of *economic value*. Hence, it opens up the possibility to develop analysis tools, such as net-value and fraud analysis. But these rigorous analyses require expertise in using the method. Consequently, these methods are less frequently adopted. Whereas, SEAM is more *generally applicable*, which makes it versatile. But the lack of a particular domain makes it difficult for users (especially practitioners) to apply it to their context.

B. Purpose

1) SEAM: The SEAM model is created to *explain* how the service exchange between the IPR society and the restaurant is done, and how the IPR society is organized internally in order to deliver the service. If the model is seen only on the first level, then the purpose would be to only *analyze* what the situation is, without going into the details of how the service delivery is achieved. We can observe this for the radio stations that are in the value network of the IPR society. The IPR receives the services of the radio stations but does not see how the stations' value network is organized. The SEAM model can include this level of detail, but the modeler can decide not to include it, based on whatever reason they create the model for. The model also shows which IPR society employees are involved in the value exchange, instead of using abstract generalizations about the IPR society. Hence in the diagram, we can observe the roles of people who would correspond to the responsibilities in the value exchange process.

The SEAM model also shows the IS that supports the service exchange. This means that SEAM could be used to elicit, document, and communicate IS requirements. By building the SEAM model, the IPR employees and their partners can build a shared understanding of how to work in order to deliver the RTMP to their service adopters and how an IS would complement the process.

2) e^{3}value *:* We could use *e^{3}value* for many purposes. Originally, the method was intended to assess whether companies can be financially sustainable in executing a service. Many model elements can be quantified, e.g., the number of restaurants, the number of music tracks they play, the fees they pay. If all required elements have an appropriate quantification, we can generate net-value cash-flow sheets for each actor. All actors should have a positive net-cash flow in order to be sustainable. Before the generation of the net value, model checking can be done, e.g., checking if each value transfer has an economically reciprocal value transfer (e.g., RTMP for money). Another purpose is to have a shared understanding of the commercial aspects of the service to be developed. In the music case, the purpose is to derive meaningful process models (in BPMN) that put the *e^{3}value* model into operation, or to separate the WHAT (*e^{3}value*) from the HOW (BPMN).

3) Commonalities: Both methods are used primarily for *explanatory* purposes. As typical applications always involve multiple stakeholders, in order for a shared understanding to emerge, there is a clear need to explain the service system to the stakeholders. Both methods can be used for building alignment among stakeholders by creating the models in a group and by expressing explicitly how involved parties see the situation.

4) Differences: e^{3}value focuses on interactions, in terms of *economic value* transfers, between enterprises and end-users. Also with *e^{3}value*, we can create testable hypotheses on the profitability of a venture. With SEAM we consider interactions to represent a generic construct. Actors' values are derived in the service exchange as *subjective perception*. Furthermore, SEAM provides a means to describe the desired behavior of an IS from the actors' points of view, hence SEAM can be used to design an IS. Thus, SEAM's purpose revolves around analyzing and designing socio-technical systems.

C. Language

1) Ontology comparison: In Table II, we present the concepts of the two ontologies. In the table, we separate the ontological elements into four logical groups. The first section presents the concepts that the modeling languages use for actors. The second section holds the value-modeling elements. The third presents the relationship elements that show the composition of elements. The fourth section presents the start/stop elements for value exchange.

We see from this side-by-side element comparison that SEAM has more specialized elements for describing the internal parts of a system. SEAM's *business working object* has the semantics of the three actors of *e^{3}value*: (1) *elementary*, (2) *composite*, and (3) *market segment*. SEAM's ontology can be used to describe humans, IT working objects, components of an IT working object, and storage elements. One important difference is that *e^{3}value* does not have an information-system element.

TABLE II
ELEMENTS FROM THE ONTOLOGIES OF e^3value AND SEAM

Groups	e^3value	SEAM
Actors	Actor	Working object
	Elementary actor	Business working object
	Composite actor	Human working object
	Market segment	IT working object
	-	Component working object
	-	Storage working object
Value elements	Activity	Distributed action (process)
	Value interface	Localized action (service)
	Value port	Localized property
	Value object	Distributed property
Relationships	Connect element	Refinement relationship
	Value transfer	Exchange relationship
	AND element	-
	OR element	-
	Explosion element	-
Start/Stop	Consumer need	-
	Boundary element	-

The way that e^3value and SEAM represent value differs as well. The e^3value ontology offers a *value object* that is exchanged via a *value port* and a *value interface* to a *value activity*. The composition of interfaces in e^3value is handled with different relationship elements (logical AND and OR operations). In SEAM, the value exchange is modeled with distributed actions (called processes) and localized actions (called services). The composition of activities in SEAM is handled with hierarchical structures via the *refinement relationship* with either different distributed actions or nesting sub-distributed actions.

To show the logical start and end of a model, e^3value has the additional elements. The *consumer's need* element represents the entry point of a diagram. The *boundary elements* represent the end of a model.

2) SEAM: SEAM includes a formalized ontology for modeling hierarchical service-systems [20], [21]. The entities in the ontology are working objects, distributed and localized actions, as well as localized and distributed properties. The ontology represents a systemic modeling language that presents objects in relation to other objects with either (1) a hierarchical relationship between a process that implements a service exposed as an interface to the higher hierarchical level, or (2) a service that the objects expose to the other elements on the same level.

SEAM also includes graphical qualitative models that are a visualization of the formalized service ontology. The example shows how a SEAM behavioral diagram looks. The model is conceptually divided in two parts to present (1) the service exposed by the IPR society to their service adopter, and (2) the implementation of the service by the value network of the IPR society. The graphical elements present the hierarchical nature of the service delivery. SEAM has a service-oriented language; it includes terms such as a service adopter, a service provider, a service exchange, and a value network. SEAM uses terms from the broader computer science vocabulary: white box/black box view, service implementation, pre- and post-conditions, etc. Hence, with SEAM, a modeler is able to express a situation in a service-oriented way.

The SEAM family of models includes models for capturing behavior and analysing motivation. Here, we present only a behavioral model that depicts how the IPR society works with their partners to deliver a service to the service adopter, the restaurants. Other models that we could have included are a motivational analysis model for depicting the goals and beliefs of the different actors [12] and a supplier-adopter relationship model for expressing the connection between service properties [11].

3) e^{3}value *:* There is an ontology for the e^3value methods, expressed in RDF/S, Prolog, and Java. The most important model elements are expressed in Section IV. We deliberately chose a graphical language to enable easy communication between stakeholders. In order we can generate net-value flow sheets, most model elements can be quantified financially. An e^3value model expresses mostly intentions. For example, we modeled the the restaurant's intentions: to obtain and to pay for the RTMP. More precisely, an e^3value model describes a perfectly honest world: if someone obtains a service they will always exchange something in return. Behavior is not modeled by an e^3value model. For example, an e^3value model does not have a notion of time ordering. In this example case, we cannot derive that the artist has to provide the RTMP before the RTMP is provided to the restaurant. The only notion of time in an e^3value method is the contract period: the period of time the model covers, for instance, one year; hence, the generated net-value flow sheets are generated for one year.

4) Commonalities: Both methods have both a *graphical* language and a meta-model. Both methods have formal requirements with respect to the internal validity of the models, expressed by their respective ontologies. This sets, e^3value and SEAM, apart from most of the other approaches in the business world; these approaches are often natural text-driven or structure the domain in only a few quadrants. The advantage is simplicity (hence a method is usable by everyone), but the disadvantage is imprecision, vagueness, and insufficiency for further rigorous (automated) analysis.

5) Differences: The e^3value method relies on the *quantification* of many elements (e.g., customer needs, number of actors, prices to be paid). SEAM is a *quantitative method*. The e^3value speaks a *commercial language*, and, coincidentally, many value object in e^3value are in fact valuable outcomes of services. Whereas SEAM speaks a *service-oriented language*.

D. Mapping

1) SEAM: Reality to model: The relationship between the observed reality and the SEAM models is influenced by the work of Cooper et al. on designing with prototypical personas [22]. A SEAM modeler has to take one concrete representative example of a service adopter. In the SEAM model of the example, the restaurant owner is called Jack. A modeler has to collect information by observing and talking with Jack about what Jack wants, needs, and provides in the service exchange, etc. This technique of using a concrete example, provides a

rich data-source that needs to be mapped later to the models by mapping observations and model elements.

2) e^{3}value: Reality to model: The *e^{3}value* modeling language comes with practical guidelines on how to create an *e^{3}value* model, along with a series of workshops that can be conducted with stakeholders. Example guidelines are (1) that each value transfer needs a reciprocal transfer, (2) that a value object should be of economic value for at least one actor in the model, and (3) that many actors that assign economic value in the same way are a market segment.

3) SEAM: Model to reality: In the SEAM family of models, there is no explicit mapping between the models and the artifact that will be constructed based on the models. The models are used by stakeholders primarily for communicating the service exchange process and negotiating features of the services they need in order to deliver their own services. The SEAM service model can be used for constructing an information model for the corresponding services, but this information modeling is not a standardized step in SEAM. This model-reality traceability is an open area for future research.

4) e^{3}value: Model to reality: The graphical models are a vehicle for stakeholders to discuss whether the model corresponds to reality. Yet, we experience that many stakeholders need time to correctly interpret the models. Therefore, we currently explore the use of cartoons to simplify this process.

5) SEAM: Model to model: The refinement between models has also been studied and includes model transformations and mapping among a motivational model, the supplier-adopter relationship model, the information model, and the behavior model. SEAM has also been mapped to an enterprise architecture method [23], [24]. Current work includes a method and a tool for mapping web-service specifications and service models [25].

6) e^{3}value: Model to model: The *e^{3}value* model is a point of departure for other models. First, we can drop the requirement that an *e^{3}value* model describe a perfectly honest world, and we can enable states where actors misbehave, for example, playing music in their restaurant without paying for it. We call such models sub-ideal models. To explore all kinds of cases of fraud, they can be (automatically) derived from the ideal models. Second, the *e^{3}value* is usually the point of departure to designing a process model, e.g., by using the BPMN. We have several guidelines how to do so [10].

7) Commonalities: Both methods have *heuristics*, although different, to build the models. These heuristics are necessary because the relationship between reality, observer, and the model is intricate, and because only by subtly understanding the mapping, a modeler can draw benefits from the methods. Both methods include more than one model in their family of methods. The models presented in the paper are used as stepping stones in the construction of other models derived from the service models.

8) Differences: SEAM includes heuristics for building information models used for the development of IS. Most SEAM models are used as initial steps in building the understanding of what an IS will do for the service system. *e^{3}value* is mapped to procedural models, e.g., BPMN.

E. Origins

1) SEAM: SEAM stands for the Systemic Enterprise Architecture Method. SEAM is a systemic method that emerged from software engineering, general systems thinking (GST), enterprise architecture, and service science. The catalysis approach was an inspiration at the time of the creation of SEAM [26]. Many of the foundational concepts are interpretations of the components of catalysis, i.e., distributed and localized actions, and declarative language. In its graphical notation, SEAM is heavily influenced by software engineering, which explains the schematic similarity with UML and other engineering modeling methods. SEAM relies on notions from GST where a service can be seen as a system, or a set of interrelated elements [27]. GST is a meta-discipline and it assumes a philosophical standpoint for connecting the other disciplines. GST is thus domain-agnostic, which explains the choice we made in designing SEAM to not focus on a single domain. In its genesis, SEAM was an enterprise architecture method, hence it was vital to present the layers of an enterprise and the place of different components in these layers. This explains the hierarchical structure of the SEAM models.

2) e^{3}value *:* The *e^{3}value* modeling technique was based on the value-chain theory of Porter [4], then later on the theory of value webs and constellations [28], [29]. *e^{3}value* is closer to the idea of a network [28] or a web [29], this enables different structures with respect to relationships (rather than only linear chains). *e^{3}value* is based on standard textbook literature on marketing [13] and accounting [30], [31], and on the theory of economic value, also called axiology [32].

3) Commonalities: Considering their way of working, both methods use the approaches followed in requirements engineering and software engineering. In terms of content, both methods use some constructs from existing modeling methods, although with slightly different meanings.

4) Differences: *e^{3}value* relies on the (standard) business literature. SEAM is built upon notions from GST and service science. Although there is some overlap in practice, the point of departure is different. *e^{3}value* is more pragmatic, whereas SEAM is more philosophical.

F. Application

1) SEAM: Tool support: In the SEAM ecosystem, there are two CAD tools that support service design: seamCAD (available to the public) and TradeYourMind (proprietary). seamCAD was developed as a part of the research agenda of our research group. It is currently being extended with the tool for REST API generation. TradeYourMind was developed in collaboration with an industry partner who wanted to use SEAM in their projects. Also, we are currently developing a new tool for both visual and textual editing.

2) e^{3}value: Tool support: There are currently two software tools available for *e^{3}value*. One tool is a reference tool that implements the full language, the other tool is a

partial implementation of the language that focuses on the generation of fraud scenarios. Around one year ago, to bring the methodology to the market, we started a company, The Value Engineers[1]; part of this venture is to build an enterprise-grade tool for the complete methodology.

3) SEAM: Community adoption: SEAM emerged from the academic community and is now used for teaching and in consulting. However, SEAM's adoption by the industry or other communities is limited. As a systemic modeling method, SEAM is flexible and can be used in many contexts. This flexibility is also a drawback because SEAM is a domain-agnostic modeling method, hence and adopters have to adapt the modeling to their domain. From our experience, if facilitated by a SEAM expert, SEAM can be successfully used by business analysts for elicitation of requirements in workshops. The popularization of SEAM has proved to be a challenge, consequentially we are experimenting with videos, cartoons, tutorials, and books to explain SEAM to a broader audience.

4) e^3value: Community adoption: In the research community, *e^3value* is well-known and often used in many disciplines, both in national and international (EU funded) projects by ourselves (the creators of the method), as well as by others. With the aforementioned startup, we now work on bringing *e^3value* to the industry and, more specifically, practitioners. We consider this to be the final step in the validation of the methodology; the first step is to have a methodology adopted by researchers, and the second step is for (many) practitioners to consider the methodology useful.

5) Commonalities: Both methods are used for research and teaching. Both methods were, to a limited extent, adopted by practitioners. Both methods provide tools for designing models and are developing new ones. It is difficult for users to grasp the usefulness of the methods because of the intangible results that they provide: building a shared understanding and communication.

6) Differences: The most significant difference in the application of the two methods is their adoption by the scientific community. *e^3value* is a widely recognized and used method in academia, whereas SEAM is not used by a large set of people. *e^3value* has been used in commercial projects where it was evaluated on its usability and usefulness by practitioners (cf. [33], [34]).

G. Summary

Table III shows a summary of our findings. The features listed in the table can be used when either SEAM or *e^3value* are considered for modeling value. The table shows that the two methods are similar more than they are different. Both have a graphical language, originate in software and requirements engineering research and teaching, and while building a common understanding among modelers, they seek to provide explanations of a value-exchange situation. The differences lie mainly in their underlying philosophy. *e^3value* is oriented toward the quantitative modeling of point-to-point economic, or monetary, exchanges with an objective view of reality. SEAM is oriented toward the subjective, qualitative co-creation of either monetary and non-monetary values, with an emphasis on the notion of service as a way to abstract the intricacies of this co-creation.

[1]https://www.thevalueengineers.nl/tools/

TABLE III
FEATURES OF THE MODELING METHODS BASED ON THE COMPARISON

Dim	Feature	SEAM	*e^3value*
Users	Need coaching	✓	✓
	Addressee	Modeler	
Purpose	From [16]	Explanation	
	Context analysis	✓	✓
	Stakeholders' alignment	✓	✓
	Type of analysis	Socio-technical networks analysis	Economic viability
Language	Graphical	✓	✓
	Formally specified	✓	✓
	Possible analysis	Qualitative	Qualitative & Quantitative
	Concepts	Service-oriented	Economic
Mapping	Heuristics for modeling	✓	✓
	Many models	✓	✓
	Model transformations	motivational analysis, IS specifications	BPM, motivational analysis
Origins	SE/RE method	✓	✓
	Foundations	Service Science	Business and economics
Application	Primary domain	Research and teaching	
	Practitioners community	small	small
	Tools	✓	✓
	Well-known in academia		✓
	Evaluation of use		✓

VII. DISCUSSION

e^3value and SEAM can be seen as coming from similar yet slightly different traditions. Both methods have their roots in the software engineering tradition of graphical models that represent a future system's environment that is software-based [35]. The main difference between the two methods is their philosophical underpinnings, i.e., the continuum between Soft Systems Thinking (SST) and Hard Systems Thinking (HST) [36]. Soft Systems Thinking (SST) is close to the interpretivistic school of thought. Interpretivism considers that objective reality per se does not exist, whereas the interpretations of the observers of a system do exist. These interpretations depend on who the observers are. Furthermore, SST is mainly concerned with fuzzy, ill-defined problems that organizations have, and with ill-structured, technical problems [37]. The philosophical discussion on the differences and similarities, as well as on the application domain of the different streams of GST literature, is present in the literature (cf. [36], [38]). In line with our comparison, in the music rights example, we see how both *e^3value* and SEAM adhere to the philosophy of SST: Both methods could be used to model different perspectives and to construct a vision of the reality as it is or as it will be.

On the other end of the spectrum is Hard Systems Thinking (HST), from the positivistic school of thought. HST has its roots in [technical] systems engineering. As such, in HST the systems under consideration exist in reality and are independent of the observers. With HST, the modeler can capture the laws that govern the dynamics of the system, i.e., rates, explicit relations that are expressible in the form of formulas. For our comparison, we believe *e*^{3}*value* exerts some traits from the HST school of thought. An *e*^{3}*value* model can capture financial dependencies and conduct an analysis of the economic viability of a system.

SST models are *representations* of *an observed portion of the reality*. These representations are potentially different for each observer, meaning that the models are not simply different representations of the same interpretation of reality, but that these interpretations of reality (called the conceptualization in SEAM [39]) are different for each observer. HST models are *the direct representation* of *the reality*. Observers are expected to share the same reality, even if their models differ somewhat.

Value is an elusive concept with a philosophical origin that is complex to define. This is apparent in the two methods, in their treatment of the concept of value. In our case, *e*^{3}*value* and SEAM have two interpretations of what value in IS is and of how to model it. *e*^{3}*value* was created shortly after the burst of the dot-com bubble; our main inspiration at that moment was to evaluate electronic-service ventures before they went to the market. The focus of the *e*^{3}*value* evaluation is on how *viable* a service is and not on how *valuable* it is in some absolute sense. The *e*^{3}*value* models help service designers create economically sound systems. However, this classic economic definition of value can exclude actors and relationships that do not contribute to the economic rationale of breaking even.

In SEAM, value is defined loosely as the benefit that a service adopter receives from [the features of] a service. This broad definition includes economic benefits but with it we mainly aspire to model how an actor contributes to and how an adopter benefits from the service. The downside of such a definition of value is that it is strictly subjective and dependent on both the modeler and the other people, who project what valuable means to them, involved in the model creation.

In our comparison, it became apparent that the nature of value is the culprit for the differences in our modeling choices, and that there is at least a dual definition. Nevertheless, the value definitions of the two methods are not mutually exclusive. The definition of service-science value is not contradictory to economic value. Service science separates value into value-in-use and value-in-exchange [2]. Economic value represents value-in-exchange, and service interactions represent value-in-use.

We believe it is useful for modelers to understand the definition of value; this stands at the core of a modeling method. By knowing how a modeling method "sees" value, a modeler would be able to choose a tool for analyzing the IS environment in an informed manner.

We also believe that such a comparison helps designers to understand better the methods that we created. This refined understanding helps us to teach and to improve them. The end goal for both research groups is to be able to better explain their method and to help others adopt it for reasoning about IS development.

Our motivation for comparing the two methods was also related to our curiosity about why both methods have closely related notions (e.g., value networks, services, and exchange) yet still slightly differently represent the world. This similarities led us to believe that the two methods could be used together. For instance, SEAM models explicitly an IS and the value it brings to the value network, whereas *e*^{3}*value* represents market dynamics. These two complementing features make it interesting to explore how to comprehensively model together a scenario and how to enrich each of the methods with additional concepts.

In a socially constructed world, maps create a territory [40]. Hence, a certain language from a modeling method leads modelers to observe the phenomena that the language has in its ontology. For example, *e*^{3}*value* has the notion of reciprocal value transfer that prompts modelers to look for this kind of relationship between actors. SEAM has the notion of a service-delivery process that prompts modelers to focus on the contribution of a set of actors to the service, rather than on the way they are rewarded in exchange for their participation in the process.

The different vocabularies of the two modeling languages enable modelers to *see* different parts of the reality and can blind them to other parts. This helps to understand what portion of the reality we are looking at when using *e*^{3}*value* or SEAM.

VIII. Related Work

We present three lines of research related to our study: (1) comparing modeling methods to show differences and similarities, (2) comparing modeling methods with the purpose of relating and showing how to use them together, and (3) comparison frameworks for comparing at scale. We show a representative sample of the field of modeling method comparison.

A. Comparing Methods to Show Differences and Similarities

Previous work in comparing modeling methods includes the work of Souza and his colleagues who compare their own Dynamic Value Description (DVD) method with *e*^{3}*value* [41]. Their comparison is an qualitative study of three experiments conducted in three countries on how the two methods were being used by students. Their work does not, however, discuss the qualitative characteristics of the methods, how they can be used together, and how to choose a modeling method for a particular purpose.

e^3*value* has been compared with the Business Model Ontology [17]. Their study shows how *e*^{3}*value* and BMO compare on an ontological level. Their work was an inspiration for this paper, and we used parts of the comparison framework. In this paper, we extend the comparison to include not only

the ontologies of the methods in question, but also other philosophical aspects that accompany the use of a modeling method.

B. Comparing Modeling Methods to Use Them Together

e^3*value* has been related to the *i** modeling method and to how the two of them could be used together [42]. The work describes how an integration of the two methods is possible, is beneficial, and gives some guidelines without formalizing the integration or the comparison.

Similar studies include the work of Caetano et al. on integrating the BMC, *e*^{3}*value*, and the business layer of ArchiMate [43] and two previous studies on integrating BMC and ArchiMate [44] and *e*^{3}*value* and ArchiMate [45] on a meta-model level. These comparisons relate mostly the ontologies of the modeling methods and give semantic interpretations to the different elements of the ontologies that present similar or the same concepts. The comparisons are not structured but guided only for the purpose of relating the meta-models.

The SEAM method emerged from the field of enterprise architecture and is compared to Zachmann's enterprise architecture framework [24]. The primary motivation of the authors was to show the value of concreteness in enterprise architecture. The result of their work explains how to use SEAM inside Zachmann's framework.

C. Comparing on Scale

There are multiple studies on how to compare modeling methods on a larger scale. Here, we mention the studies of Andersson et al. [46], Lambert [47], Pfeiffer and Gehlert [48], Jasper and Uschold [49], D'Souza et al. [50], and Pateli [51] on how to analyze conceptual models and how to analyze business models. All of the above-mentioned works present, either as a by-product or as a main artefact, structured frameworks for analyzing the elements of a modeling method.

For example, Andersson et al. use three modeling methods to define a reference ontology for business models that can be potentially used for a model comparison of other methods [46]. The works of Jasper and Uschold [49] and Pfeiffer and Gehlert [48] take another approach for comparing conceptual models that help automatically or semi-automatically relate concepts presented with different elements in the ontologies. The two studies focus only on the ontological level of the modeling methods under consideration.

Lambert presents an analysis framework with three generic attributes (level of analysis, unit of analysis, conceptual focus), but the framework has a limited application for detailed comparisons due to its generic nature [47]. Pateli and Giaglis also give various criteria based on an extensive literature review for analyzing business models [51]. Their framework lacks, most notably, the users and the purpose dimensions for comparing modeling methods. D'Souza et al. present a thorough framework for analysis viability in business modeling methods [50]. However, their work is focused only viability and is unsuited for comparison of models for different purposes.

IX. Threats to Validity

We consider certain threats to the validity of our comparison. First, we use a historical example for comparing the two methods. This passive modeling example might threaten the validity of the models created with *e*^{3}*value* and SEAM. However, the example is based on a case study that the second author has conducted, modeled with *e*^{3}*value*, and presented previously (cf. [10]). Thus, the *e*^{3}*value* model in this paper has been validated. Subsequently, we question of the quality of the SEAM model. Given that the second author conducted the case study, he was able to provide us with various details. In this paper, we use the example to simply illustrate the expressive powers of the two modeling methods. We do not attempt to validate usability or usefulness of the created models for practitioners. We strive to create models that show the strengths and weaknesses of the modeling methods for our discussion.

The next threat to the validity of our comparison is that the creators of the modeling methods under comparison are the authors of this paper. The threat comes from the intimate relationship that the creators have with their creations: we risk having biased opinions. Nevertheless, the creators of the modeling methods are an incomparable source of information. Creators are able to provide details of the most intrinsic properties of their methodology and to justify the modeling choices that have to be made using their method and the history of the evolution of their modeling methods. For our purpose, to qualitatively compare *e*^{3}*value* and SEAM, this source of information proved to be vital, even if it is not easily reproducible. When the methods are openly described in the academic literature, it is possible to compare modeling methods without the creators being involved in the comparison, which is the case for both of these methods.

We must mention one last threat to the validity of our study that is related to the comparison framework we use. The comparison framework is not validated in its current form. However, our purpose for using a comparison framework is to structure and guide our discussions, and not to produce a complete and comprehensive comparison framework with this paper. We also rely on the fact that our framework is largely based on already known published research.

X. Conclusion and Future Work

In this paper, we have presented a comparison of two value-modeling methods, SEAM and *e*^{3}*value* ; we have developed them during the last 20 years. The results we present only scratch the surface of how to compare and combine the two methods. This paper provides an exploratory study for answering the question about if SEAM and *e*^{3}*value* have sufficient overlap: to which the answer is 'yes'. One path to explore is how to combine *e*^{3}*value*, a classic value-modeling method, with SEAM, a service-oriented value-modeling method that is closer to IS development.

We created a comparison framework, which we extended from existing literature, and we applied it to both methods. The results we present here can help researchers, educators,

and even practitioners to select the method that best matches their needs. Having accomplished this work, we realize that the main field of application of both methods is education. Education is a special case because, as it is concerned with learning rather than with implementation, it allows for the simultaneous use of several methods. In this case, our results can be used for courses that include value modeling. The work on the comparison framework is preliminary, and we intend to extend, formalize, and apply the framework to other methods as well. We would also like to extend our work towards comparing different models from the same modeling method and comparing multiple models from one modeling method with multiple models of another modeling method. We envision to collaborate further in order to integrate the two methods based on the results presented here.

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An Ontology for Representing and Annotating Data Flows to Facilitate Compliance Verification

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***Abstract*— In this paper, we argue that there is a gap to be bridged between the development and maintenance of services and the various internal and external policies that emerge and evolve outside of these systems. To bridge this gap, we propose a semantic model, i.e. ontology, for representing Data Flows and linking them with structured representations of the data that is processed (datasets, databases, queries, etc.). Data Flow Diagramming is a technique for capturing the various data and information flows between an information system and external stakeholders as well as within such a system. This technique is used in the analysis phase of information systems development and captures the inputs and outputs of various processes. Our model allows these data flows to be presented and linked with structured representations of the data that is to be used, consulted, processed, etc. We demonstrate that this model can facilitate compliance verification processes of (intelligent) systems by allowing these flows to be analyzed. Next to the ontology, which has been made available according to best practices in the field, we furthermore posit our contributions within the state of the art.**

Keywords-component; Data Flows, Data Flow Diagrams, Semantic Models

I. INTRODUCTION

Data processing, in general, is increasingly the subject of various regulations such as the General Data Protection Regulation (GDPR)[1], an EU law that came into effect on May 2018. While not new, principles such as *privacy by design* or *data protection by design* have been explicitly mentioned by some of these legislations, encouraging developers to account for, at the start, the measures necessary to be compliant. Policies may be internal or external and even evolve over time. This means that not only the development but also the maintenance of information systems and their intelligent processes should co-evolve.

In this context, the adoption of Data Flow Diagrams to support this co-evolution appears as a practical solution as it is already widely used in industry for structured software analysis and design, providing efficient means of communication between developers and business administration [1]. However, as Data Flow Diagrams are merely used during analysis and for communication and documentation, there is a disconnection between the data flow models and the artifacts that have been produced during development phases. In order to tie the analysis and design of services with the resulting or used artifacts (databases, datasets, etc.), appropriate solutions are needed. These solutions could also facilitate data governance. Data governance is defined as *"[referring] to what decisions must be made to ensure effective management and use of IT (decision domains) and who makes the decisions (locus of accountability for decision-making)."* [2] As a solution, we propose an ontology usable for capturing data flows and annotate them with information that will allow compliance to be analyzed. The resulting model cannot only be used at design time but at any time components of the system are to evolve.

The literature on the adoption of Semantic Web technologies (i.e., models) for analyzing GDPR compliance has been investigated. Much of the work in the state of the art addresses assessing compliance *a posteriori* [3] [4], in other words: assessing the compliance of past events by, for instance, annotated and querying logs. Others propose models for describing policies and prescriptions of the various data processing steps [5], [6]. We instead propose a model to bridge the gap between both the analysis and design, and the development and maintenance of information systems, and the various policies those systems should comply with. This allows analysts to better describe systems, more in particular in terms of the (types of) data used by their processes. Therefore, it enables to verify compliance with the necessary measures that need to be put in place during the analysis and design phases of a project.

Our solution relies on standardized Semantic Web technologies – the Web Ontology Language (OWL) [7] and the Resource Description Framework (RDF) [8] – to facilitate the integration of other models, ontologies and vocabularies.

The remainder of this paper is structured as follows: Section 2 provides a brief introduction to Data Flow Diagrams (DFDs); Section 3 presents our Data Flow ontology and exemplifies its use; Section 4 illustrates how one can avail vocabularies to enrich data flows for compliance analysis, demonstrating that our model is apt to tackle aforementioned gap between the analysis and design of services, and development; in Section 5 we present the related work and argue for the use of DFDs over workflow-oriented models; and finally, in Section 6, we summarize contributions and describe future work.

[1] https://eur-lex.europa.eu/eli/reg/2016/679/oj

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II. Data Flow Diagrams (DFD)

Data Flow Diagrams "*enable [one] to model how data flow through an information system, the relationships among the data flows, and how data come to be stored at specific locations. Data flow diagrams also show the processes that change or transform data.*" [9] Figure 1 depicts the various elements of a component diagram:

- *Interfaces* are rectangles and represent the external entities or "actors" that engage with the system. They can send and receive data flows. In Figure 1, interfaces are the customer, the restaurant's kitchen and the restaurant's manager.
- Processes, shown as ellipses, process the data they receive as input and send output on to other DFD entities. A process always has at least one input and at least one output. In the example, there are processes for ordering food, updating the records and inventory, and producing management reports.
- Data stores, represented as rectangles with only a top and a bottom border, represent the places where data is stored (in any form) for other processes to consult. In Figure 1, there are two data stores that facilitate keeping track of the restaurant's sales and inventory.
- *Data flows* are depicted as arrows and indicate data moving from one DFD entity to another. For example, in Figure 1, there is a data flow "order" that denotes the information submitted by the customer to the "Order Food" process.

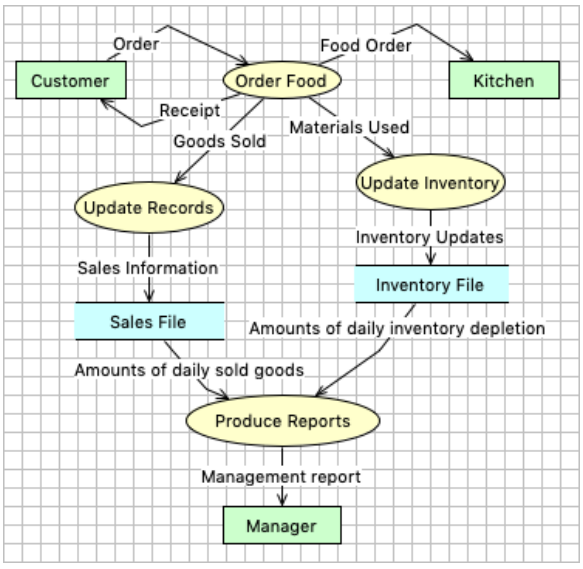


Figure 1 Example of a Data Flow Diagram (inspired from [9])

The notation also has a set of rules including that interfaces and data stores should not be connected (a process needs to be modeled in the middle); data flows should have unique names; etc. Some notations allow processes to be decomposed into subprocesses and comes with its own set of rules such as balancing: "*The conservation of inputs and outputs to a DFD process when that process is decomposed.*" [9]

DFDs are not well suited for modeling a highly distributed system as services provided by other systems should be modeled as interfaces (i.e., an "actor" outside the information system) in a DFD. As DFDs are focused on data flows, however, one can consider the distributed system as one information system. This allows one to model the services as processes (owned by actors), even though the details of which may not be known to the modelers.

For the purpose of this paper, we limit ourselves to "simple" DFD diagrams and data flows that cannot be forked or merged. Our semantic model, which we will present in the next section, can be easily extended to support more complex DFDs.

III. The DFD Ontology

This section presents an ontology for representing Data Flows. This ontology provides predicates to represent data flows and entities. We have decided not to include capturing the graphical representation of the *diagram*, as this does not pertain to the aim of analyzing the processes and flows. If this would be needed, one can easily add statements about the location, size, etc. of the various entities and flows with, for instance, WKT[2].

The ontology[3] is implemented using OWL 2 [7]. The ontology has been made available with a CC-BY-4.0 license and published according to best practices and guidelines in the Semantic Web community. Documentation was generated using WIDOCO [10], which integrated LODE [11] and WebVOWL [12]. The former generated documentation for the OWL ontology using its axioms and annotations, and the latter visualizes the ontology.

The ontology contains 4 disjoint classes: `dfd:DataFlow`, `dfd:DataStore`, `dfd:Interface`, and `dfd:Process`. `dfd:DataStore`, `dfd:Interface`, and `dfd:Process` are subclasses of `dfd:Entity`. There are two object properties relating Data Flows to DFD Entities: `dfd:from` and `dfd:to`. Both have `dfd:DataFlow` as the domain and `dfd:Entity` as range. All the components of a DFD diagram are named, for which we will reuse the `rdfs:label` predicate. All DFD entities and all data flows are supposed to have unique names in a diagram. Using Semantic Web technologies, this is a rule that is more difficult to impose. We, therefore, redefine this rule to state that all DFD entities and all data flows have a unique name and that these names are to be unique in the base or in the RDF graph they are used.

Given the DFD example of Figure 1, a snippet of the DFD's representation in RDF is given below. In this snippet, the default namespace is http://example.org/ and URI encoding

[2] WKT stands for Well-Known Text and is a markup language for representing geometric objects (https://en.wikipedia.org/wiki/Well-known_text)
[3] https://w3id.org/dfd

was used for the URIs. The RDF was generated using an Eclipse plugin written for this study (see Figure 2).

```
@base <http://example.org/> .
@prefix : <http://example.org/> .
@prefix dfd: <https://w3id.org/dfd#> .

:Customer  a          dfd:Interface ;
           rdfs:label "Customer" .
<http://example.org/Order+Food>
           a          dfd:Process ;
           rdfs:label "Order Food" .
:Order     a          dfd:DataFlow ;
           rdfs:label "Order" ;
           dfd:from   :Customer ;
           dfd:to     <http://example.org/Order+Food> .
```

Listing 1 An RDF representation of the "Order" data flow between "Customer" (an interface) and "Order Food" (a process). Note that the RDFS namespace was omitted for brevity.

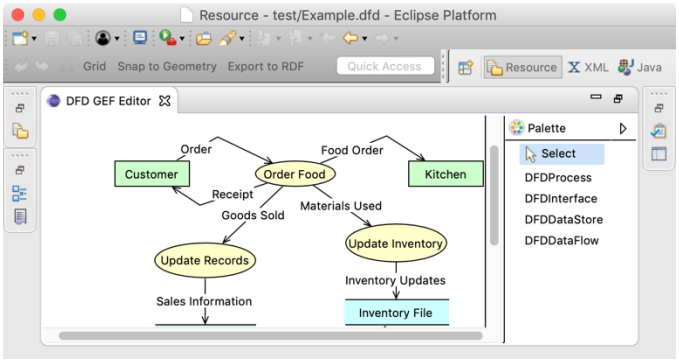


Figure 2 Graphical DFD editor written in Eclipse

IV. Knowledge Organization: Towards Annotating DFDs for Compliance Analysis

The RDF data model allows one to easily add statements to a graph. Using the RDF that was generated (as explained in the previous section), one can extend the graph with 1) structured information about the data shared or stored, and 2) the purpose of data being processed. For both, we can avail of existing (often standardized) vocabularies.

To describe data that is used in a data flow or stored in a data store, we can:

- Use a reference to a vocabulary or ontology that can be used to describe the concepts and relations that will be used in a data flow or store.
- Avail of SPARQL Inferencing Notation (SPIN) [13] to represent SPARQL queries in a structured manner. Such structured descriptions of queries are suitable for describing flows from a data store to a process. Related work has shown that these representations can be used to interrogate these queries [14].
- Describe datasets with the RDF Data Cube Vocabulary [15], which also offers a vocabulary to prescribe a data sets' "schema". The VoID Vocabulary [16] allows one to describe Linked Data datasets and offers predicates for detailing where one can find the data, such as a SPARQL endpoint.

For capturing data processing purposes, we can adopt:

- The PAM ontology proposed in [17] relating *purpose, dataset* and *consent*, with consent information limited to that what is stored by a system. Instances of `dfd:Process` can be directly linked to instances of `pam:Purpose`.
- An ontological "design pattern", recently proposed in [6], for capturing the personal data captured in an organization's privacy policy. This ontology provides predicates not only to describe the purposes for data processing, it also provides predicates for describing what data is collected, who it will be shared with, and how long it is retained for (amongst others). Combined with the ontology proposed in [5], one can interrogate the legal basis of a particular data processing activity.

It is clear that possibilities are vast, but the goal of this section is not to propose a governance framework in which all models are unified, which would be the subject of future work, but rather to demonstrate what is feasible.

A. An Example

We will use the simple example of using names and email addresses to send out newsletters. A *part* of *a* DFD capturing this process and its corresponding RDF are shown in Figure 3 and Listing 2. Note that the data flow containing the email to the customers (the interface, not the data store) has been omitted for brevity.

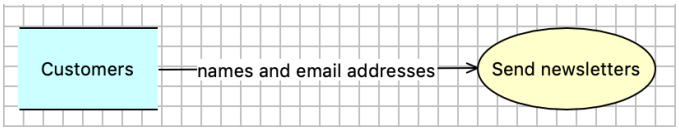


Figure 3 DFD for the process of sending newsletters

```
:Customers  a          dfd:DataStore ;
  rdfs:label  "Customers" .

<http://example.org/Send+newsletters>
  a           dfd:Process ;
  rdfs:label  "Send newsletters" .

<http://example.org/names+and+email+addresses>
  a           dfd:DataFlow ;
  rdfs:label  "names and email addresses" ;
  dfd:from    :Customers ;
  dfd:to      <http://example.org/Send+newsletters> .
```

Listing 2 An RDF representation of the DFD in Figure 3

Let's assume that the customer database is accessible via a SPARQL endpoint using FOAF[4]. The data flow can be anno-

[4] http://xmlns.com/foaf/0.1/

tated with the SPARQL query for retrieving the `foaf:name` and `foaf:mbox` of customers. We will use SPIN to represent the SPARQL query and the predicate `dfd:representedBy` to relate the data flow and the query. This would look as follows:

```
# PREFIX foaf: <http://xmlns.com/foaf/0.1/>
# SELECT ?name ?email WHERE {
#   ?x foaf:name ?name .
#   ?x foaf:mbox ?email .
# }
<http://example.org/names+and+email+addresses>
  dfd:representedBy [
        a sp:Select ;
        sp:resultVariables ( _:b1 _:b2 ) ;
        sp:where ( [ sp:object sp:_arg1 ;
                     sp:predicate foaf:name ;
                     sp:subject _:b1 ]
                   [ sp:object sp:_arg1 ;
                     sp:predicate foaf:mbox ;
                     sp:subject _:b2 ] )
  ].
_:b1  sp:varName "name"^^xsd:string .
_:b2  sp:varName "email"^^xsd:string .
```

Listing 3 The SPARQL query and its corresponding SPIN representation. Notice how the URI of the data flow is connected to the query.

The GDPROV ontology[5] proposed in [5] allows one to state RDF resources to be an instance of `gdprov:PersonalData`. We will use this ontology to state the two FOAF properties we use are such instances using `rdf:type`. Assuming that one can query the RDF representation of the data flows, its representation of the data, and information about its nature, the following SPARQL query allows an agent to find out whether a data flow is using personal data:

```
1.  SELECT ?dataflow ?predicate WHERE {
2.    ?dataflow a dfd:DataFlow .
3.    ?dataflow sp:where/rdf:rest*/rdf:first
4.                [ sp:object ?object ;
5.                  sp:predicate ?predicate ;
6.                  sp:subject ?subject ] .
7.    ?predicate a gdprov:PersonalData .
8.  }
```

Listing 4 SPARQL query to list all personal data that data flows use. Note that the third line allows us to iterate over each of the triple patterns in the where clause. The `rdf:rest*` in the property path will match with both the 0th and 1st occurrence of `rdf:rest` in our list.

The SPARQL query in Listing 4 only checks whether the predicates used are considering personal data. The query can be extended to check whether this holds true for other parts of the triple patterns. One example is to test whether the subject is an instance of personal data when the predicate is `rdf:type`. This shows that a set of SPARQL queries can be written to inform users of aspects to be taken into account.

[5] http://purl.org/adaptcentre/openscience/ontologies/gdprov#

B. *Towards governance and a feedback loop*

We demonstrated how enriched RDF representations of data flows can be used to engage with the services being designed. Those representations, when *combined* with the work, for example, proposed by [5], allows one to ask more complex questions such as: "What is the legal basis of using personal data for this process?" or "Are we allowed to use the personal data in an information purpose for a particular process?" These are the questions that appropriate data governance platforms need to answer. These models, when stored, can be furthermore used for reassessing processes whenever datasets, policies, etc. change. The models we propose have the potential to *facilitate* not only compliance analysis but also the impact of certain changes.

We emphasize that this facilitation will be achieved through integration with work proposed in for instance [3]–[5] (which includes support for formulating compliance), as the ontology is meant to bridge the gap between design, development, and monitoring. The integration of our approach and the models we adopted into a governance framework will be the subject of future work.

V. Related Work

We briefly described related work on compliance analysis in Section I. In this section, we will describe the related work on representing processes with Business Process Model and Notation (BPMN) [18] and other initiatives for representing processes with ontologies and motivate our choice for DFDs.

A. *DFD vs. BPMN*

Before discussing the reasons for adopting DFDs, we first want to elaborate on the difference between Data Flow Modeling, and Business Process Modeling and Flow Charts.

As stated in Section II, Data Flow Diagrams depict the movement of data as data flows between external entities (called interfaces), and internal entities (processes and data stores) within an information system. Data Flow Diagramming is useful to describe a solution during the *analysis* phase of the systems development life cycle (SDLC), and is not a detailed design for it. As [19] noted, DFDs focus on data and have no means to model decisions, branches, workflows, etc. DFDs thus provide a "snapshot" of all possible data flows within a system.

The Business Process Model and Notation, or BPMN [18], does provide constructs for modeling sequences with evens support for branching and converging sequences (based on decisions). The notation is used to graphically model business processes. Similar to flowcharts and UML Activity Diagrams, the models are *process-oriented* with support for events and capturing the sequence of tasks. Indeed, the major difference between the arrows in DFD and BPMN models is that the arrows in the former denote the data being exchanged and the latter the order of tasks being executed. As BPMN proposes a

logical breakdown of processes, they are more suitable for the *design* phase of the SDLC.

In [20], the authors proposed sBPMN, an ontology to serialize BMPN. Much like the purpose of our study, their aim was to enrich models, in their case with Semantic Web Services. While we are aware of these ontologies, we have adopted DFDs for two reasons. First, DFDs are used primarily during the analysis phase; they primarily focus on the data flows and provide a more abstract view of the process that a system should support. Secondly, we deem the data-centric perspective on a system more suitable for our approach; we are concerned with the data used by processes at any given time rather than a logical breakdown of processes that use that data. In DFDs, we are able to annotate both the data being exchanged (the data flows are explicit) as well as the data stores.

Although BPMN does provide support for so-called data objects and data store references (which can be associated with tasks in processes), the modeling focus is on the processes and less on the data. In addition, their representation clutters and complicates the model. For instance, when one process' output is another process' input, there is a need for additional arrows pointing to and from the data object to indicate input and output. This is demonstrated in Figure 4. This makes the models less suitable for analysis, as modeling at the same time processes and data is cognitively harder.

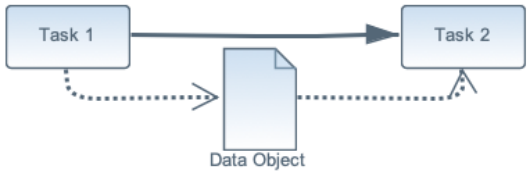


Figure 4 Tasks where one's output is the other's input in BPMN

Therefore, given the purpose of this study – representing and annotating data and information flows – we deem DFD diagrams more appropriate. However, the types of annotations proposed in this study can also be applied to BPMN models.

B. *Relation with other Vocabularies*

We already discussed the difference between our model and sBPMN in the previous section. In this section, we will discuss existing vocabularies. The vocabularies in this section all share some notion of "process", "activity" or "task".

A popular vocabulary for describing activities is provided by the Provenance Ontology PROV-O [21]. PROV-O allows one to represent provenance information in terms of *activities*, entities and agents. It is important to note that PROV-O is used to capture the provenance information of things that have happened in the past, that is why quite a few predicates are written in a past tense (e.g., `prov:wasGeneratedBy`). While PROV-O had a predicate to relate activities to a plan, it did not allow for plans to be described. This was provided by P-PLAN [22], which extended `prov:Plan` to be related with steps, which in turn correspond with activities. Both PROV-O and P-PLAN where then reused by OPMW [23], which allowed one to create workflow-templates, and instantiations thereof, of scientific processes (publishing an article, generating results, etc.). Not only is OPMW domain specific, the models that one can create with this ontology focuses on *workflows,* much like BPMN. We do note that the ontology proposed in this paper can be aligned with PROV-O when there would be a need to create instances of `dfd:Process` that are also instances of `prov:Activity`, which may be an opportunity in the future.

Furthermore, in bioinformatics an ontology for detailing workflows in that domain has been proposed [24]. [25] proposed an ontology for modeling ontology engineering workflows in the Protégé [6] ontology development environment. While generic enough for various ontology engineering projects and methodologies, it is fit for a specific type of project only. In [26], the authors proposed semantically annotating the manipulation and analysis of data in data processing "pipelines". Their efforts are much closer to the execution level of a particular data processing purpose. For this reason, we deem their contribution complementary, as the "implementation" of processes happen after the design process.

We can conclude that – to the best of our knowledge – semantic models to describe processes are not manifold, often focus on the workflow, and are at times domain specific or close to an execution model. We have, while looking into related work, not taken into account initiatives concerned with projects such as DOAP[7], as the constructs they provide are too superficial.

VI. Conclusions and Future Work

The increasing pressure for organizations to be compliant with various regulations and policies provided the motivation for this study. As organizations need to demonstrate that their data processing activities (which evolve over time) are compliant (e.g., with GDPR), they can benefit from semi-automated processes that facilitate compliance processes.

In this study, we argued that there is a disconnection between appropriate techniques for analyzing services, such as Data Flow Diagrams, and the development and maintenance of these services. We therefore proposed an ontology for representing Data Flow Diagrams, of which its instantiations can – thanks to the RDF model – be extended with structured descriptions of information (queries, datasets, databases, etc.) shared between Data Flow entities. We believe that this approach brings us closer to semi-automated compliance analysis at design time. The contributions of this work can be integrated in data governance frameworks where the roles and responsibilities of stakeholders are stored, which is the subject of future work.

[6] https://protege.stanford.edu/

[7] Description of a Project (DOAP) vocabulary: http://usefulinc.com/ns/doap

A current limitation of our ontology is the lack of support for functional decompositions of processes. While not necessary, such function decomposition does allow service designer to separate concerns and keep diagrams tidy. To support functional decomposition the ontology needs to be extended. The extension would require relations between processes and its children as well as set of constraints to validate models. As checking balanced DFDs is outside the capabilities of OWL, these will have to be written in a constraint language such as SHACL [27]. Finally, we foresee aligning our model with workflow-oriented models by integrated existing work, such as sBPMN [20], as to provide support for both analysis and design phases in the systems development life cycle.

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Ontology-Based Model Abstraction

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***Abstract*—In recent years, there has been a growth in the use of reference conceptual models to capture information about complex and critical domains. However, as the complexity of domain increases, so does the size and complexity of the models that represent them. Over the years, different techniques for complexity management in large conceptual models have been developed. In particular, several authors have proposed different techniques for *model abstraction*. In this paper, we leverage on the ontologically well-founded semantics of the modeling language OntoUML to propose a novel approach for model abstraction in conceptual models. We provide a precise definition for a set of Graph-Rewriting rules that can automatically produce much-reduced versions of OntoUML models that concentrate the models' information content around the ontologically essential types in that domain, i.e., the so-called *Kinds*. The approach has been implemented using a model-based editor and tested over a repository of OntoUML models.**

***Index Terms*—Model Abstraction, Complexity Management in Conceptual Modeling, Ontology-Based Conceptual Modeling**

I. Introduction

In recent years, there has been a growth in the use of reference conceptual models to capture information about complex and critical domains. These models play a fundamental role in different types of critical semantic interoperability tasks. Therefore, it is essential that domain experts are able to understand the subtleties of their content and reason with them. In other words, it is important that conceptual models remain cognitively tractable. However, as complexity of the information about the represented domain grows, so does the size and complexity of the artifacts that represent them.

Over the years, different techniques for complexity management in large conceptual models have been developed. In particular, a number of authors have proposed different techniques for *model abstraction*. These techniques aim at systematically producing reduced versions of the original conceptual models omitting details while concentrating on the gist of the semantic content at hand. However, since basically all traditional techniques have been produced for ontologically neutral conceptual modeling languages (e.g., ER, UML), they are constrained to rely solely on syntactical properties of the models and, more specifically, on topological properties of the graph. This happens because these languages treat all types as being the same, semantically overloading one single construct (e.g., Class or Entity Type) by using it to represent different types of ontological categories.

In contrast, ontology-driven conceptual modeling (ODCM) languages are systematically designed to conform to an underlying ontological theory. In particular, an ODCM language contains exactly the modeling primitives that are necessary to represent the ontological distinctions put forth by its underlying ontology. For example, as different ontological categories of types (e.g., Kinds, Mixins, Roles) play different roles with respect to their instances regarding issues such as classification (e.g., dynamic versus static) and identity, these distinctions should be explicitly represented by the language's constructs.

ODCM approaches have enjoyed an increasing adoption by the Conceptual Modeling community as a number of independent results consistently show their benefits for improving the quality of conceptual models [3], [21], [28]. An example of an ODCM language is OntoUML [12]. It has been successfully employed in academic, industrial and governmental settings to create conceptual models in a number of different domains, including Geology, Biodiversity Management, Organ Donation, Petroleum Reservoir Modeling, Disaster Management, Context Modeling, Datawarehousing, Enterprise Architecture, Data Provenance, Measurement, Logistics, Complex Media Management, Telecommunications, Heart Electrophysiology, among many others [14]. In fact, research shows that it is among the most used ODCM languages in the literature [27]. Moreover, empirical evidence shows that OntoUML significantly contributes to improving the quality of conceptual models without requiring an additional effort to produce them. For instance, the work of [28] reports on a modeling experiment conducted with 100 participants in two countries showing the advantages (in these respects) of OntoUML when compared to a classical conceptual modeling language (EER).

In this paper, we leverage on the ontologically well-founded semantics of OntoUML to propose an approach for model abstraction in conceptual models. We provide a precise definition for a set of Graph-Rewriting rules that can automatically produce much-reduced versions of OntoUML models. These reduced models concentrate the models' information content around the ontologically essential types in that domain, i.e., the so-called *Kinds*. The approach has been implemented using a model-based editor and tested over a varied set of OntoUML models.

The remainder of the paper is organized as follow. Section II discusses related work in the area of complexity manage-

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ment of conceptual models; Section III briefly presents the OntoUML language and its ontological foundations; Section IV presents the main contribution of this paper by defining a set of Graph-Rewriting abstraction rules; Section V presents a plug-in to a model-based editor that implements the proposed abstraction rules. The implementation of this plug-in itself counts as a first validation of the approach (claim to *practical realizability*). However, in that same section, we also report on a study conducted with a varied set of OntoUML models to assess both the proposed rule set and its implementation; Section VI systematically compares the results presented here with relevant related work; Finally, Section VII concludes the paper with some final considerations.

II. Complexity Management of Conceptual Models

The discipline of *complexity management of large conceptual models* (henceforth CM-CM) has been around for quite some time and has been represented in the literature by a series of different approaches and techniques. In fact, [29] claims that "one of the most challenging and long-standing goals in conceptual modeling... is to understand, comprehend and work with very large conceptual schemas".

The challenge and importance of this discipline lies in the following. On one hand, real information systems often have large and extremely complex conceptual models [29]. On the other hand, this complexity poses a serious additional challenge in the comprehension and, consequent, quality assurance of these models. For example, [22] reports on an empirical study conducted with a large and professionally constructed conceptual model.[1] In that study, the authors managed to show that the model contained 879 occurrences of error-prone structures (anti-patterns), 52.56% of which really introduced representation errors according to the creators of the model. A more dramatic case (both in size and percentage of occurrences of anti-patterns) is reported in [4], in which the authors show a case of an anti-pattern present in 85% of the relevant relations in Wikidata.

According to [29], the methods for CM-CM can be classified in three areas, namely, *Clustering Methods*, *Relevance Methods*, and *Summarization Methods*. Clustering is about classifying the elements of a conceptual model into groups, or clusters, according to some criteria (e.g., a similarity function); Relevance Methods are about the application of ranking functions to the elements of a model in order to obtain ordered lists (i.e., a ranking) of model elements according to their perceived relevance in representing the domain at hand; finally, Model Summarization is about producing from an original model a reduced version consisting only of the elements that are judged to be of more relevance for representing the domain at hand. A variation of Model Summarization is Model Abstraction, which can be described as "a process that transforms lower-level elements into higher-level elements containing fewer details on a larger granularity" [7]. The idea here is to allow for the possibility of "zooming out" of models in order to provide the user with the "bigger picture" of the domain at hand, allowing her to focus on the gist of the model by filtering out specific details [7]. In clustering methods, the goal is to break down a model in fragments such that the sum of these fragments should be informationally equivalent to the whole (i.e., to the original model). In contrast, relevance and summarization methods (including model abstraction) aim to produce partial views of the original model at hand. In other words, while clustering methods have *lossless model transformations*, the latter classes of methods are based on *lossy transformations*.

Given the purpose of this paper, we henceforth focus our discussion in this class of lossy methods and, in particular, in summarization/abstraction methods. First, however, we elaborate on a drawback that is common to the majority of existing methods in all these classes. Namely, as nearly all these methods are based on classic conceptual modeling notations (e.g., UML, ER) [29], they are constrained to rely almost exclusively on syntactic (mainly topological) properties of the addressed models. These properties include *closeness* (a quantitative evaluation of the links among elements in the model) [10], *hierarchical distance* (length of the shortest relationship path between entities), *structural-connective distance* (elements are considered closer if they are neighbors in a hierarchy mereological or subtyping structure), or *category distance* (elements are considered to be closer if one subtypes the other) [1]. For example, [5] proposes a (relevance) method based on the assumption that the number of attributes and relations characterizing an element in a model can be used as a (heuristic) measure of its relevance for that model. In the same spirit, [25], [26] go as far as proposing PageRank-style algorithms to infer the relevance of elements in entity-relationship diagrams and RDF schemas (even ignoring the difference between association and subtyping relations). The problem with relying solely on these properties is that there is no guarantee that a model element satisfying some topological requirement (e.g., a node with more edges connected to it) by necessity represents the model's most important concepts. This is related to the work by [18], [19], that while criticizing existing CM-CM methods, referred to it as *lack of cognitive justification*.

One of the main approaches for Model Abstraction in the literature is the one proposed by Egyed in [6]–[8]. It is a tool-supported approach that provides conceptual model designers with the ability to 'zoom out' from a model to investigate and reason about its bigger picture. Like in our case, the proposed approach is based on a set of pattern detection and replacement rules. The approach is built around a classic conceptual modeling technique (UML) and, hence, it heavily relies on structural (topological) properties of the diagram. As a consequence, it is subject to some extent to all the aforementioned drawbacks. In fairness, the author makes a significant effort in defining structural patterns that reflect the intuitive semantics of UML class diagrams, for instances, re-

[1] This model consisted of 3800 classes, 61 datatypes, 1918 associations, 3616 subtyping relations, 698 generalization sets and 865 attributes, i.e., navigable association ends [22].

garding transitivity of dependence, method calling, inheritance and propagation from parts to wholes. However, the whole approach has a strong focus of the use of these diagrams from the point of view of Object-Oriented Programming and, hence, many fundamental conceptual modeling primitives are simply ignored. These include not only modal aspects of class instantiation, existential dependence relations, but also more basic aspects such as generalization sets and association classes (or reified associations).

In contrast with all the aforementioned approaches, our proposal in this paper focuses mainly on the *ontological semantics* [12] of the elements represented in a conceptual model. In particular, it produces an abstraction of an original model by representing a summarized version of the domain information around the backbone of the ontological *kinds* of entities represented therein. As supported by a significant body of evidence in cognitive psychology [17], [31], [32], these *kinds* (also termed *substance sortals*) represent the most salient category of types in human cognition, being responsible for our most basic operations of object individuation and identity.

The approach presented here (and detailed in section IV) is only made possible because it is based on a non-classical CM language, namely, the ODCM language OntoUML (briefly presented in section III). There are two CM-CM methods in the literature that are based on the same language, namely, the approaches of [9] and [15], [16]. However, none of these are methods of model abstraction. The former proposes a method for model clustering by viewpoint extraction. The idea is to divide the model into a number of clusters, each of which represents a well-founded *ontological viewpoint*. As a clustering method, the approach produces a set of clusters whose sums are informationally equivalent to the original model (lossless transformation). The latter approach, although also being about view extraction, can be considered as a summarization method, since it produces partial versions of the original model (lossy transformation). It is, nonetheless, not a method of model abstraction. The idea there is that, given a set of entities from the original model provided by the model user, the method produces a subset of that model containing the elements that are more relevant for the context of the selected entities. One important point is that the notion of relevance there is not a syntactic but an ontological one, related to notions such as conservation of identity, of existential dependence, of parthood, etc. In any case, different from our proposal, the approach achieves summarization by presenting a model that is identical to a proper part of the original model, not by producing a global view of the entire model in a much higher level of abstraction.

III. A Brief Introduction to UFO and OntoUML

OntoUML is a language whose meta-model has been designed to comply with the ontological distinctions and axiomatization of a theoretically well-grounded foundational ontology named UFO (Unified Foundational Ontology) [12], [14]. UFO is an axiomatic formal theory based on contributions from Formal Ontology in Philosophy, Philosophical Logics, Cognitive Psychology, and Linguistics. A recent study shows that UFO is the second-most used foundational ontology in conceptual modeling and the one with the fastest adoption rate [27]. In the remainder of this section, we briefly explain a selected subset of the ontological distinctions put forth by the Unified Foundational Ontology (UFO). We also show how these distinctions are represented by the modeling primitives of OntoUML. In order to do that, we rely on the running example depicted in fig. 1. For an in-depth discussion, philosophical justifications, formal characterization and empirical support for these categories one should refer to [11], [12].

Take a domain in reality restricted to endurants [12] (as opposed to events or occurrents). Central to this domain we will have a number of object *Kinds*, i.e., the genuine fundamental types of objects that exist in this domain. The term "kind" is meant here in a strong technical sense, i.e., by a kind, we mean a type capturing essential properties of the things it classifies. In other words, the objects classified by that kind could not possibly exist without being of that specific kind. In fig. 1, we have represented three kinds, namely, 'Person','Car' and 'Organization'. These are the fundamental kinds of entities that are deemed to exist in the domain.

Kinds tessellate the possible space of objects in that domain, i.e., all objects belong necessarily to exactly one kind. However, we can have other static subdivisions (or subtypes) of a kind. These are naturally termed *Subkinds*. As an example, the kind 'Person' can be specialized in the subkinds 'Man' and 'Woman'; the kind 'Organization' also be specialized in subkinds, e.g., 'Car Agency' is a static subkind of *Organization* (fig. 1).

Object kinds and subkinds represent essential properties of objects (they are also termed rigid or static types [12]). We have, however, types that represent contingent or accidental properties of objects (termed anti-rigid types [12]). These include *Phases* and *Roles*. The difference between the contingent properties represented by a phase and a role is the following: phases represent properties that are intrinsic to entities; roles, in contrast, represent properties that entities have in a relational context, i.e., contingent relational properties.

Phases but also typically subkinds appear in OntoUML models forming (disjoint and complete, i.e., exhaustive) *partitions* following a *Dividing Principle* [30]. For example, in fig. 1, we have the following *phase partitions*: the one including 'Living Person' and 'Deceased Person' (as phases of 'Person' and according to a 'life status' dividing principle); the one including 'Child', 'Teenager' and 'Adult' (as phases of 'Living Person' and according to a 'developmental phase'); the one including 'Available Car' and 'Under Maintenance Car'(as phases of 'Car' and according to a 'operational status'). Since they are exclusively composed of phases, these are all dynamic partitions [30]. In this model, we also have a (static) *subkind partition* formed by the subkinds 'Man' and 'Woman', dividing 'Person' according to 'gender'.

Kinds, Subkinds, Phases, and Roles are categories of object *Sortals*. In the philosophical literature, a sortal is a type that provides a uniform principle of identity, persistence, and

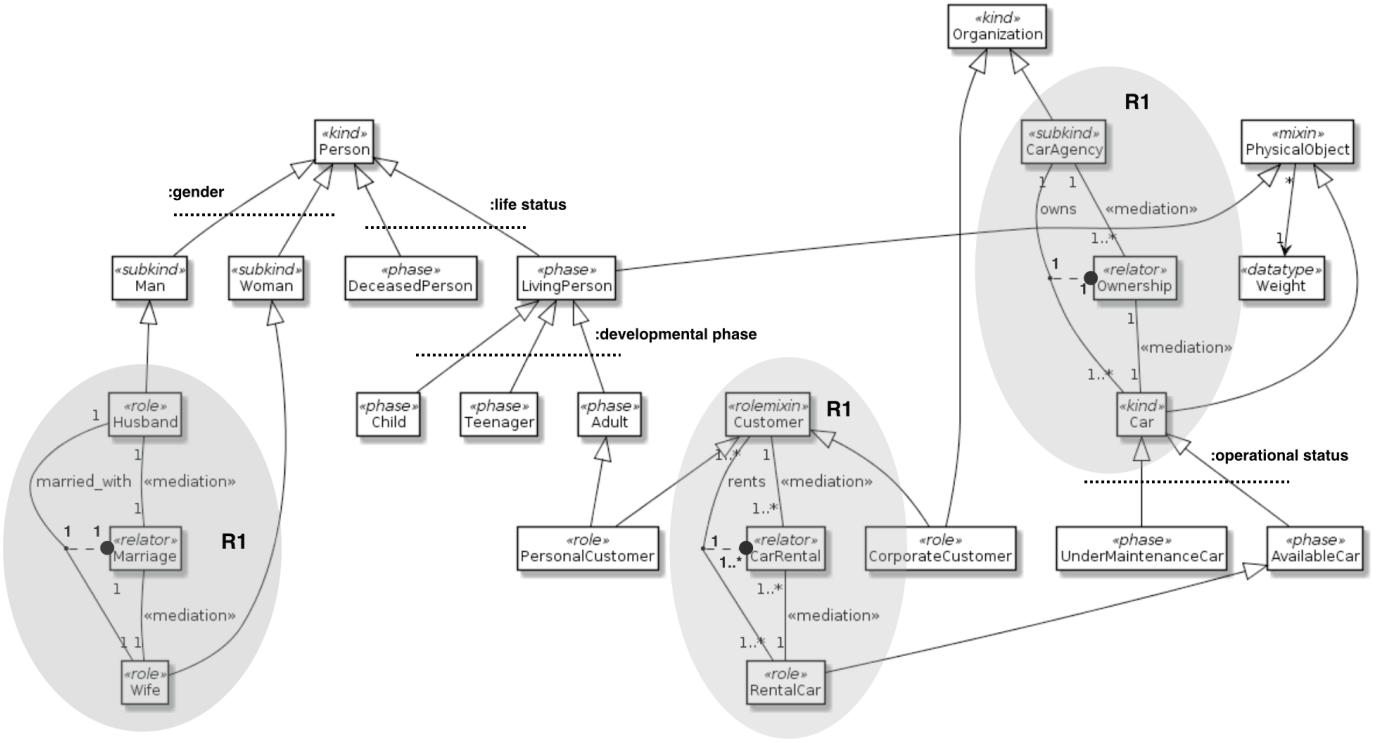


Fig. 1. An Example of an OntoUML Model.

individuation for its instances [12]. To put it simply, a sortal is either a kind (e.g., 'Person') or a specialization of a kind (e.g., 'Husband', 'Teenager', 'Woman'), i.e., it is either a type representing the essence of what things are or a sub-classification applied to the entities that "have that same type of essence".

Relators (or *relationships* in a particular technical sense [11]) represent clusters of relational properties that "hang together" by a nexus. Moreover, relators (e.g.,'enrollments', 'employments', 'presidential mandates', 'citizenships', but also 'marriages', 'Car Rentals', and 'Ownerships' (fig. 1)) are full-fledged *Endurants*. In other words, entities that endure in time bearing their own essential and accidental properties and, hence, first-class entities that can change in a qualitative manner while maintaining their identity. As discussed in depth in [11], [12], relators are fundamental for addressing a number of problems in conceptual modeling, ranging from ambiguity of cardinality constraints, to ambiguity in relation specialization, to transitivity of part-whole relations.

As discussed in depth in [11], relators are the truthmakers of relational propositions, and relations (as classes of n-tuples) can be completely derived from relators [12]. For instance, it is the 'marriage' (as a complex relator composed of mutual commitments and claims) between 'John' and 'Mary' that makes true the proposition that "John is the husband of Mary". In other words, the pair <John,Mary> is an instance of the relation 'married-with' because there is a particular instance of the relation 'Marriage' connecting John and Mary (fig. 1). In OntoUML, the relation of *derivation*, connecting relations to the relator types from which they are derived is represented by a dashed line with a black circle in the relator type association end (fig. 1). Technically, Relators bind their relata because they are existentially dependent entities (e.g., the marriage between John and Mary can only exist if John and Mary exist). The formal connection between Relators and their relata is made by the so-called *mediation* relations, a particular type of existential dependence relation [12].

Objects participate in relationships (relators) playing certain *Roles*. For instance, people play the role of spouse in a marriage relationship; a person plays the role of president in a presidential mandate. 'Spouse' and 'President' (but also typically 'Student', 'Teacher', 'Pet', 'Rented Car'[2]) are examples of what we technically term a *role* in UFO, i.e., a relational contingent sortal (since these roles can only be played by entities of a unique given kind). There are, however, relational and contingent role-like types that can be played by entities of multiple kinds. An example is the role 'Customer' (which can be played by both people and organizations). We call these role-like types that classify entities of multiple kinds *RoleMixins*.

In general, types that represent properties shared by entities of multiple kinds are termed *Non-Sortals*. In UFO, besides rolemixins, we have two other types of non-sortals, namely

[2]In order to illustrate different combinations of cardinality constraints, in fig.1, we assume here that a RentedCar can be related to several rentals provided that they do not overlap in time, hence, the cardinality '1..*' on the side of Car Rental as well as the corresponding cardinality constraints on the derived 'rents' relation.

Categories and *Mixins*. Categories represent necessary properties that are shared by entities of multiple kinds (e.g., the category 'Physical Object' represent properties of all kinds of entities that have masses, spatial extensions, etc.). In contrast, mixins represent shared properties that are necessary to some of its instances but accidental to others. For example, in fig. 1, we have the mixin 'Physical Object', since it represent properties (e.g., having a 'Weight') that are necessary to 'Cars', while being accidental to instances of 'Person' (people are only physical objects when they instantiate the *phase* 'Living Person'). Categories and mixins are, in contrast to rolemixins, considered as Relationally Independent Non-Sortals.

Finally, as all OntoUML models are valid UML models, the classes in the model can also be connected (via particular types of relations termed *navigable association ends*) with datatypes. Datatypes, in UML, are classifiers that include the so-called 'pure values'. As discussed in [12], datatypes are sets of abstract elements. As sets they can be defined by a formula or by extension, in which the total membership of that datatype is explicitly enumerated. In these cases, these datatypes are termed *enumerations*. Still, in all UML models, association ends of relations can be characterized by so-called *rolenames*, which are intended to represent the way an instance of a type (connected to that association end) participates in that relation. Examples of enumerations and rolenames are shown later in this article.

IV. Abstraction Rules

In this section, we present a set of *graph-rewriting rules*.[3] As a system of graph-rewriting, the approach replaces fragments of the original model by reduced fragments that, while filtering out details, maintain essential information. In particular, these rules and their specific order of application (from R1 to R4) have been designed according to the following rationale.

As previously explained, in ODCMs, we have that:

1) objects take a precedence over relators, given that the latter are existentially dependent on the former. So, in the reduced model, we focus on the representation of objects as well as the relations derived from these relators without representing the latter explicitly. In other words, instead of explicitly representing the relators that are truthmakers of certain relational properties involving objects, we simply represent these derived properties. R1 was designed to address this abstraction step and should be the first to be applied to a model;

2) the most important object types in an ODCM are the *Kinds* of entities that exist in that domain, i.e., the rigid identity-supplying types. Once relator types have been abstracted from a model (R1), the goal is to distribute the information in a such a way that it ends up being concentrated around the *kinds* represented in the model. We do that by: firstly, taking all properties of Non-Sortal types and moving it downwards towards the sortals in the model. These non-sortals are then abstracted away in the resulting fragment (R2); secondly, we move all properties of sortals that are not kinds upwards towards the kinds in the model. These (non-kind) sortals are then abstracted away in the resulting fragment (R3); finally, for all subkind and phase partitions, after moving their properties upwards according to (R3), we abstract from these partitions by representing their concrete leaf types in enumeration datatypes (R4). As a result of the application of these rules, the final abstracted model should only contain Kinds and Enumerations, hence, making redundant the use there of the stereotype «kind».

Each of these four rules (R1-R4) occupy a row in Table I. Once more, following the aforementioned rationale, the rules should be applied in this specific order. For each of these rules, whenever a graph structure satisfying the pattern in column *Matching Graph* is found in an OntoUML model, that portion of the model is replaced by the corresponding structure in column *Replacing Graph*. In the remainder of this section, we elaborate on each of these rules by relying on our running example of fig. 1.

A. Abstracting Relators (R1)

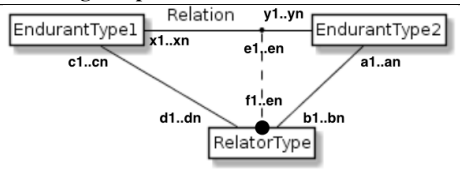
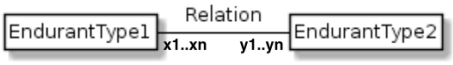
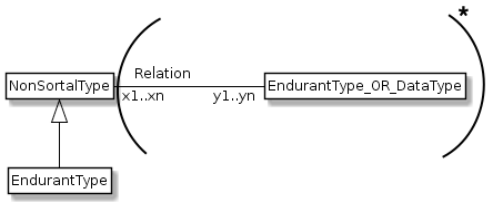
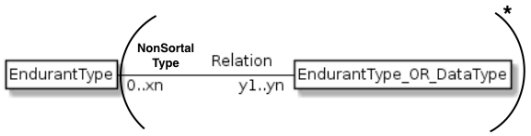
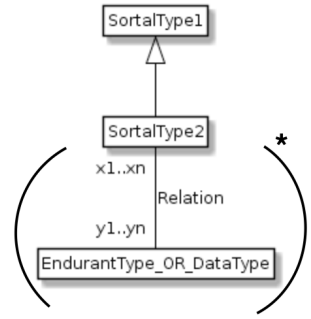
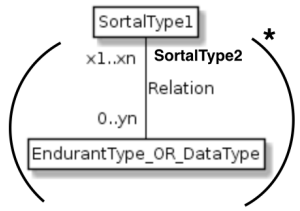
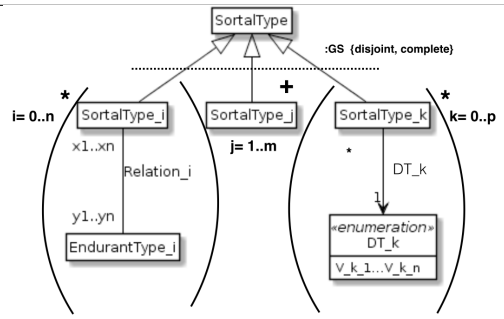
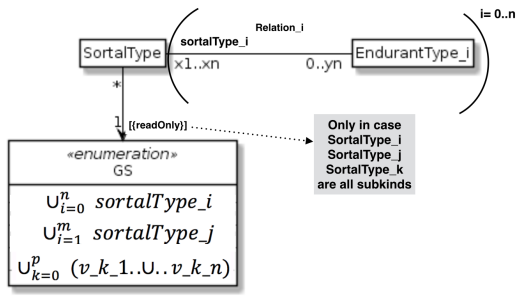
As previously discussed, relators are fundamental in ODCMs. For instance, by representing the cardinality constraints $c_1..c_n$, $d_1..d_n$, $a_1..a_n$ and $b_1..b_n$ in table I, we can eliminate instances of the so-called *single-tuple/multiple-tuple cardinality ambiguity problem* [12] in the model; by representing the the cardinality constraints $e_1..e_n$ and $f_1..f_n$, we can eliminate occurrences of the *repeatable instances* anti-pattern as discussed in [22]. However, in order to compress our model, and following the previously discussed rationale, we abstract from this *relator pattern* by replacing each of its occurrences with a structure in which only the derived relations are shown. For example, in the model in fig. 1, there are three occurrences of this pattern (highlighted by oval shadows). By applying R1 to that model, we obtain the model in fig. 2. Hence, for example, instead of having represented there the full relator pattern connecting 'Marriage' to 'Husband' and 'Wife' (as well as the corresponding full set of cardinality constraints and the derivation relation), this pattern is replaced by the graph structure that only represents the 'married-with' and associate roles and cardinality constraints (see the oval marked as R1* in fig. 2).

B. Abstracting Non-Sortals (R2)

As discussed in [12], Non-Sortals capture properties that are shared by individuals of different kinds. As discussed there, they play a significant role in *model refactoring*. However, for the sake of model compression, R2 reverses this refactoring operation by replicating the information represented in non-sortal types in its concrete concrete sortal subtypes. This rule serves as an intermediate step for the application of rule R3.

[3] Due to lack of space for this article, we present these rules without employing a specific formal language. In an extension of this paper, we shall present their formalization using the same tools we used for formalizing OntoUML as a Pattern Grammar [33].

TABLE I
GRAPH-REWRITING RULES FOR ONTOUML MODEL ABSTRACTION

Rule	Matching Graph	Replacing Graph
R1		
R2		
R3		
R4		

In summary, as shown by the rewriting scheme of row 2 in table I, this rule consists of:

1) Abstracting from all Non-Sortal types in the diagram;
2) Replicating all properties of these Non-Sortal in the concrete sortal types that specialize them.

More precisely, as demonstrated table I, given a pattern in which we have zero or more occurrences (symbolized there as '*') of a relation R' connecting a non-sortal type NS to another Endurant type T' (or to a datatype D'), we replace this pattern by a structure in which a copy of each R' is created connecting each Endurant Type ST' (direct specializing NS) to T' (or D'). The original non-sortal NS is represented in the replacing structure as a *rolename* connected to the association end attached to each ST'. Although it is true that every T' or D' must associate with at least x_1 instances of NS, for each of the specific subtypes ST', it is not the case that T' or D' must associate with their instances. For this reason, the cardinality constraint x_1 in the original pattern is relaxed to an optional cardinality constraint (i.e., $0..x_n$).

For example, in the model of fig. 2, we have two occurrences of this pattern (highlighted by oval shadows tagged R2). By applying R2 to that model, we obtain the model of fig. 3. So, for example, in fig. 3, the property of having a 'weight' (R' above) connects 'Physical Object' (NS) to the datatype 'Weight'(D' above). This property is then now replicated in the specific concrete types of physical objects, namely, instances of 'Living Person' (ST_1) and 'Car' (ST_2) (see oval marked as R2* in fig. 3). Moreover, the *rolename* 'Physical Object' is attached to the association end connected to each of these sortal types.[4] Finally, the minimum cardinality constraint for each of these association ends are relaxed to zero. After all, given a particular weight, it is neither necessarily associated with a 'Living Person' nor with a 'Car'.

[4]This represents that it is *qua-physical-object* that cars and living people have weights.

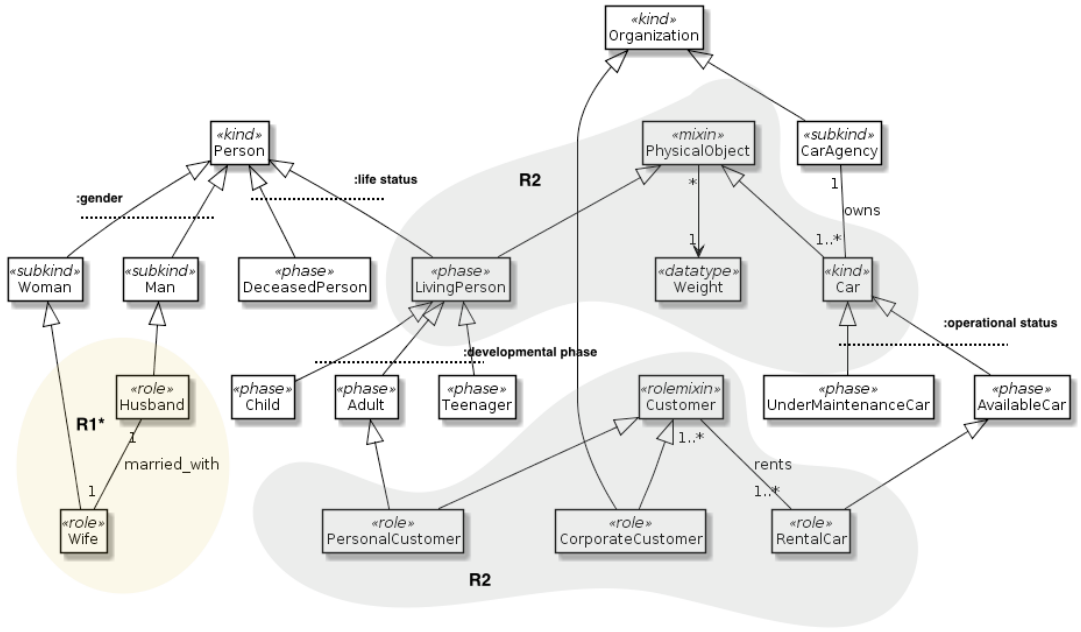


Fig. 2. Model produced as a result of the application of R1 on the model in fig. 1.

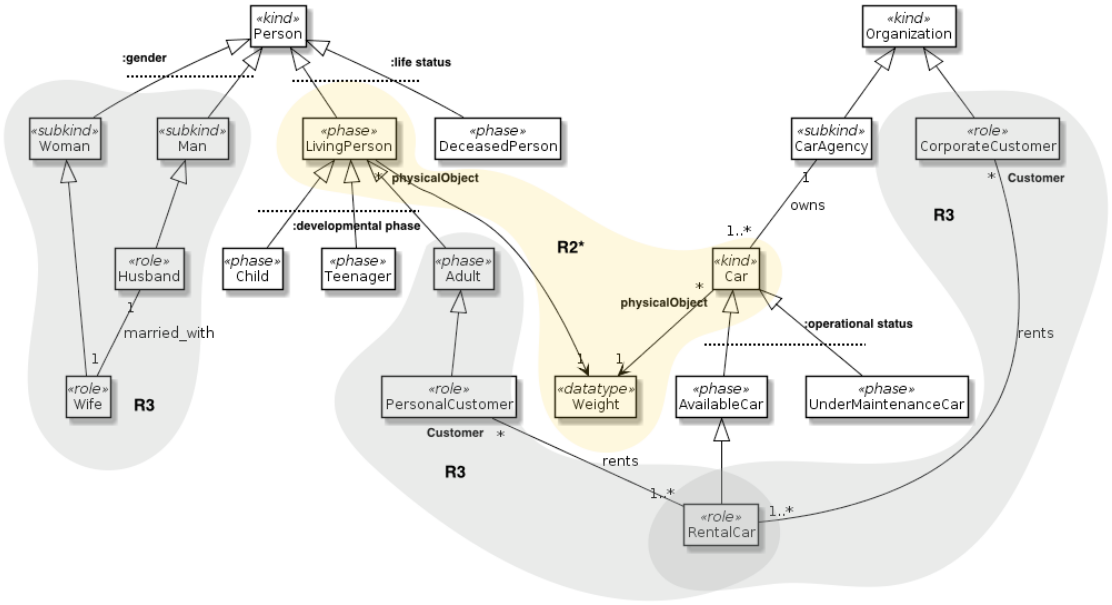


Fig. 3. Model produced as a result of the application of R2 on the model in fig. 2.

C. Abstracting Sortals (R3)

From an ontological point of view, the most important types of any given domain are the so-called *Kinds* (also called *Substance Sortals*), given that: these are types that provide a principle for identity, individuation and persistence for their instances; they classify their instances necessarily, i.e., in all possible situations (in a modal sense) [12]. As previously discussed, the objective of the R3 is to (through one or more iterative application of this rule) abstract from all other sortals in a model (i.e., subkinds, phases and roles), concentrating the information about the domain around these kinds.

In summary, as shown by the rewriting scheme of row 3 in table I, this rule consists of:

1) Eliminating all non-substance sortal types from the diagram;
2) Moving the properties of these non-substance sortal types to their sortal supertype, until these properties are eventually used to characterize the *kinds* in the model.

More precisely, as demonstrated in table I, given a pattern in which we have zero or more occurrences (symbolized there

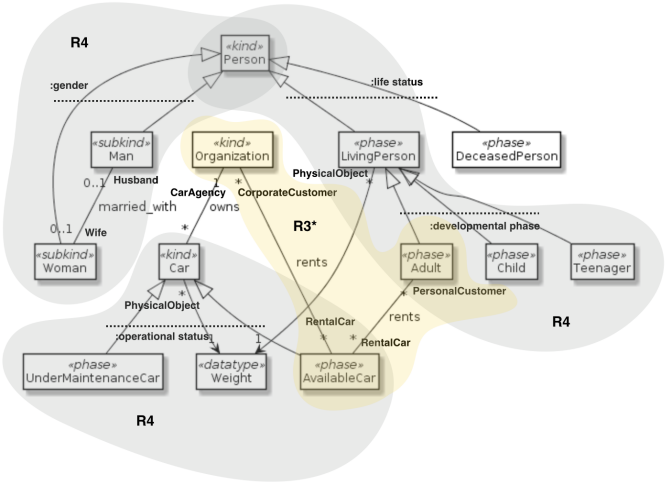


Fig. 4. Model resulting from the application of R3 on the model in fig. 3.

as '*') of a relation R' connecting a sortal type ST to another Endurant type T' (or to a datatype D'), we replace this pattern by a structure in which a copy of each R' is created connecting each sortal type ST' (direct supertyping ST) to T' (or D'). The original sortal ST is represented in the replacing structure as a *rolename* connected to the association end attached to each ST'. Although it is true that instances of ST must be associated with at least y_1 instances of T' (or D'), it is not the case that instances of ST' in general must satisfy the same constraint. For this reason, the cardinality constraint y_1 in the original pattern is relaxed to an optional cardinality constraint (i.e., $0..y_n$).

For example, in the model of fig. 3, we have initially three occurrences of this pattern. By applying R3 to that model, we obtain the model of fig. 4. So, for example, in fig. 3, the relation 'rents' (R' above) connects the sortal 'Personal Customer' - a role played by an 'Adult Living Person' when renting a car (ST_1) - to another sortal 'Rental Car' - a role played by an 'Available Car' when being rented by a customer (ST_2). Due to the application of R3, this relation is then now moved to connect a more abstract supertype of 'Personal Customer' ('Adult' - ST_1') and a more abstract supertype of 'Rental Car' ('Available Car'- ST_2') (see oval marked as R3* in fig. 4). Moreover, the *rolenames* 'Personal Customer' and 'Rental Car' are attached to the association ends connected to 'Adult' and 'Available Car', respectively.[5] Finally, the minimum cardinality constraint for each of these association ends are relaxed to zero. After all, it is neither the case that every 'Adult' rents at least one car nor the case that every 'Available Car' must be rented. Of course, as illustrated in R3* in fig. 4, an analogous case can be made for the abstraction of 'Corporate Customer' into the supertyping sortal 'Organization'.

[5]Again, this represents that it is *qua-personal customer* that an adult person rents a car and, analogously, it is *qua-rental car* that an available car participates in a renting relation with a person.

D. Abstracting Subkind and Phase Partitions (R4)

As previously discussed, phases always appear in ODCMs as parts of the so-called *phase partitions*. This is often the case also with multiple subkinds of a given kind, hence, forming *subkind partitions* [13]. Both these partitions define disjoint and complete *generalization sets* over a common supertype. The difference between these partitions is the following. Since phases are anti-rigid types, the phase partitions are dynamic, i.e., the instances of a phase (e.g., 'Child') in a partition (e.g., 'developmental stage') can always possibly (in a modal sense) move to another phase in the same partition (e.g., 'Adult' or 'Teenager'). In contrast, since subkinds are rigid, instances of a subkind (e.g., 'Man') in a given subkind partition (e.g., 'gender') cannot move to other subkinds in the same partition, i.e., subkind partitions are static.

Rule 4 is designed to abstract away non-substance sortals in these partitions by: (i) eventually mo all their propvingerties to their unique supertyping kind (through one or more iterated applications of this rule); (ii) represent all leaf types in these partitions as values in a *enumeration* datatype eponymous to that partition. In summary, as shown by the rewriting scheme of row 4 in table I, this rule consists of:

1) Moving all the properties of a SortalType ST' participating in a partition to the common sortal supertype K in that partition;[6]
2) Transforming each leaf sortal type ST' in a partition into an item in a new enumeration datatype that has the same name as the partition at hand. This enumeration is then related to the common immediate supertype in that partition (K) via a datatype relation D_R (navigable association end in (Onto)UML);
3) If a SortalType being abstract by this rule is already related to another existing enumeration E' then all elements of this enumeration will be included as elements of the new enumeration E created by this rule.

More precisely, as demonstrated table I, we start with a pattern in which we have a generalization set GS containing a number of (all rigid or all anti-rigid) sortal types that share a common (sortal) supertype *SortalType*. Then in GS we have one or more occurrences (symbolized there as '+') of sortal types $SortalType_j$ as well as zero or more occurrences (symbolized there as '*') of sortal types $SortalType_i$ and $SortalType_k$. We then create an enumeration datatype called GS such that all sortal types $SortalType_j$ and $SortalType_i$ appear as elements of the newly created enumeration datatype GS. As for the sortal types $SortalType_k$, which are connected to their own enumeration datatypes, a special treatment is reserved as explained below. We also create a datatype relation D_R connecting *SortalType* to GS. Given that the original generalization set is *disjoint* and *complete*, the cardinality constrains on the association end connected to GS via D_R must be of exactly 1 (minumum cardinality of 1 due to completeness and maxinum cardinality of 1 due to disjointness). Iff the

[6]Notice that in, this sense, R4 contains a special variant of R3 for abstracting sortals that are part of a partition.

original generalization set GS represents a subkind partition then the association end connected to enumeration GS via D_R must be declared immutable (*readOnly* in (Onto)UML) and, hence, its value must be the same in all possible worlds.[7]

Moreover, suppose that in the generalization set GS we have one or more occurrences of a sortal types $SortalType_i$ bearing a relation $relation_i$ to another endurant type $EndurantType_i$. In this case, we replace this pattern by a structure in which a copy of each $relation_i$ is created connecting the common (direct) supertype *SortalType* in that partition to $EndurantType_i$. If there are *rolenames* connected to the original sortal $SortalType_i$, these are represented in the replacing structure as *rolenames* connected to the association end attached to *SortalType*. Although it is true that instances of $SortalType_i$ must be associated with at least y_1 instances of $EndurantType_i$, it is not the case that instances of *SortalType* in general must satisfy the same constraint. For this reason, the cardinality constraint y_1 in the original pattern is relaxed to an optional cardinality constraint (i.e., $0..y_n$).

Finally, suppose that in the generalization set GS we have one or more occurrences of a a sortal type $SortalType_k$ connected by datatype relations D_i to respective enumerations DT_k. In this case, we replace this pattern by a structure in which all elements of each of these DT_k are included as elements of the newly created enumeration datatype GS aforementioned. The $SortalType_k$ itself is not include as an item in the enumeration GS.

For example, in the model of fig. 4, we have three occurrences of this pattern. By applying R4 to that model, we obtain the model of fig. 5. So, for example, in fig. 4, we have the phase partition 'developmental phase' connecting the phases 'Child' ($SortalType_j1$),'Teenager' ($SortalType_j2$) and 'Adult' ($SortalType_i$) to the sortal (another phase) 'Living Person' (*SortalType*). As one can observe, in the model of fig. 5 (see R4* in the lower part of the figure), this configuration is replaced by a structure in which we have, connected to the common supertype 'Living Person', an enumeration named 'Development Phase' that contains as members the values 'Child', 'Teenager' and 'Adult'. Moreover, since the phase 'Adult' ($SortalType_i$) was originally connected via a 'rents' relation ($relation_i$) to the type 'Car' ($EndurantType_i$) then, in the replacing structure, the relation 'rents' is now connected to the common supertype 'Living Person' (with the appropriate relaxing of cardinality constraints). As one can observe, the *rolename* (in this case, 'Personal Customer') connected to the abstracted phase 'Adult' is now represented in the association end of 'rents' connected to 'Living Person'.[8]

In fig. 5, we also see another matching graph for the application of R4. In this case, we can apply once more R4 over the 'life status' generalization set (phase partition). The result of this is depicted in fig. 6. As one can observe in this figure, a new generalization set termed 'Life

[7]Following OntoUML's grammatical rules, these sortal type partitions are either exclusively composed of phases or of subkinds.

[8]After all, it is as personal customers that living people participate in car renting relations.

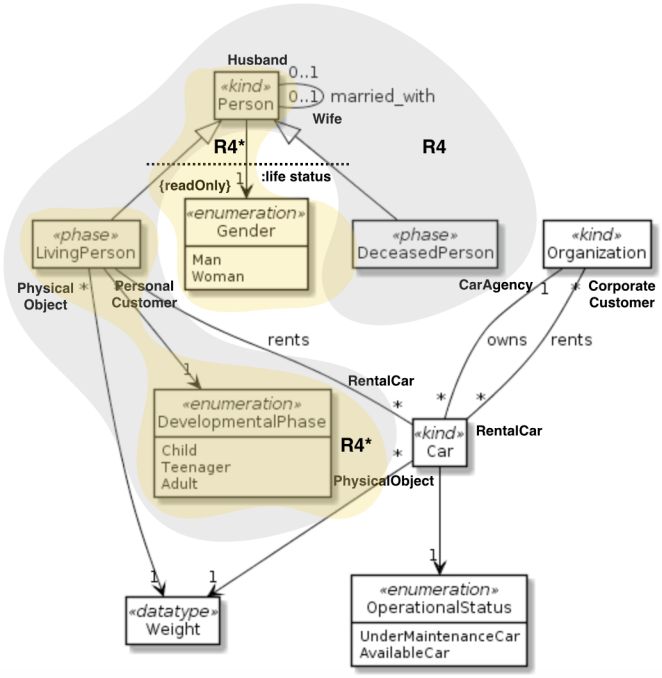


Fig. 5. Model resulting from the application of R4 on the model in fig. 4.

Status' is produced including items representing the phase 'Deceased Person' but also all the items that are members of the enumeration 'Developmental Phase'. Following the aforementioned rules, the latter enumeration is absorbed in the former. Moreover, following the same rules, the phase 'Living Person' is not included in this latter enumeration. Finally, since 'Living Person' participates as a 'Personal Customer' in the relation 'rents' with 'Car', in the fig. 6, this relation (with its corresponding *rolenames* and relaxed cardinality constraints) is move to the kind 'Person' (the direct supertype of 'Living Person').

The model of fig. 6 is the final result of applying our ruleset R1-R4 to the original model of fig. 1[9]. In such a final model, besides enumeration and datatypes, all remaining classes represent kinds and, hence, the annotations with the stereotype «kind» can be omitted. Notice that the union of these three kinds amounts to the objects that are really considered to exist in this universe of discourse. In other words, 'Person', 'Organization' and 'Car' tessellate the universe circumscribed by our conceptualization of the domain. As such, the final model can be said to represent the essence of this conceptualization. In fact, we argue that this model

[9]In UML, *navigable association ends* are semantically equivalent to attributes. For this reason, this model is equivalent to a model in which the navigable associations connecting the types (kinds) Person, Car and Organization to the respective datatypes and enumerations are represented as attributes of these kinds. The alternative model consists of these three kinds occupying the center of the diagram while datatypes and enumerations can be left as secondary notational elements represented in the border of the diagram. This alternative visualization can, in principle, improve even further the presentation of the abstracted model. However, it is important to highlight that this move does not constitute a transformation, given that the models are equivalent. We refrain from further entertaining this possibility here.

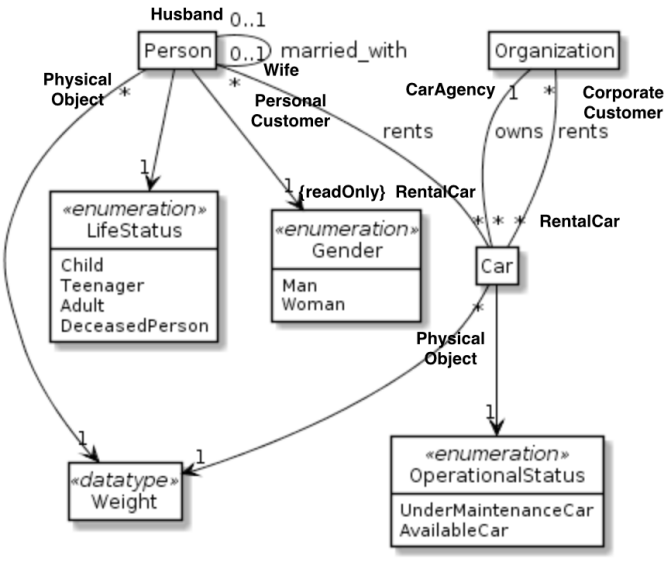


Fig. 6. Model resulting from the application of R4 on the model in fig. 5.

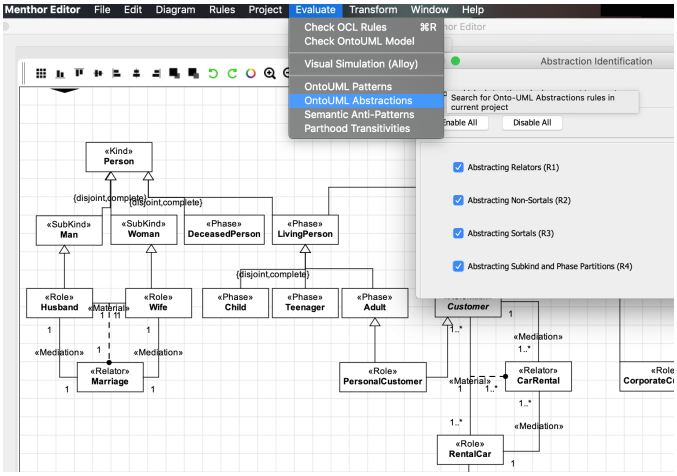


Fig. 7. Screenshot of the implementation at the rule selection.

does capture the gist of the semantics of this domain while (in this case) achieving a compression rate of more than 70% in relation to the original model of fig.1[10].

V. Computational Support and Evaluation

In this section, we describe a tool for Ontology-Based Model Abstraction implemented according to the graph-rewriting rules proposed in section IV. This tool was built as a plug-in for the Menthor Editor [20], an open-source ontology-driven conceptual modeling platform which incorporates the theories of the Unified Foundational Ontology (UFO). The tool supports modeling, verification, validation, and implementation of OntoUML models.

In this plug-in, by employing the explicitly defined MOF metamodel on which this editor is based, we have manage to implement a set of transformations that automatically generate different abstractions of OntoUML models following our proposed rule set. For instance, as one can observe in fig. 7, the tool can generate model abstractions corresponding to steps of the abstraction process, i.e., models resulting from the application of R1 (equivalent to fig.2), R2 (equivalent to fig.3, R3 (equivalent to fig.4) and R4 (equivalent to fig.5 and fig.6).

We have tested the tool against a number of models from the OntoUML model repository. These models vary in terms of size and setting in which they were produced (i.e., whether produced in an industrial or governmental setting, or in an academic environment). Moreover, they cover a variety of domains ranging from Biodiversity (OpenBio) and Heart Electrophysiology (ECG) to Optical Networks (G.805) and Governamental Organizations (MPOG). For a discussion about the OntoUML model repository and these particular models, the reader should refer to [22].

Table II reports on the result of these tests. The table includes a column reporting on the size of the original models in terms of the total sum of modeling elements. It also contains the compression rates for each of these models achieved by applying the proposed abstraction rule set. As one can observe, the latter range from 47,22% to 85,48%. Moreover, we also recorded the execution time for the largest of these models, namely, OntoBio (with 274 model elements) and for an even larger syntactically created model (with 777 model elements). In a MacBook Intel Core i5 2.3GHz with 4GB of RAM, the entire rules set was executed for these models in 3.061 seconds and 19.11 seconds, respectively.

TABLE II
Testing the plug-in on a diverse set of OntoUML models

Model	#Modeling Elements (Original)	Compression Rate of the Abstracted Model
Cloud Vulnerability	83	72,28%
ECG	49	60%
G.805	139	85,48%
MPOG	15	51,35%
Normative Acts	64	62,14%
OpenBio	274	75,56%
Open Provenance	34	47,22%
OpenFlow	20	70,83%
PAS 77	76	61,39%
Software Requirements	23	59%

VI. Comparison to Related Work

The results presented in this paper complement the research in [9] as part of a general program of Ontology-Based Complexity Management of Large and Complex Conceptual

[10]We calculate this compression rate by comparing the sums of all classes and relations present in the original model with the analogous sum in the abstracted one.

Models. Whilst that work addresses the problem of model clustering by viewpoint extraction, here we focus on model abstraction, i.e., on a particular type of model summarization. In that sense, the approaches in the literature that are more similar to the one presented here are the ones of Lozano et al. [15], [16] and Egyed [6], [7].

As previously discussed, the method of Lozano et al. only deals with viewpoint selection, thus, not providing any mechanism for abstraction. Moreover, the selection of views is largely dependent on the selection of focal concepts provided by the user. In particular, given the large degree of propagation of their rules throughout the model, the resulting views themselves might end up having a level of complexity that is similar to the original model. For instance, if for the model in fig.1 the user selects 'Car Rental' as a focal type, the resulting summarized model will contain all elements of the original model with the exceptions of the types 'Physical Object' and 'Ownership' (as well as the mediation and derived relation around it), and the datatype 'Weight'.

The approach of Egyed does provide both viewpoint selection and abstraction, i.e., the produced viewpoints are abstractions of the original fragments of the model. In particular, they are abstractions hiding elements in the paths connecting focal elements of the original model selected by the user. Like in the previous approach, the results produced by Egyed's method are partial models. In contrast, our method supports views that cover the entire scope of the underlying conceptualization. As such, our abstracted models can support not only the activities that are normally supported by model summarization (e.g., model understanding, consistency checking[11]and reverse engineering [7]) but also activities such as high-level appraisal of conceptual models (e.g., domain ontologies) in large model repositories. For example, as discussed by [23], an approach that affords 'glancing' over complex models in large repositories can support users in making well-informed decision about which model should be more suitable for reuse.

Finally, regarding the abstraction of conceptual models, we believe our approach offers two additional benefits when compared to the one proposed by Egyed: (i) simplicity of the abstraction rule set; (ii) determinism in producing the abstracted model.

Regarding (i), our proposal is constituted by 4 graph-rewriting rules. In contrast, in [7], Egyed proposes a set of 121 patterns, 92 of which are abstractions-generating rules. The main reason why we manage to rely on such a reduced set of rules is by leveraging on the highly-structured syntax of OntoUML models. Due to the ontological foundations behind the language, its modeling elements combine in very specific ways forming *modeling patterns*.[12]. In constrast, because of its ontological neutrality [12], UML elements can be combined in large variety of ways.

Also due to these ontological foundations, our approach can rely on well-demarcated differences between the multiple types of types (e.g., kinds, phases, roles, etc.) that can occur in OntoUML models, as well as on their different levels of ontological significance. This feature of the language has been systematically exploited, for example, in the rationale defining the order of application of our proposed rules R1-R4 (see section IV). In Egyed's approach, instead, there is no predefined order constraining the application of his rules. As a consequence, the user must reason with a multitude of possible sequences of applications, each of which can create rather different results. For instance, if we apply his approach to the model of fig. 1 and select as focus types both 'Person' and 'Car' we can produce both a model consistuted by 'Person', 'Personal Customer' and 'Car' but also an alternative model constituted by Person', 'Car' and 'Rental Car', depending on the selection of rules to be applied and the order in which they are applied.[13] In the case of large conceptual models, the number of alternative strategies for the application of these 92 rules explodes. Besides the inherent complexity, this introduces a second drawback in the approach, namely, the non-determinism of the produced models (point ii above).

The resulting viewpoints produced by Egyed's approach depend on a number of factors that are extrinsic to the model itself. As previously discussed, these factors include: the particular selection of focal types provided by the user; the particular selection of rules and their ordering in the process. A third type of factor is what Egyed calls 'model ambiguities' and these are related to the defesability of inferences produced by some of his rules. In contrast, our method always produces deterministic results and, for this reason, it can be fully automated. As observed by Egyed himself [7]: "given the large and complex nature of models, semi-automated abstraction can become very costly...[and it is not] computing time but human-intervention [that] constitutes key complexities in dealing with these large models."

VII. Final Considerations

In this paper, we propose an approach for model abstraction of conceptual models based on the ontologically well-founded semantics of the modeling language OntoUML. The main contribution of the work is to present a set of graph-rewriting rules and their definitions. These rules can automatically produce abstracted global versions of complex conceptual models, while simultaneously preserving the essential concepts of the model and their semantic relevance. By leveraging on the

[11]For example, OntoUML is supported by an approach of model validation and anti-pattern detection by visual simulation [2], [22]. Two limitations of that approach are: the computational complexity of the simulation process - which relies on constraint satisfaction over a SAT solver; the cognitive tractability of the model instances generated by these simulations. We believe that the approach proposed here can be used to address both of these problems.

[12]In fact, as formally demonstrated in [33], OntoUML is a pattern language and its modeling primitives are actually design patterns representing the multiple micro-theories of the UFO foundational ontology

[13]Notice that, for example, that by selecting 'Living Person' and 'Car' as focus types, one can even produce a view including only as types 'Living Person','Personal Customer' and 'Car', i.e., a model without an identity-providing *kind* for the instances of 'Person'. Such a view would be problematic from an ontological point of view [12].

ontological semantics of OntoUML, the approach produces a version of the original model that is reduced to a small number of elements, in essence, the (ontologically fundamental and cognitively salient) *Kinds* of things that exist in that domain.

In an extension of this paper, we shall formally implement a specification of this rule set using the approach employed in [33] (a Single-Pushout Graph Transformation system and the GROOVE tool). The idea is to use an automated tool support to prove the consistency and completeness of the rule set. Moreover, we intend to extend this ruleset to address additional OntoUML constructs (e.g., events, part-whole relations, multi-level modeling structures). Although the ones dealt with here amount to the most used constructs in the language,[14] in certain domains, specific kinds of constructs can play a fundamental role (e.g., partonomies in biomedical applications, events in historical models, multi-level modeling in product design).

As a second contribution, the paper also presents a fully implemented plug-in tool for a Model-Based OntoUML Editor that automates these rules. Despite the encouraging results of the tests performed with this plug-in, we intend to subject it to a more comprehensive and systematic series of tests. Moreover, despite the empirical demonstration of performance scalability with these tests, we shall provide a formal proof of the complexity of the algorithm implemented therein. As an ultimate goal of this project, we intend to develop a version of the tool that supports not only the compression of models but also their 'unfolding' back to its original form (i.e., round-trip operations of model abstraction and refinement). The idea is to fully implement a notion of *Ontological Zoom* that would allow users to interact with models and their parts in different levels of abstraction (each level corresponding to the result of a transformation using each of the rules proposed here).

In order to properly evaluate the cognitive effectiveness of these contributions, we are already in the process of designing a series of empirical studies. The core focus concerns speed and accuracy of obtaining information from the model, as well as balancing this (hypothesized) improvement with the model's information loss.

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UMLto[No]SQL: Mapping Conceptual Schemas to Heterogeneous Datastores

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***Abstract*—The growing need to store and manipulate large volumes of data has led to the blossoming of various families of data storage solutions. Software modelers can benefit from this growing diversity to improve critical parts of their applications, using a combination of different databases to store the data based on access, availability, and performance requirements. However, while the mapping of conceptual schemas to relational databases is a well-studied field of research, there are few works that target the role of conceptual modeling in a multiple and diverse data storage settings. This is particularly true when dealing with the mapping of constraints in the conceptual schema. In this paper we present the UMLto[No]SQL approach that maps conceptual schemas expressed in UML/OCL into a set of logical schemas (either relational or NoSQL ones) to be used to store the application data according to the data partition envisaged by the designer. Our mapping covers as well the database queries required to implement and check the model's constraints. UMLto[No]SQL takes care of integrating the different data storages, and provides a modeling layer that enables a transparent manipulation of the data using conceptual level information.**

***Index Terms*—Database Design, UML, OCL, NoSQL, RDBMS, constraint, SQL, model partitioning**

I. Introduction

The NoSQL movement [6] is recognized as one of the main solutions to handle large volumes of diverse data. NoSQL solutions are based on a flexible schemaless data model focused on efficiency, horizontal scalability, and high availability, and can be categorized into four major groups: key-value stores, document databases, graphs, and column databases [22]. NoSQL stores complement relational databases and other hybrid solutions to offer a large number of options when it comes to decide where to store the data managed by a software system. In fact, it is not unusual that the best alternative is to combine several technologies for an optimal result. E.g., the same application could use a relational database for transactional data but opt for a key-value store for event log management.

Unfortunately, current conceptual modeling methods and tools offer little support for this "multi-store" modeling and generation challenge. Modelers should be able to easily annotate the model with details on the type of data solution to use as storage mechanism and to generate from that annotated model the corresponding implementation in a (semi)automatic way. Still, only the mapping of conceptual schemas to relational databases has been widely investigated so far. Very few solutions targeting NoSQL backends exist and, when they do, they target individual datastores and typically skip the mapping of the model constraints.

In this paper, we present UMLto[No]SQL, a new approach to partition conceptual schemas (including constraints and business rules) and to map each fragment to a different data storage solution. Without loss of generality we assume that the conceptual schema is modeled as a UML class diagram [25] and its integrity constraints are expressed in OCL [24] (Object Constraint Language), both OMG standards.

UMLto[No]SQL is based on existing works targeting the mapping of conceptual schemas to specific datastore technologies [9], [11] and integrates them in a unique multi-datastore design method. The main contributions of the paper are:

- A conceptual model partitioning approach integrated as an UML profile allowing to group model elements in regions to be persisted in a specific datastore.
- A set of mappings from conceptual schema regions to datastore-specific models, including a new mapping from UML class diagrams to document databases.
- A translation approach from constraints and business rules to database-specific queries, also covering constraint expressions that require evaluating elements stored in different and heterogeneous backends.
- A runtime modeling layer that automatically deploys the modeled application, and provides a high-level API to manipulate and check constraints on top of the underlying persistent storage mechanisms transparently.

The rest of the paper is organized as follows: Section II presents the UMLto[No]SQL approach, Section III introduces our model partitioning technique, Section IV details the mapping of (UML) models to a variety of store metamodels and Section V does the same for the OCL constraints. Section VI introduces the UMLto[No]SQL runtime layer. Finally, Section VII describes the related works, and Section VIII summarizes the contributions and draws future work.

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II. UMLto[No]SQL Approach

The MDA standard [23] proposes a structured methodology to system development that promotes the separation between a platform independent specification (Platform Independent Model, PIM), and the refinement of that specification (Platform Specific Model, PSM) adapted to the technical constraints of the implementation platform. In this context, a model-to-model transformation (M2M) generates the PSMs from the PIMs, while a model-to-text transformation (M2T) typically takes care of producing the final system implementation out of the PSM models. This PIM-to-PSM phased architecture brings two important benefits: *(i)* the PIM level focuses on the specification of the structure and functions, raising the level of abstraction and postponing technical details to the PSM level; and *(ii)* multiple PSMs can be generated from one PIM, improving portability and reusability.

This PIM-to-PSM staged development perfectly fits the phases of our UMLto[No]SQL approach, where a runtime modeling layer – able to interact with heterogeneous datastores – is generated out of a conceptual schema expressed in UML and OCL. Thus, following the MDA approach, Fig. 1 describes a typical UMLto[No]SQL development process together with the main artifacts involved.

The only actor involved in a UMLto[No]SQL process is the system modeler, who specifies the conceptual schema of the system using a *UML class diagram* and its corresponding *OCL constraints* at the PIM level. At this level, the modeler can manually annotate ***i*** the conceptual schema (see Section III-B for more details) to group its entities in different *regions*. A *region* is a logical partition that determines the conceptual elements that should be persisted in the same datastore. For example, the *Annotated UML class diagram* in Fig. 1 has been annotated specifying two regions: one contains the elements with horizontal stripes, and the other contains the elements with vertical stripes. The initial OCL expressions remain unaffected.

Next, two automatic M2M transformations are executed in parallel to convert our PIMs into PSMs:

- **UmlTo[No]SQL** ***ii*** transforms each region – and its elements – of the annotated model at the PIM level, into a set of datastore-specific models at the PSM level (the so-called (*Datastore Models*), precisely representing the data structures to be used to record the data in that particular datastore. In Fig. 1, elements annotated with vertical stripes are transformed to a *Datastore model* for the ○ backend, while elements annotated with horizontal stripes are transformed to a *Datastore model* for the ⬠ backend. Note that this transformation also handles the translation of relationships among elements in different regions producing cross-*Datastore Models* relationships (⇔). These special relationships are discussed in Section IV.
- **OCLToQuery** ***iii*** transforms the OCL constraints at the PIM level into a set of *Query Models* adapted to the selected storage technology. As it can be seen in Fig. 1, *Query Models* can contain both elements of the ○ and the ⬠ backend. This is because the transformation also handles the translation of queries spanning different datastores. Such cross-datastore queries exploit a dedicated query mechanism presented in Section V.

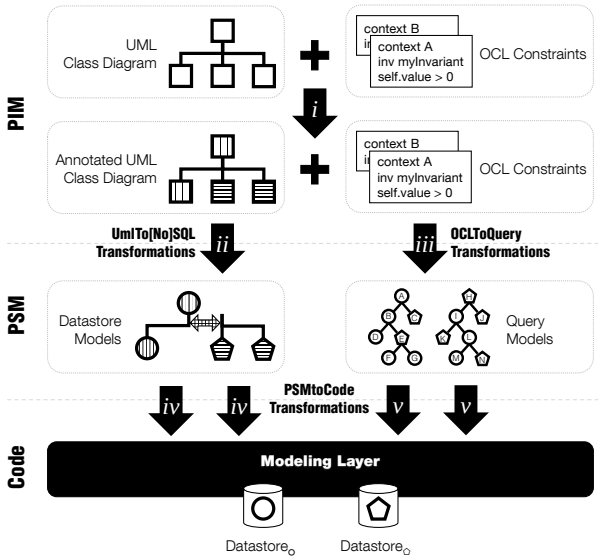


Fig. 1. Overview of the UMLto[No]SQL Infrastructure

Finally, the generated *Datastore Models* and *Query Models* are sent to a final set of *PSMtoCode* M2T transformations. These transformations generate the database schema definitions (in the case of SQL datastores) and software artifacts (in all cases) that are capable of retrieving the different entities of the conceptual schema from their corresponding datastores ***iv***. Additionally, the code to evaluate the different queries and constraints is also generated ***v***.

The result of these transformations is an integrated *Modeling Layer* that allows interacting with the different databases, retrieving and modifying the data stored in them, and also checking the corresponding integrity constraints. All accesses to the underlying data are done in a transparent way, only using conceptual level information. This *Modeling Layer* can be seen as a runtime model [2] built on top of the storage solutions. That way, users can query the data by directly referring to the types and associations they are interested in, instead of having to know the internal data structure names used to record that data in each specific datastore.

III. Conceptual Schema Partitioning

As introduced in the previous Section, the first step of our approach is partitioning the initial conceptual schema into a set of *regions*. Each region identifies a group of entity types in the schema that should be stored together in the datastore associated to the region. A schema can have one or more regions. The regions of a schema can be homogeneous (all regions are linked to a different backends but all backends are of the same "family") or heterogeneous (different regions may be linked to completely different types of backends).

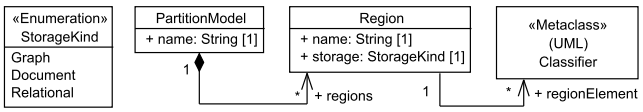


Fig. 2. Partition Domain Model

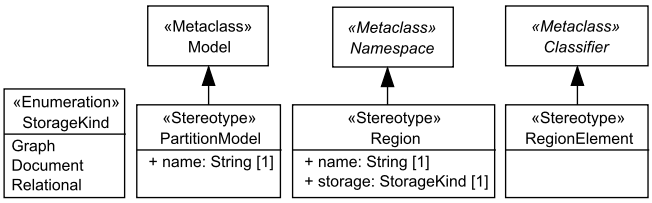


Fig. 3. Partition Profile

At the PIM level, the modeler only needs to focus on defining the limits of the region and the desired type of datastore. Low-level details (e. g., connection information) are provided later on, in the PSM models, as part of the typical MDA refinement process (see Section IV).

Without loss of generality, conceptual schemas are expressed as UML class diagrams but other conceptual modeling languages could have been used instead. Still, UML offers a modeling primitive that is especially useful to implement our concept of regions, the UML *profiling mechanism*.

Profiling opens the possibility of extending or restricting UML to satisfy the modeler needs in a standard way. Moreover, the vast majority of UML tools support this mechanism, facilitating a quick adoption of profiles like ours.

To construct a technically correct high-quality UML profile, several steps need to be followed according to the generally accepted good practices [27]. First, a *domain model* defining the additional modeling concepts must be created. In our case, this domain model should capture the concepts to specify schema partitions as presented next in Sect III-A. Second, a *profile* is defined by mapping the concepts from the domain model to UML concepts. In our case, each class of the partition domain model is examined, together with its attributes, associations and constraints, to identify the most suitable UML base concepts for it. Based on this, we built the partition profile presented in Sect. III-B.

A. A domain model for conceptual schemas partitioning

Figure 2 shows our proposed domain model for the partitioning of conceptual schemas. In this proposal, a given conceptual schema (not shown) relates to one *Partition Model* containing the *Regions* for the different datastores the modeler wants to use. *Regions* have a *name* that identifies them, and a *storage* attribute indicating the type of data storage approach that will be used in subsequent steps. Thee possible data storage approaches can be specified, each one associated to a different data persistence technique: *Graph* for graph-based databases, *Document* for document-based stores, and *Relational* for classical *relational* databases. Finally, UML classes from the conceptual schema may be associated to a specific region via its *regionElement* association. All UML classes belonging to the same region should be stored together at the end of the development process.

B. A profile for conceptual schemas partitioning

In order to put our partition approach in practice, we have defined the accompanying UML profile as proposed by Selic [27]. Following the good practices proposed by Lagarde [18], Figure 3 shows our UML profile for conceptual schemas partitioning.

As it can be seen, there exists almost a one-to-one mapping between the concepts of the *Partition Domain Model* and the *Partition Profile*. Now, the link between a *Partition Model* and a conceptual schema represented as a UML *Model* is explicit via the *extension* relationship. For its part, *Regions* extend *Namespaces*, which typically, are *Packages* containing the entity types (e. g., classes) of the conceptual schema. Finally, the *RegionElement* stereotype is used to annotate the *Classifiers* (typically UML *classes*) within a *Region* that will be persisted.

The *Partition Profile* is exemplified in Figure 4. The conceptual schema shown in the figure depicts an e-commerce application that will be used as running example for the rest of the paper. The schema specifies the *Client*, *Orders*, *Products*, and *Comment* concepts and the relationships among them, organized in three packages *Clients*, *Business*, and *Comments*.

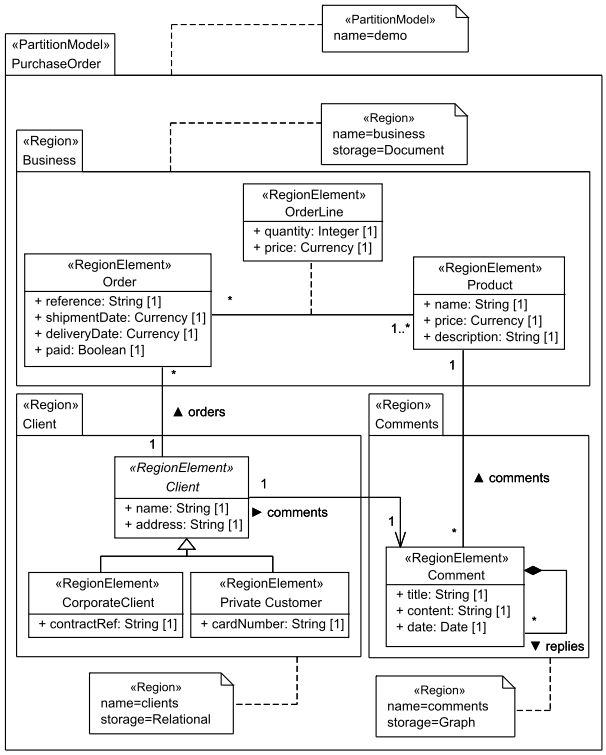


Fig. 4. Example Schema Partition

By means of the profile, we have expressed that the *business* part of this schema should be stored in a document database, the *clients* one should go to a relational database, and the *comments* one to a graph database. Therefore, we have defined three *Regions*, each one tagged with a different target storage solution. Note that in our example *Regions* are created based on the domains of their data, but alternative *Partition Models* based on performance requirements (e.g. data proximity) can also be specified through our profile

IV. Mapping Class Diagram Fragments

The partitioned conceptual schema is the input of our UMLto[No]SQL transformation component, in charge of generating the PSMs representing the logical database structure corresponding to each conceptual region in the partition.

Our approach currently embeds three transformations, each one associated to a specific data store. Two of them are based on previous works: *UmlToGraphDB* covering mappings to graph databases (taken from [9]) and *UmlToSQL* that reuses "classical" works on mapping UML (or ER) to relational databases (e.g. [11]). The third one is completely new. As it is also a novel contribution the possibility to have in the same schema regions linked to heterogeneous backends. As such, in this section we review the relevant parts of existing UML to database mappings and show how we adapt them to handle cross-datastore associations. We also introduce *DocumentDB*: a novel metamodel representing the structure of Document databases, as well as the associated mapping rules to derive DocumentDB instances from class diagrams.

In the following we denote a partitioned class diagram *CD* as a tuple $CD = (Cl, As, Ac, I, R)$, where *Cl* is the set of classes, *As* is the set of associations, and *Ac* is the set of association classes. *I* is a set of pairs of classes such as (cl_1, cl_2) represents the fact that c_1 is a direct or indirect subclass of c_2, and *R* is a set of pairs (cl, r) mapping each class of the conceptual model to a region defined with the help of our partition metamodel. Note that for the sake of simplicity attributes of classes and associations are denoted $cl.attr$ (e.g. $cl.name$ represents the name of a class).

We also define two additional predicates that are reused across our mappings: $reg(cl) = r.storage, (cl, r) \in R$ represents the *storage* value of the region containing the class *cl*, and $parents(c) \subset Cl, \forall p \in parents(c), (c, p) \in I$ represents the set of super-classes in the hierarchy of *c*.

A. Relational Database Mapping

1) RelationalDB Metamodel: Figure 5 presents our RelationalDB metamodel which is a simplified version of existing metamodels aiming at representing relational databases. It contains a top-level *Schema* that stores a set of named *Tables*. *Tables* contain *Columns* that store information of a given *DataType*. Our metamodel currently supports primitive types, as well as an *UUID* type which is used to identify elements across datastores. A *Table* also contains a *PrimaryKey* which refers to one or multiple *Columns*. Finally, *Tables* can contain

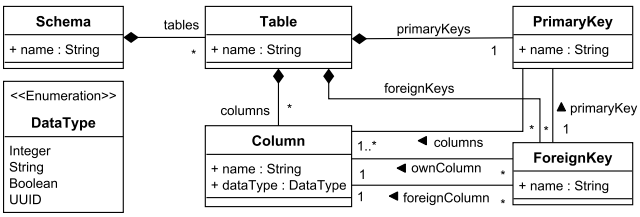


Fig. 5. RelationalDB Metamodel

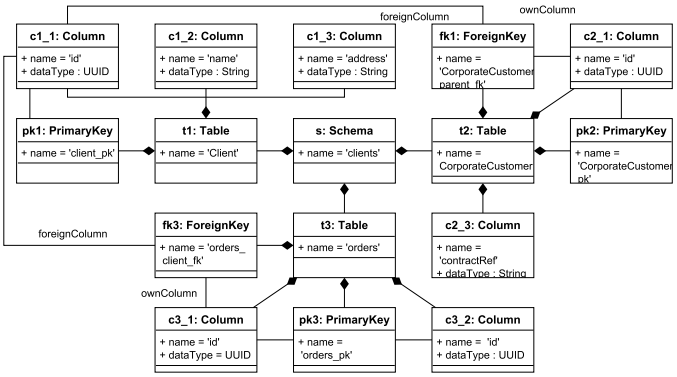


Fig. 6. RelationalDB Instance

ForeignKeys, each one associated to an existing *PrimaryKey* and linking a *Column* to a foreign one stored in another *Table*[1].

2) Class Diagram to RelationalDB Transformation: We denote a RelationalDB model *RM* as a tuple $RM = (S, T, C, P, F)$, where *S* is a schema, *T* is the set of tables, *C* is the set of columns, *P* is the set of primary keys, and *F* is the set of foreign keys that compose the relational model. In the following we present the mapping from *CD* to *RM*. This mapping is based on existing approaches from the literature [11], and adapts them to support cross-datastore queries.

- **R1:** each relational region $r.storage = Relational$, $\forall cl(cl, r) \in R$ is mapped to a schema s such as $s.name = r.name$.
- **R2:** each class $cl \in Cl$ is mapped to a table $t \in T$, where $t.name = cl.name$, and added to the schema s mapped from its containing region such as $t \in s.tables$. In addition, a column $c \in C$ is created such as $c.name = id$, $c.dataType = UUID$, $c \in t.columns$. This column is set as the primary key pk of t such as $pk \in P$, $pk.name = cl.name + _pk$, $c \in pk.columns$, $pk \in t.primaryKey$.
- **R3:** each inheritance relationship between two classes cl_1, $cl_2 \in Cl$, $(cl_1, cl_2) \in I$ (respectively mapped by R2 to t_1, $t_2 \in T$) such as $reg(cl_1) = reg(cl_2) = Relational$ is mapped to a foreign key such as $fk \in F$, $fk.name = cl_1.name_parent_fk$, $fk \in t_1.foreignKeys$ such as $fk.primaryKey = t_2.primaryKey$, $fk.ownColumn = t_1.primaryKey.column$, $fk.foreignColumn =$

[1]For simplicity purposes, this metamodel does not support foreign keys spanning over multiple columns

$t_2.primaryKey.column$. Note that this rule does not create foreign keys for cross-datastore inheritance links.

- **R4:** each attribute of a class $cl \in Cl$ such as $a \in cl.attributes$ is mapped to a column $c \in C$ where $c.name = a.name$, $c.datatype = a.type$[2], and added to the column list of its mapped container t such as $c \in t.columns$.
- **R5:** each single-valued association $as_{single} \in As$ between two classes $cl_1, cl_2 \in Cl$ is mapped to a column $c \in C$, $c.name = as.name$, $c.dataType = UUID$ added to the table t_1 such as $c \in t_1.columns$. If $reg(c_1) = reg(c_2) = Relational$, a foreign key $fk \in F$ is also created such as $fk.name = as_{single}.name + _ + cl_2.name + _fk$, $fk.primaryKey = t_2.primaryKey$, $f.ownColumn = c$, $f.foreignColumn = t_2.primaryKey.column$ and added to the containing table's foreign key set such as $f \in t_1.foreignKeys$. This means that cross-datastore associations are mapped to UUID columns (with no corresponding foreign key).
- **R6:** each multi-valued association $as_{multi} \in As$ between two classes cl_1, $cl_2 \in Cl$ is mapped to a table $t \in T$, $t.name = as.name$ containing two columns c_1, $c_2 \in C$, c_1, $c_2 \in t.columns$ such as $c_1.name = cl_1.name + _id, c_1.dataType = UUID$, $c_2.name = cl_2.name + _id, c_2.dataType = UUID$. This mapping rule also creates a primary key $pk \in P$, $pk.name = as_{multi}.name_pk$, $pk \in t.primaryKeys$ such as c_1, $c_2 \in pk.columns$. Finally, classes involved in the association such as $reg(cl_n) = Relational$ are mapped to a foreign key $fk \in F$, $fk.name = as_{multi}.name + _cl_n.name + _fk, fk \in t.foreignKeys$ such as $fk.primaryKey = t_n.primaryKey$, $fk.ownColumn = c_n$, $fk.foreignColumn = t_n.primaryKey.column$.

Figure 6 presents the RelationalDB model produced when applying the mapping rules to our running example. The produced model defines a top-level *Schema* element named *clients* and containing three *Tables*. The *Table* `t1` is mapped from the *Client* abstract class, and contains three columns to store the *Client*'s UUID, name, and address. It also defines a *PrimaryKey* `pk1` defined over the UUID column. The *Table* `t2` is mapped from the *CorporateCustomer* class, and defines two columns to store its UUID and its contractRef attributes. It also define a *PrimaryKey* `pk2` over its id column, and a *ForeignKey* `fk1` associating the *CorporateCustomer id* to its parent *Client* one. Finally, `t3` is created from the *order_client* association, and contains two *Columns* (set as primary key through the `pk3` instance) storing the identifiers of the involved *Client* and *Order* instances. This *Table* contains a single *ForeignKey* linking the *client_id Column* to the *id Column* of the *Client* table. Since *Order* is not part of the relational region, the mapping does not produce a foreign key for this column. Navigation of this cross-datastore association

[2]We assume that a mapping mechanism is available to convert conceptual model types to the ones defined in our target metamodels.

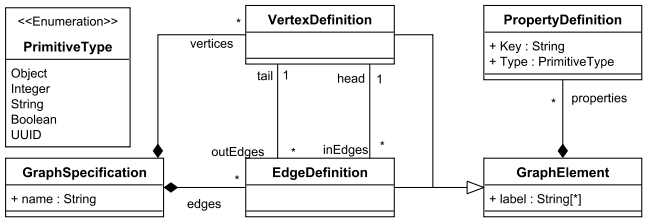


Fig. 7. GraphDB Metamodel

is detailed in Section V.

B. Graph Database Mapping

1) GraphDB Metamodel: Figure 7 presents the GraphDB metamodel [9] that defines the possible strutural elements in graph databases. This metamodel is compliant with the Blueprints specification [28], which is an interface designed to unify graph databases under a common API.

The GraphDB metamodel defines a top-level *GraphSpecification* which contains all the *VertexDefinitions* and *EdgeDefinition* of the database under design. *VertexDefinitions* and *EdgeDefinitions* can be linked together using *outEdges* and *inEdges* association, meaning respectively that a *VertexDefinition* has outgoing edges and incoming edges. In addition, *VertexDefinition* and *EdgeDefinition* are both subtypes of *GraphElement*, which defines a set of *labels* describing the type of the element, and a set of *PropertyDefinition* through its *properties* association. In graph databases properties are represented by a *key* (the name of the property) and a *type*. The GraphDB metamodel defines 5 primitives types (Object, Integer, String, Boolean, and our own UUID type).

2) Class Diagram to GraphDB Transformation: Herein we present the mapping from a partitioned class diagram to the GraphDB metamodel. This mapping is an adaptation of our previous work [9].

We denote a GraphDB model *GD* as a tuple $GD = (G, V, E, P)$, where *G* is a *GraphSpecification*, *V* is set of *VertexDefinitions*, *E* the set of *EdgeDefinitions*, and *P* the set of *PropertyDefinitions* that compose the graph. The mapping from *CD* to *GD* is formalized in the following rules:

- **R1:** each graph region $r.storage = Graph, \forall cl(cl, r) \in R$ is mapped to a graph specification g such as $g.name = r.name$.
- **R2:** each class $cl \in Cl, \neg cl.isAbstract$ is mapped to a vertex definition $v \in V$, where $v.label = cl.name \cup parents(cl).name$. In addition, a property $p \in P, p.key = id, p.type = UUID$ is added to the property list of the created vertex such as $p \in v.properties$. This property is used to uniquely identify the element and will be used to retrieve specific instances when navigating cross-datastore associations.
- **R3:** each attribute $a \in (cl \cup parents(cl)).attributes$ is mapped to a property definition p, where $p.key = a.name$, $p.type = a.type$, and added to the property list of its mapped container v such as $p \in v.properties$. Note

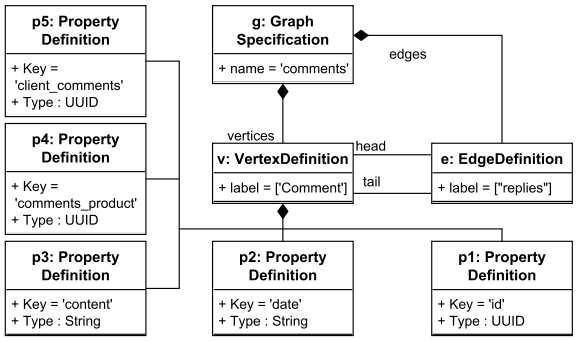


Fig. 8. Mapped GraphDB Instance

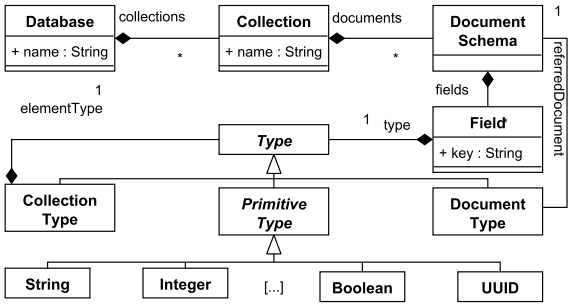


Fig. 9. DocumentDB Metamodel

that this rule flattens the inheritance hierarchy by mapping the attributes of all cl's parents in the produced vertex.

- **R4:** each association $as \in As$ between two classes $c_1, c_2 \in Cl$ with $reg(c_1) = reg(c_2) = Graph$ is mapped to an edge definition $e \in E$, where $e.label = as.name$, $e.tail = v_1$, and $e.head = v_2$, where v_1 and v_2 are the *VertexDefinitions* representing c_1 and c_2. Note that $e.tail$ and $e.head$ values are set according to the direction of the association. Aggregation associations are mapped the same way, but their semantic is handled differently at the application level. In order to support inherited associations, *EdgeDefinitions* are also created to represent associations involving the parents of c.
- **R5:** each association $as \in As$ between two classes $c_1, c_2 \in Cl$ with $reg(c_1) = Graph, reg(c_2) \neq Graph$ is translated to a property $p \in P$ where $p.key = as.name$, $p.type = UUID$ and added to the property list of its mapped container v such as $p \in v.properties$.

Figure 8 shows the result of applying this mapping rules on our running example. The created model defines a *GraphSpecification* mapped from the *comments* region, and contains a single *VertexDefinition* `v` mapped from the class *Comment*. This *VertexDefinition* is associated to a single *EdgeDefinition* `e` representing the *replies* association. `V` contains a single label representing its class, and a *PropertyDefinition* `p1` holding its UUID identifier. `V` also contains two *PropertyDefinitions* corresponding to its *content* and *date* attributes, and two additional *PropertyDefinitions* `p4` and `p5` representing references to the *Clients* and *Products* classes, respectively stored in a relational and a document database.

C. Document Database Mapping

1) DocumentDB Metamodel: Figure 9 shows the *DocumentDB metamodel*, our contribution to represent the internal structure of document-oriented datastores. A *Database* is defined by a *name*, and contains a set of *Collections* representing families of *DocumentSchemas*. *DocumentSchemas* are low-level data structures that can be seen as associative arrays containing a set of *Fields*. A *Field* is identified by a *key*, and a *Type* of data it can hold. In our metamodel, *Types* are categorized into three groups: (i) *PrimitiveTypes* representing primitive type values (including the UUID introduced before), (ii) *DocumentTypes* representing *document* references, (iii) *CollectionTypes* representing list of nested elements (containing an *elementType* attribute representing the type of the collection). Note that the *DocumentType* construct is independent of the concrete, platform-specific implementation of document references (e.g. logical link between existing document such as in MongoDB vs. duplication of its content in a nested copy).

2) Class Diagram to DocumentDB Transformation: A Document diagram *DD* is defined as a tuple $DD = (C, D, F)$, where *C* the set of collections, *D* is a set of documents, and *F* the set of documents' fields. In addition, we define the *CollectionType* and *DocumentType* constructs that are derived from the *DocumentDB* metamodel, and are initialized with a single parameter, representing respectively their *elementType* and *referredDocument*. Based on these definitions, the mapping rules are expressed as:

- **R1:** each document region $r = Document, \forall cl(cl, r) \in R$ is mapped to a document database d such as $d.name = r.name$
- **R2:** each class $cl \in Cl, reg(cl) = Document, \nexists x(cl, x) \in I$ is mapped to a collection $c \in C$ such as $c.name = cl.name$. Note that this rule produces a collection for each superclass in the model.
- **R3:** each class $cl \in Cl$ (including the ones mapped by R2) are mapped to a document schema $d \in D$ and its containing collection is set as $d.collection = c$, where c represents the mapped collection of the top-level element in cl inheritance hierarchy. As a result, document schemas mapped from classes in the same inheritance hierarchy will be contained in the same collection. This mapping rule also creates a field $f_{id} \in F, f_{id} \in d.fields, f_i d.name =' _id', f_{id}.type = UUID$ representing the unique identifier of the element. Finally, an additional field $f_{classe} \in F, f_{classes} \in d.fields, f_{classes}.key =' _classes', f_{classes}.type = String$ is also created to store the names of the classes in cl's hierarchy, and is required to filter concrete subclasses from generic super-class collections.
- **R4:** each attribute $a \in (c \cup parents(c)).attributes$ is mapped to a field f, where $f.key = a.name$,

$f.type = a.type$, and added to the property list of its mapped container d such as $f \in d.fields$. Multi-valued attribute are mapped similarly, using the *CollectionType* construct to represent multiple values: $f.type = CollectionType(a.type)$.

- **R5:** each association $as \in As$ between two classes $c_1, c_2 \in Cl, reg(c_1) = reg(c_2) = Document$ is mapped to two fields $f_{c1}, f_{c2} \in F$ where $f_{c1} \in d_1.fields, f_{c1}.key = a.name$, $f_{c2} \in d_2.fields, f_{c2}.key = a.name$, $f_{c1}.type = DocumentType(d_2)$, $f_{c2}.type = DocumentType(d_1)$, where d_1 and d_2 are the *Documents* representing c_1 and c_2. This rule creates *Fields* in the documents representing the classes involved in the association, and set their type as a *DocumentType* referring to the other end of the association. In order to support inherited associations, *Fields* are also created to represent associations involving the parents of c. Note that multi-valued ends of the associations are mapped as multi-valued attributes using the *CollectionType* construct: $f_{c1}.type = CollectionType(DocumentType(d_2))$.
- **R6:** each association between two classes from heterogeneous datastores $c_1, c_2 \in Cl, reg(c_1) = Document, reg(c_2) \neq Document$ is mapped to a field $f_{c1} \in F$ where $f_{c1} \in d_1.fields, f_{c1}.key = a.name, f_{c1}.type = UUID$. Multi-valued ends of the associations are mapped similarly to R5. Note that this initial version of our mapping does not consider associations involving more than two classes.
- **R7:** each association class $ac \in Ac$ between classes $cl_1 ... cl_n$ is mapped to a document d_{ac} such as $d_{ac}.collection = c, c \in C, c.name = ac.name$. As for a regular class, d_{ac} contains the *Fields* corresponding to the attributes $ac.attributes$, and a set of *Fields* $f_{aci} \in F$ where $f_{aci}.key = c_i.name, f_{aci}.type = DocumentType(d_i)$ linking to each document representing a class involved in the association. In addition, an identifier *Field* $f_{id} \in F$ is also produced such as $f_{id} \in f_{ac}.fields, f_{id}.name = '_id', f_{id}.type = UUID$ and added to the contained fields. Multi-valued ends are mapped as multi-valued attributes using the *CollectionType* construct: $f_{ci}.type = CollectionType(DocumentType(d_{ac}))$.

To better illustrate the different mapping rules, we present in Listing 1 the output of the *UmlToDocumentDB* translation when applied on the running example. For clarity, the resulting *DocumentDB* model is shown using a JSON-like concrete syntax derived from the metamodel (abstract syntax) presented in Figure 9. A *Database* instance named *business* contains three collections representing the classes of the input model: *order*, *product*, and the association class *orderLine*. The *order* collection defines a single document schema *orderDoc* which contains a set of *Fields* mapping *Order* class attributes in the conceptual schema. *orderDoc* also includes a multi-valued document reference to *orderLineDoc*, as a result of the mapping of

```
Database "business" {
  Collection "order" {
    DocumentSchema orderDoc {
      _id : UUID
      _classes : [String]
      reference  : String
      shipmentDate : Date
      deliveryDate : Date
      paid : Boolean
      client : UUID
      orderLine : [orderLineDoc]
  } }
  Collection : "product" {
    DocumentSchema productDoc {
      _id : UUID
      _classes : [String]
      name : String
      price : Integer
      description : String
      orderLine : [orderLineDoc]
  } }
  Collection : "orderLine" {
    DocumentSchema orderLineDoc {
      _id : UUID
      _classes : [String]
      quantity : Integer
      productPrice : Integer
      orderLine_order : orderDoc
      orderLine_product : productDoc
} } }
```

Listing 1. Mapped DocumentDB Model (Textual Syntax)

the relationship between Order and the OrderLine association class, and an external reference to *client* (materialized as a UUID), as part of the mapping between Order and the Client class, located in a different region in the conceptual schema.

V. Mapping OCL Expressions

To complete the PIM-to-PSM transformation process, the OCL constraints attached to the input conceptual schema are translated to queries expressed in the query language/s available in the data stores where the model elements affected by the query will be mapped.

In this section, we first discuss the translation of OCL queries local to a single region and, later, how the process deals with global OCL constraints, i.e. constraints referencing model elements in different regions. Note that the generated queries can be manually integrated in an existing database infrastructure, or wrapped in constraint checking methods provided by the runtime component presented in Section VI.

To illustrate this section, we will use the four OCL constraints of Listing 2 defined on top of our running example (Figure 4). The first one checks that the *price* of a *Product* is always positive, the second one checks that the date of a comment is always greater than its parent one, the third one verifies that once an *Order* has been *paid* all its *orderLines* have a positive *quantity* value, and the last one ensures that a *Client* has less than three unpaid *Orders*. Note that constraints 1-3 target a single region, while the last one references elements from the relational and document datastores.

Currently, UMLto[No]SQL supports three simple mappings: *OCLToGraphDB* [9] that complements the *UmlToGraphDB* transformation by generating graph queries, *OCLToSQL* that is adapted from existing work on UML/OCL translation to rela-

```
context Product inv validPrice: self.price ≥ 0
context Comment inv validComment: self.date > self.
    repliesTo.date
context Order inv validOrder: if self.paid then self.
    orderLine→forAll(o | o.quantity > 0) else false endif
context Client inv maxUnpaidOrders: self.orders→select(o |
     not o.paid)→size()< 3
```

Listing 2. Textual Constraints

TABLE I
OCL TO SQL MAPPING

OCL expression	SQL Fragment
Type	"Type.name"
C.allInstances()	select * from C
o.collect(attribute)	select attribute from C where id in o.id
o.collect(reference) (single valued)	select reference from C where id in o.id
o.collect(reference) (multi valued)	select * from reference where reference_C_id in o.id
size()	count()
col_1→union(col_2)	col_1 union col_2
col_1→including(o)	col_1 union select * from o.class where id = o.id
col_1→excluding(o)	col_1 except select * from o.class where id = o.id
col→select(condition)	select * from o.class where condition
col→reject(condition)	select * from o.class where not(condition)
=, >, >=, <, <=, <>	==, >, >=, <, <=, <>
+, -, /, %, *	+, -, /, %, *
and, or, not	and, or, not
literals	*literals*

tional models [3], [11], and *OCLToMongoDB* that maps OCL constructs to the MongoDB query language [7]. Below we detail this last mapping, which is a new contribution of this paper.

A. Relational Query Mapping

SQL [16] is the obvious target for our translation process on relational databases. Given the (mostly) universal support for this standard language, our generated SQL expressions will be useful no matter what particular RDBMS vendor is used.

Table I shows an excerpt of the OCL to SQL mapping used in our translation process [3]. This mapping is adapted from the one presented by Demuth et al. [11].

Specifically, attribute and single-valued association navigations are mapped to projections of the corresponding column in the table containing instances of the input object. Instance filtering is performed based on the *id* field defined in our relational metamodel. Element selections are mapped into *select* statements, with a *where* clause containing the translation of its condition. Collection operators (such as *union*), mathematical operations, logical operators and literals are direclty translated to their SQL equivalent.

The created fragments are combined into a query that retrieves all the records which do not satisfy the constraint, a common pattern when evaluating OCL constraints over models [11]. As an example, Listing 3 shows the result of applying our OCL to SQL translation on the first constraint of our running example.

[3]We focus on the mappings applicable to the running example for brevity.

```
select * from product where price < 0
```

Listing 3. Generated SQL Query from the validPrice Constraint

TABLE II
OCL TO GREMLIN MAPPING

OCL expression	Gremlin step
Type	"Type.name"
C.allInstances()	g.V().hasLabel("C.name")
collect(attribute)	property(attribute)
collect(reference)	outE('reference').inV
oclIsTypeOf(C)	o.hasLabel("C.name")
col_1→union(col_2)	col_1.fill(var_1); col_2.fill(var_2); union(var_1, var_2);
including(object)	gather{it << object;}.scatter;
excluding(object)	except([object]);
size()	count()
isEmpty()	toList().isEmpty()
select(condition)	c.filter{condition}
reject(condition)	c.filter{!(condition)}
exists(expression)	filter{condition}.hasNext()
=, >, >=, <, <=, <>	==, >, >=, <, <=, !=
+, -, /, %, *	+, -, /, %, *
and,or,not	&&,||,!
variable	variable
literals	*literals*

B. Graph Query Mapping

1) Gremlin Query Language: Gremlin is a Groovy domain-specific language built over *Pipes*, a lazy data-flow framework on top of *Blueprints*. We have chosen Gremlin as the target query language for our graph query translation due to its adoption in several graph databases.

Gremlin is based on the concept of process graphs. A process graph is composed of vertices representing computational units and communication edges which can be combined to create a complex processing flow. In the Gremlin terminology, these complex processing flows are called *traversals*, and are composed of chains of simple computational units named *steps*. Gremlin define four types of steps: *transform steps* that map inputs of a given type to output of another one, *filter steps*, selecting or rejecting input elements according to a given condition, *branch steps*, which split the computation into several parallel sub-traversals, and *side-effect steps* that perform operations like edge or vertex creation, property update, or variable definition or assignments.

In addition, the step interface provides a set of built-in methods to access meta information: number of objects in a step, output existence, or first element in a step. These methods can be called inside a traversal to control its execution or check conditions on particular elements in a step.

2) OCL to Gremlin Transformation: Table II presents the mappings between OCL expressions and Gremlin concepts. Supported OCL expressions are divided into four categories based on Gremlin step types: transformations, collection operations, iterators, and general expressions. As before, we only present a subset of the OCL expressions we support[4].

[4]A complete version of this mapping is available in our previous work [10]

These mappings are systematically applied on the input OCL expression, following a postorder traversal of the OCL syntax tree. Listing 4 shows the Gremlin query generated from the third OCL constraint of our running example. The `v` variable represents the vertex that is being currently checked, and the following steps are created using the mapping.

C. Document Query Mapping

1) MongoDB Query Language: We have chosen the MongoDB query language as a representative of the family of query languages for document databases. A similar mapping could be implemented for other document query languages. Together with the DocumentDB metamodel presented in the previous section, this OCL transformation enables a complete translation of UML/OCL schemas to document databases. As we said above, this transformation complements other available transformations from UML to other relational and NoSQL backends, including mixed solutions.

The MongoDB Query Language is a Javascript-based language that defines additional constructs to retrieve documents within a collection, filter them, or retrieve fields given a specific condition. This language is embedded in the MongoDB shell, and can be sent for computation to a MongoDB server.

2) OCL to MongoDB Query Language Transformation: Table III shows the OCL to MongoQL mapping (again, focusing on a number of the most relevant OCL operations; many others can be easily reexpressed in terms the ones listed here [5]).

In the following, we explain these mappings using the example constraints introduced before. Note that we apply a similar translation process as we did for the SQL mapping, i.e. the generated queries return the instances violating the constraints.

According to this, Listing 5 shows how the first constraint is mapped to a `db.product.find()` method with a *where* condition that traverses all documents in the product collection and returns those with a negative price (if any). Second constraint includes an *if-then* construct to first filter out unpaid orders. For the paid ones, the translation proceeds with a document lookup (mapped to a nested collection lookup in MongoDB) to retrieve all the order lines of the order being processed searching for at least one that violates the *forAll* condition in the original OCL expression. If found, the order is returned as part of the query result. Note that the *find* operation is one of the cornerstones of our mapping since it is expressive enough to be the mapping target of multiple OCL operations.

In addition, we reuse the Javascript native support of the query language to map general expressions such as arithmetic and logical operators, comparisons, literals, and variables. We also define the *union*, *intersection*, and *set subtraction* operations, that can be called as regular functions. Finally, our mapping relies on the methods *push* and *splice* of Javascript arrays to translate *including* and *excluding* operations.

```
v.property('date')>v.outE('repliesTo').inV.property('date')
```

Listing 4. Generated Gremlin Query from the validComment Constraint

```
db.product.find({$where: "this.price ≤ 0"}) // validPrice
db.order.find({_id: {$where:
  "if(this.paid) {
    !(db.orderLine.find({_id: {$in : db.order.find({$where:
          "_id == this._id"}, {orderLine : 1})}, $where: "
        this.quantity ≤ 0"}).hasNext());
  } else {false}"}}); // validOrder
```

Listing 5. Generated MongoDB Queries from the Running Example

```
Context Client inv maxUnpaidOrders:
// clients region (Relational)
let orders : Sequence(Order) =
  self.orders
in
// business region (Document)
  orders→select(o | not o.paid)→size()<3
```

Listing 6. Rewritten OCL Constraint Example

D. Cross-Datastore Query Mapping

Cross-datastore queries are OCL expressions that reference elements in separate regions. Typically, they include a navigation operation from an element in a region to an element in a neighbour region. Our approach handles such queries by: 1) translating datastore-specific fragments of the input expression into native database queries, and 2) providing a composition mechanism to complete their overall evaluation.

To do so, we first perform a simple rewriting of the OCL expression that encapsulates each datastore-specific operation sequence in an intermediate variable. This initial step decouples datastore-specific OCL fragments, and allows to easily translate the value of each variable using our mappings. Listing 6 shows the result of this initial processing for the third query of our running example: a variable *orders* is created to store the results of the `self.orders` navigation (from the relational region), and the `in` clause reuses the created variable to compute the `select` operation (in the document region).

This refactored OCL expression is then translated into an instance of our *Cross-Datastore Query Metamodel* (Figure 10) that provides primitives to compose native database queries. Specifically, a cross-datastore script (*CDScript*) is composed of an ordered collection of *instructions* representing *Function* calls. A *Function* takes a set of *Variables* as *parameters* and returns a *result* which is also stored in a *Variable*. This first version of our metamodel supports two kind of *Functions*: *NativeQueries* that are produced by the native translations presented above, and *JoinFunctions* that handle the computation of cross-region associations. Generate *NativeQueries* take has parameter the result of the previously executed *JoinFunction*, allowing to push most of the data processing to the datastores. Note that the concrete implementation of *JoinFunctions* is discussed in the next section.

Instances of the Cross-Datastore Query Metamodel are generated by mapping each `let source` expression to a *NativeQuery*, and each `in` clause to a *JoinFunction* adapting the previous query's results, followed up by a the *NativeQuery* generated from its inner expression. Figure 11 shows the result of this translation for the *maxUnpaidOrders* constraint

TABLE III
OCL TO MONGODB

OCL expression	MongoDB Query Fragment
Cl.allInstances()	db.C_{cl}.find()
o.$attr_a$	db.$C_{type(o)}$.find({$where : "_id == o"},{$attr_a$: 1})
o.ref_a	db.$C_{type(refa)}$.find({_id: {$in: db.$C_{type(o)}$.find({$where : "_id == o"},{ref_a: 1})}})
o.oclIsTypeOf(Cl)	db.C_{cl}.contains(o)
col_1->union(col_2)	union(col_1, col_2)
col_1->intersection(col_2)	intersection(col_1, col_2)
col_1 - (col_2) (set subtraction)	subtract(col_1, col_2)
col->including(o)	col.push(o)
col->excluding(o)	col.splice(col.indexOf(o), 1)
col->select(condition)	db.C.find({_id: {$in: col}, $where : "condition"})
col->reject(condition)	db.C.find({_id: {$in: col}, $where : "!(condition)"})
col->exists(expression)	db.C.find({_id: {$in: col}, $where : "condition"}).hasNext()
col->forAll(expression)	!(db.C.find({_id: {$in: col}, $where : "!(condition)"}).hasNext())
col->size()	C.length
col->isEmpty()	C.length == 0
if(c) then e_1 else e_2 endif	if(c) { e_1} else {e_2}
=, >, >=, <, <=, <>	==, >, >=, <, <=, !=
+, -, /, %, *	+, -, /, %, *
and, or, not	&&, ||, !
variable	variable

Legend — Cl: class; o: object; col: *object* collection; C_a: *database* collection containing objects of type *a*; the *:1* suffix is a boolean flag to indicate the expression should return only the indicated field and not the whole document.

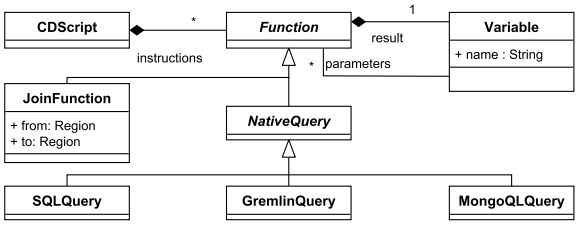


Fig. 10. Cross-Datastore Query Metamodel

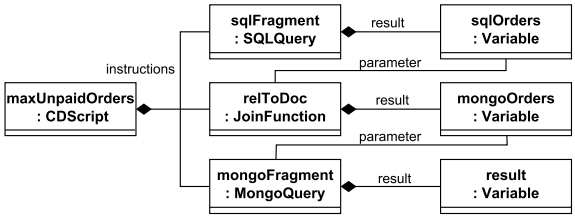


Fig. 11. Cross-Datastore Query Instance

of our running example, which contains an initial *SQLQuery* computing the *orders* navigation, a *JoinFunction* that adapts the *Orders* returned by the relational database to documents, and a final *MongoQuery* that computes the *Order* selection.

VI. CODE GENERATION

As a final step in UMLto[No]SQL, a code generation process takes as input the previous PSMs and query models and generates the software artifacts to guarantee the proper implementation of such models in the chosen data stores.

The concrete artifacts to generate depends on the type of storage solution. For instance, for relational databases, most of the code generation focuses on creating the SQL DDL scripts to setup the database. Instead, for NoSQL databases (which are mostly schemaless), a large part of the generation process is devoted to producing application code that integrates and enforces the designed structures and constraints. To ease this process, we provide a generic *Modeling Layer* that defines primitives to persist, query, and update data in NoSQL datastores. The generated application code is then plugged into this generic infrastructure, and extends it to provide additional operations derived from the conceptual schema (e.g. getting all the *clients* stored in the system).

Figure 12 shows the architecture of our generic *Modeling Layer*. The *Middleware* class is the central component that allows to create, search, and delete *Beans* representing the model elements at the PIM level. It contains a set of *Datastores* that are responsible for the raw database initialization and accesses. Currently, our framework embeds three *Datastore* subclasses, that allow to access MongoDB, PostgreSQL, and Blueprints. The *Middleware* also embeds a set of *QueryProcessors*, that are responsible of the constraint computation. *NativeProcessors* support the execution of native queries over their associated *Datastore*, and *CDProcessor* handles the computation of cross-datastore queries. The *CDProcessor* relies on a set of *NativeProcessors* that are used to compute the native fragment of the composite query, and uses the *join* method provided by the *Datastores* to compute the join function introduced in Section V. This method retrieves the stored records matching the provided *UUIDs* and *type*, that can be provided as input of the next composite query computation defined in the *CDQuery*. Note that these functions do not return *Bean* instances, but native objects that can be handled by the *Datastore* to compute a query.

The UMLto[No]SQL code generator creates additional

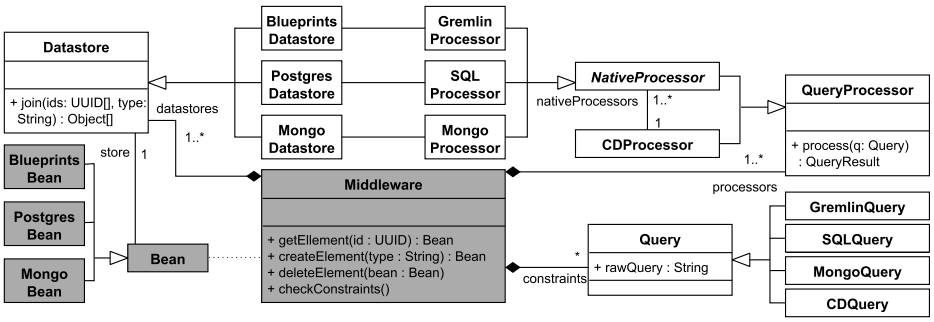


Fig. 12. UMLto[No]SQL Modeling Layer Infrastructure

classes that extend the ones shown in Figure 12 (light-grey nodes). Individual *Beans* are created, wrapping the classes defined in the conceptual schema, allowing to natively manipulate them. In our example, this process generates the *Client*, *Order*, *Product*, and *OrderLine* beans, and creates a set of methods to access and update their attributes and related associations by delegating the operation transparently on the corresponding datastore. Finally, a specific implementation of the *Middleware* class containing the generated constraint *Queries*, and initialized with the *Datastores* and *QueryProcessors* associated to the conceptual schema is also generated.

We would like to remark that an important benefit of this middleware is that it enables users to access the data using the same concepts and types they employed when modeling the domain, regardless of how those model elements have been refined and transformed to implement them in the data store. Still, our approach can be used to simply generate standalone database artifacts, that could then be integrated into separate solutions.

```
public class Order extends MongoBean {
  public Order(ObjectId id, MongoDatastore mongoDatastore){
    super(id, mongoDatastore);  }
  public Date getShipmentDate() {
    Long timestamp = getValue("shipmentDate");
    return new Date(timestamp);  }
  public void setShipmentDate(Date newShipmentDate) {
    Long timestamp = newShipmentDate.getTime();
    updateField("shipmentDate", timestamp);  }
  // Cross-datastore reference
  public Client getClient() throws ConsistencyException {
    ObjectId clientId = getValue("client");
    return DemoMiddleware.getInstance().getClient(clientId.
        toString());  }
  public void setClient(Client newClient) {
    if(isNull(newClient))
      throw new ConsistencyException("Cannot set null
          Client, the association cardinality is 1");
    String clientId = newClient.getId();
    ObjectId oId = new ObjectId(clientId);
    updateField("client", oId);  }
}
```

Listing 7. Generated Order Class

As an example, the Listing 7 shows an excerpt of the code generated for the class *Order*. The generated bean extends the *MongoBean* class, that provides generic methods such as *getValue* and *updateField*, and is responsible of the connection to the underlying *MongoDatastore*. Getters and setters are generated for all the attributes and associations. The *getClient* method shows how cross-datastore associations are handled: the *UUID* stored in the the *Order* document is deserialized into a String, that is used to retrieve the *Client* instance thanks to the *Middleware* singleton class (which delegate the search to the relational database managing *Client* instances). A similar process is followed to implement the constraints. See the project repository for a full implementation of the example.

VII. Related Work

UMLto[No]SQL can be related to several works focusing on the mapping of conceptual schemas to databases. We propose here a classification of relevant approaches into two families: generative approaches that translate conceptual schemas to data storage solutions, and abstraction layers built on top of existing backends that aim to unify them under a common model/API that could be used to simplify the mapping.

The mapping of conceptual schemas to relational databases is a well-studied field of research [20]. A few works also cover (OCL) constraints. For example, Demuth and Hussman [11] provide a code generator from UML/OCL to SQL [12]. Similarly, Brambilla et al. [3] propose a methodology to implement integrity constraints into relational databases recommending alternative implementations based on performance parameters. Fewer works address non-relational databases. Zhao et al. [29] propose an approach to model MongoDB databases starting from a relational model. Li et al.focus on the transformation from UML class diagrams into HBase [19] while NoSQL Schema Evaluator [21] focuses on generating column family definitions and query implementation plans from a conceptual schema optimized for a given workload. Nevertheless, none of these approaches support multiple data stores nor provide support for the constraint mapping part.

On the other hand, some approaches try to provide some kind of modeling language or abstraction to simplify the interaction with NoSQL databases. Bugiotti et al. [4] propose a design methodology for NoSQL databases based on NoAM, an abstract data model that aims to represent NoSQL systems in a system-independent way. NoAM models can be implemented in several NoSQL databases. Federated data management and querying approaches can also be related to our work [13]. For instance, CloudMdsQL [17] is a SQL-like query language

capable of querying multiple data stores within a single query. To do so, the language extends the standard SQL syntax with additional constructs allowing to call native queries that target a specific datastore. Apache Drill [15] is a similar framework that provides an extended SQL syntax to query multiple data sources including relational databases, Json documents, or document databases. These approaches could be potentially useful as intermediate representations in our own mapping process as a way to enlarge the number of stores that we could support but we believe our UML-based approach offers a lower barrier of entry since it allows designers to model their schemas using well-known notations (and tools, most likely already part of their standard modeling tool chain) instead of requiring them to learn new languages and adhoc solutions from the very beginning.

VIII. Conclusion and Future Work

In this paper we have presented UMLto[No]SQL, a MDA-based framework to partition and map conceptual schemas to several data storage solutions. Our approach combines model mapping techniques with a set of rules to translate OCL constraints into various native query languages, including an ad-hoc mechanism to compute multi-platform queries. Our code generator hides all internal details of the chosen data stores, allowing designers to keep a unified view of the model regardless the actual data storage.

As future work, we plan to evaluate our approach through real-world use cases, and benefit from the modular architecture of our framework to add more data storage options. We also want to improve the flexibility of our approach by proposing PSM-level refactoring operations to let designers tune the mappings according to specific needs (e.g. performance requirements, availability, data replication, data locality, etc.). In addition, we plan to benchmark the performance of the produced queries, especially cross-datastore ones. In this sense, we also envision to reuse advanced query composition techniques such as CloudMdsQL [17] or Apache Drill [15].

Another ongoing work is the integration of automatic schema partitioning techniques according to an expected/measured workload. This optimization problem has been heavily studied in the context of relational database physical schema design [1], [14], and can be adapted to define regions on the conceptual schema. Finally, we would like to work on the reverse direction, i.e. the automatic extraction of conceptual schemas from an existing set of datastores. This is a complex problem even when targeting a single NoSQL data store (e.g. see works such as [26] or [8]) that becomes much harder to tackle when considering the relationships between data across different data stores.

Acknowledgement

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Problematic Attachment to Social Media: the Psychological States vs Usage Styles

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***Abstract*—Many people worldwide rely on social media to satisfy their social needs for relatedness, learning and enhancing self-esteem. However, over-reliance on social media often results in problematic attachment, which risks personal, social and financial wellbeing. From a design perspective, we argue that social media can be improved with tools to manage such problematic attachment and help users reform their interaction style, social expectations and online identity to restore a healthy reliance. Designing such behaviour change tools can be challenging due to the characteristics of people with problematic behaviours, e.g. denial, relapse and cognitive dissonance. This paper explores the role of social media in such attachment and reveals associated psychological states. Our method provides an ecologically valid exploration through employing diary studies as a data collection method, aiming to introduce countermeasures for problematic attachment in future social media design.**

Keywords—social media design, online behaviour, digital wellbeing

I. INTRODUCTION

Worldwide, individuals, particularly young people, are embracing the use of social media in their daily lives [1]. Social media enables people to engage with others, forming and maintaining relationships without the need to take part in real-life social activities [2]. Many use social media to connect with friends, organise events and express opinions, significantly affecting their everyday life and well-being.

The range of social media platforms has increased over time, facilitating communication and entertainment [3]. The number of active Facebook users was 500 million in 2010 but had increased to 2 billion by 2018 [4]. The rapid expansion in the use of social media has prompted academics to examine its impact. Recent studies advocate that social media can have both positive and negative impacts on users [3, 5].

Problematic attachment can be defined as over-reliance on social media to satisfy social and personal requirements, which can eventually harm personal and social wellbeing. People rely on social media to enhance their self-esteem [6] and maximise social capital [7]. This reliance can be problematic and cause impaired decision making, poor impulse control and anxiety, leading to excessive social media usage [8].

Social media addiction has been defined as compulsive use of social media, resulting in addictive behavioural symptoms [9]. Griffiths [10] noted addictive behavioural symptoms include: "convenience, tolerance, conflict, withdrawal, relapse, and mood modification". Although digital media addiction is not classified as a mental disorder in the Diagnostic and Statistical Manual of Mental Disorders (DSM) [11], given its possible impact on wellbeing, more research is needed.

Recent research concluded people with low self-esteem tend to overuse social media to enhance their self-image and self-esteem, e.g., [6, 12]. However, peer interaction and failure to obtain recognition may worsen their mood. Similarly, social media addiction is linked to anxiety, depression and stress. Moreover, it can contribute to poor academic performance and dissatisfaction with life [9]. Also, people who engage obsessively with social media are more likely to experience undesirable life experiences such as reduced creativity, increased anxiety and withdrawal from reality [13].

Despite social media being potentially problematic, it can also contribute to the solution by using software tools to help individuals self-regulate their social media addiction. Persuasive techniques can be incorporated into social media platforms to encourage healthy usage [14]. Unlike other addictions, technology can monitor its usage and report back to users, making them more informed and conscious of their usage [14]. For instance, users can request to receive notifications if their usage patterns suggest they are at risk as well as advice on how to combat the problem [15].

Existing literature on digital media addiction has mainly focused on psychological perspectives, such as the role of social skills [16] or personality traits [17], in facilitating digital media addiction. Certain patterns of social media use negatively impact psychological well-being [18]. However, there is limited research on the role of social media design in triggering problematic usage and regulating it. Further, it is uncertain how this would work beyond making people more aware of usage. The research identified a range of risks in software- behavioural change tools making their engineering complex and requiring a multidisciplinary approach combining expertise from information systems and psychology. Further research to enhance understanding of the role such software can play in combatting problematic attachment to social media is needed.

In this paper, we provide insights into the real-world experience of people with a problematic attachment to social media. We adopt a multi-stage qualitative research method using diary studies as a primary data collection technique to enhance the ecological validity of the study. We report on findings regarding psychological states experienced by the participants. The paper is aimed at informing a healthier use of

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social media and driving further development of behavioural change software tools for responsible social media usage.

II. RESEARCH METHOD

To obtain insights into problematic experiences on social media, we conducted a multi-phase qualitative study consisting of an exploratory phase (Section A) and a confirmatory and refinement phase (Section B). Different qualitative methods were employed in each phase to ensure the accuracy of the data capture and analysis. The data analysis and theoretical framework are described in Section C. The conceptual diagram of our research methods is presented in Fig.1.

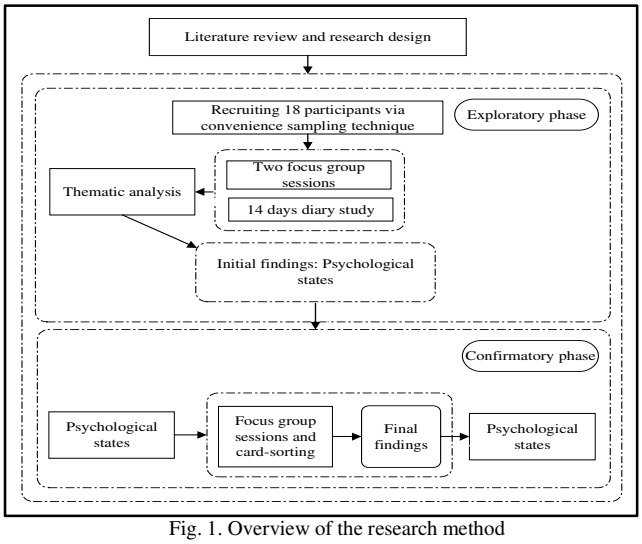


Fig. 1. Overview of the research method

A. First Phase: Exploring Problematic Attachment

This phase aimed to explore people's problematic attachment to social media. A qualitative method was adopted, involving focus groups and diary study methods. A focus group was used to gather initial insights, with the diary study capturing and refining users' problematic experience as lived.

Considering the representative population on social media and high social media usage in universities, participants were recruited using convenience sampling. Eighteen participants (nine male and nine female), were recruited from the authors' institution. Participants had to be 18 or over and self-identify as having a problematic attachment to social media.

The inclusion criteria were adhered to using a pre-selection questionnaire from the Generalised Problematic Internet Use Scale with necessary adaptations [19]. For example, "Internet" was replaced with "social media" to reflect the context.

We conducted two focus groups with nine participants each. The focus group study aimed to familiarise participants with the study objectives and obtain insights into their problematic relationship to social media. To prepare these participants for the diary study, at the end of each focus group session, training on using Evernote was provided. Evernote[1] allows users to take notes, pictures, and recordings and regularly share them with the research team. The app also allows the facilitator to send questionnaires to team workers. The diary study with the same 18 participants lasted two weeks and participants completed two tasks: 1) identifying their online styles and behaviour by emphasising their online presence. 2) detaching themselves from specific activities on social media, such as avoiding instant replies to their friends' messages, to discover accompanying side-effects. Participants provided their notes three times a day (morning, afternoon and night) using the Evernote application. Daily reminders were also sent. We then invited each participant to a face-to-face interview to discuss their entries.

[1] https://evernote.com/

B. Second Phase: Refinement and Confirmation

A closed card sorting technique within focus group sessions was carried out with 14 participants to refine the findings of phase one.

Six participants were selected from the exploratory phase sample to avoid analysis bias and to increase the credibility of the findings. This also served as a technique for member checking [20] to validate qualitative study findings. Eight other participants were recruited from a different cohort following the same recruitment procedure in the exploratory phase. A closed card sorting approach was used to refine the exploratory phase findings. The card sorting technique is useful for gaining participants' perspective regarding findings.

C. Data Analysis

The data collected from the interviews and the diary study was analysed using thematic analysis [21]. However, psychological states were the main findings of the analysis process. The published literature in problem gaming and substance abuse [10, 22], reinforced our findings in problematic behaviours. In light of this background, the nature of the social media platform was taken into account. The findings were also validated through the card sorting in the study's second phase.

III. PROBLEMATIC ATTACHMENT TO SOCIAL MEDIA: FINDINGS

Problematic attachment to social media and its design may reinforce psychological states triggered by interaction. We present psychological states and usage styles in Section A, psychological states and strengths in Section B, and problematic attachment and behavioural change tools in social media in IV.

A. The Psychological States Vs Usage Styles

People may experience psychological states depending on their interaction on social media. For example, problematic social media attachment may lead to psychological states such as craving, anxiety, loneliness, loss of interest, depression and boredom, contributing to the individuals' problematic attachment to social media. In Fig.2, we present frequent usage styles encountered by people with problematic attachment and related psychological states. The exploration of potential linkages between psychological states, e.g. anxiety and social media is complex and in its early stages [8, 23].

1) Craving: Craving can be defined as a conscious experience that occurs when an individual pays excessive attention to social media [24]. Perceived attractiveness of

social media-related content increases with repeated online engagement. Craving manifests in problematic attachment to social media. Such craving to interact in social media allows individuals to adapt and strengthen their self-esteem, resulting in excessive and impulsive behaviours and ultimately generating negative effects [25]. When individuals re-form their online interaction style, cravings can be triggered by positive expectations, further fueling problematic attachment. The following are explanations for cravings arising concerning a problematic attachment:

- Increase reputation: Individuals with a problematic attachment to social media crave online interaction to increase their number of friends and likes, which in turn increases their reputation and social capital. This could involve excessively updating their user profile: *"I feel craving because I want to increase my followers and bring life to my timelines"*.
- Daily routine: Individuals with problematic attachment to social media may develop a craving for social media because they habitually engage online as a daily routine, to eliminate craving. This encourages social media users to interact more than they need to improve their self-esteem and satisfy their needs; *"I cannot imagine myself not using social media every day"*.
- Acquire intrinsic rewards: Individuals with problematic attachment to social media may feel negative about life. This triggers a desire for intrinsic rewards through online interaction, minimising their preoccupation with offline activities. Thus, individuals may engage online excessively to eliminate cravings for incentives [26]; *"The first thing that comes to my mind when I want to feel pleasure, I go to social media"*.
- Relapse to problematic style: Individuals might re-form a problematic attachment style on social media to regulate online interactions. Under some circumstances, their cravings could be provoked by positive expectations such as those maintained by popularity and relatedness, resulting in the compulsion for excessive interaction; *"I minimised my online interaction pattern, but I felt that I might lose my social contacts. Then I feel a craving to increase them through online activities"*.

2) Anxiety: Anxiety that results from using social media can be defined as a sense of stress or worry. This is linked to the user's popularity, or how others perceive them on social media. Individuals with a problematic attachment to social media may feel anxious about their online interactions, which may negatively impact on their life satisfaction. Evidence supports the claim that excessive social media use interferes with work performance and undermines well-being [27]. Our exploratory study in Phase I revealed that individuals with problematic attachment might feel anxious during online interactions and that certain situations contribute to anxiety:

- Commitment to be highly responsive: Individuals with a problematic attachment to social media are anxious as a result of the commitment to stay constantly connected, causing challenges when they are unable to use their social media [28].
- Unconscious quick response: Individuals with a problematic attachment to social media may act quickly or unconsciously, resulting in a level of anxiety that negatively influences their well-being; *"I cannot resist the urge to respond immediately to any activity on social media platforms. This makes me feel anxious"*.
- Excessive usage: Overuse of social media may cause anxiety regarding problematic attachment. Time spent online could conflict with user's duties and affect performance, in turn triggering anxiety; *"I feel anxious when I am delaying important things that I have to do because of using social media for a longer time than I need"*.
- Displeasing content: Users feel anxious when social media content displeases them, often after receiving repetitive and ambiguous content, such as advertisements and anonymous friend requests, which could affect popularity if reposted. *"I feel anxious when I receive an ambiguous email"*.
- Unmet expectations: Unmet expectations from an event on social media likely cause anxiety in individuals with a problematic attachment. For example, when users re-formulate their presence and profile online this could lead to peer behaviour below the individual's expectations. They may not have received 'likes' on a post as expected, reducing their self-esteem and triggering anxiety.

3) Loneliness: This state arises when people feel a lack of authentic communication with others. Individuals with a problematic attachment to social media may feel lonely due to prolonged time spent on online interactions to maintain relationships and self-image [29]. From the exploratory study, two situations were identified regarding how participants experienced loneliness:

- Lack of accessibility: Inability to access social media

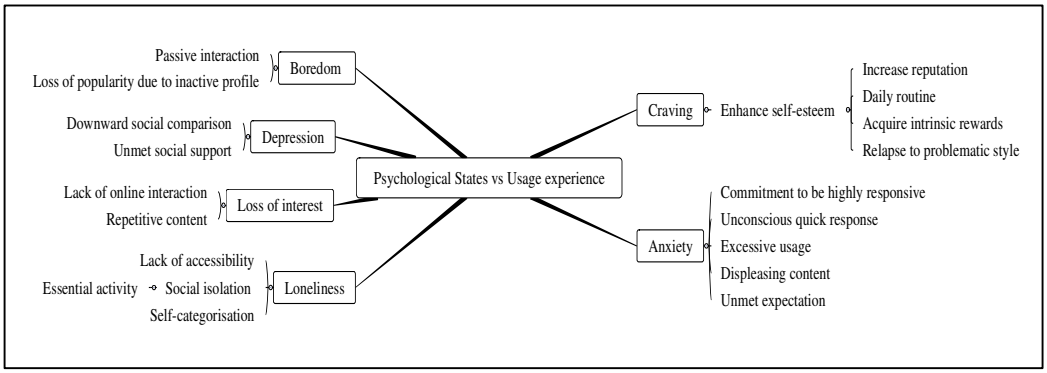


Fig. 2. Problematic Attachment to Social Media: the Psychological States Vs Usage Styles

due to technical or personal factors, or failing to achieve an expected quantity and quality of interaction may trigger loneliness. This could increase in individuals with problematic attachment: *"I felt lonely when I could not access my social media sites"*.

- Social isolation: Individuals with a problematic attachment to social media are typically involved in a variety of online activities such as chatting, texting, posting and communicating with others, leading to excessive use of social media. Without self-control, such excessive interaction can increase the time spent online and provoke loneliness; *"I feel isolated from the real world because I stay online most of my time"*.
- Self-categorisation: Individuals classify themselves based on their class, age, gender and characteristics. For example, a user in Snapchat may classify themselves as a comedian, affecting their online behaviour. Self-categorisation is related to group formation and membership, which depends on perceived similarities amongst group members in a particular context. This categorisation leads to self-evaluation, highlighting social isolation and provoking loneliness: *"Social media is part of my life but I do not have many contacts because I only make contact with like-minded and educated people, I feel loneliness sometimes"*.

4) Loss of interest: Loss of interest refers to when individuals show no intention to maintain previously enjoyed social media activities. Individuals with problematic online attachment may feel less interested in social media, i.e. no longer caring about previously enjoyed activities, but being unable to reshape their relationship with it. The below situations illustrate how users experience this loss of interest:

- Lack of online interaction: Individuals with problematic attachment to social media experience a loss of interest without online interaction. Lack of online activities and friendships may lead to declining access to information and relatedness, which in turn decreases self-esteem and triggers loss of interest; *"I am eager to Facebook, to know the news and communicate with others but I lose that desire if there is no continuous interaction"*.
- Repetitive content: Individuals with a problematic online attachment overly rely on social media to be aware of events and social communities. However, repetitive content in social media platforms may lead them to lose interest as they are used to receiving diverse content all the time; *"New information and activities are exciting to me, but I may feel less interested to social media when the content is repetitive or outdated"*. Also, loss of interest can be bi-directional when users with problematic online attachment repost the same content through various social media platforms aiming to maximise outreach. This repetition may affect their popularity and relatedness due to others feeling less interested in their profiles: *"I lost my popularity because people are less interested in following me posting the same content on my online profile"*.

5) Depression: Depression is characterised by low self-worth or a sense of guilt and reduced ability to enjoy life. Social media allows an individual to form connections with others who share similar interests and consequently have greater social capital. Individuals with a problematic attachment to social media may feel depressed in the following situations:

- Downward social comparison: Social media users may engage in comparison with others, to meet self-evaluation needs. Social capital acquired, acceptance from others or online activities posted may give the impression that others are more prolific than them. This negative impression may provoke low self-evaluation and depression [30]; *"I think life is not fair because I have a greater number of followers than my friend but frequently I see my friend getting more likes on his posts than me"*. People who spend excessive time on social media are likely to start social comparison with others, which could lead to depression [31].
- Unmet social support: Individuals with a problematic attachment to social media tend to have a high number of online friends [32]. Online communication methods such as messaging and posting, enable them to perceive support from their friends and establish intimacy with them, which can reduce depression [33]. When close friends are not available online to satisfy social support needs, individuals may feel depressed; *"I think my close friends in social media are important for support and life happiness. However, I feel depressed when I do not find them online for an urgent situation"*.

6) Boredom: Boredom is experienced by individuals who have nothing to do either in social media or the real world. They are available online to occupy their free time and maintain connections with others. However, users with a problematic attachment to social media may experience boredom as explained below:

- Passive interaction: Online interaction may hurt self-esteem. With low self-esteem, the individual may engage in interaction such as scrolling passively, resulting in boredom; *"I feel bored sometimes when using social media due to comparisons made. I then lose confidence because of those who are better than me in their posting. When this happens, I prefer to browse rather than posting"*.
- Loss of popularity due to inactive profile: Individuals may be occasionally inactive online, rarely posting even for their friends, negatively impacting on their popularity. Since their accounts appear inactive, other users no longer interact with them. This, in turn, provokes boredom; *"Sometimes my interaction on social media is low which stops friends interacting with me and this makes me feel bored"*.

B. Frequency and strengths of psychological states

The study conducted a diary with 18 participants for 14 days with three daily diary entries. Out of a possible 756 diary entries, psychological states were provided in 712 entry

documents. Table I summarises six emergent themes, their frequencies, and thematic exemplars. Exemplars were extracted from their original written documents as a means of adding "thickness" to the data [34].

TABLE I. FREQUENCY-PSYCHOLOGICAL STATES

Psychological States	Frequency	Occurrences	%	Illustrative example
Anxiety	489/756	12 Participants	64.68	When I upload photos to Facebook, I feel so anxious till I start to receive a high number of Likes.
Boredom	444/756	10 Participants	58.73	I rely on social media to change my mood even at odd times of the day. I feel so bored if no one responds to my posts and messages.
Loneliness	356/756	9 Participants	47.09	I feel isolated from society because I stay in my online gaming groups most of time.
Loss of Interest	311/756	8 Participants	41.14	I overly check the updates in social media, but I quickly lose interest and stop reading, still cannot stop checking
Craving	267/756	6 Participants	35.32	I can not wait to be online and interact, it is part of my daily routine so not having it even during work hours would feel very strange
Depression	89/756	3 Participants	11.77	I do not compare favourably to peers profiles and posts on social media. I stop posting and continue watching, and this makes me feel at times depressed
Entry doc. with code(s)	712	18 participants	94.12	
Entry doc. without code(s)	44		5.88	
Analysed doc.	756		100.0	

The large number of diary entries in this longitudinal study provides a good benchmark for how often such themes arise [35]. Frequency was computed via MAXQDA analysis software by identifying words such as anxiety, or phrases consisting of one of the variables. Almost all diary entries (94.12%) included at least 1 of the items in the content of the states while engaging with social media. This can be inferred as an indicator of problematic online attachment. The results indicate a high frequency of anxiety (12 participants, representing 64.68% of feedback), but less depression (three participants (11.77%).

IV. PROBLEMATIC ATTACHMENT AND BEHAVIOURAL CHANGE TOOLS IN SOCIAL MEDIA

Users with problematic attachment are characterized by denial of their online behaviour; resistance, when they feel their freedom to use social media, is controlled by measures like reminders and timers, and relapse when they try to regulate that relationship both in terms of usage style and preoccupation [36]. Thus, social media design needs to consider differences between users in configurations of software-based intervention to meet the social and wellbeing needs of users [37]. Also, users showing problematic attachment may yearn to increase their reputation or feel anxious when unable to interact as wished. We identified negative psychological states that are facilitated by social media design, suggesting that the current design adopted by social media may impact negatively on users' wellbeing in the absence of any countermeasures to help self-regulation and mindfulness. People with poorer wellbeing may be more likely to use social media to alleviate loneliness.

Software is usually designed in line with user requirements. However, in this case, user requirements regarding social connectivity may contribute to problematic attachment to social media. Changes to software design to meet care needs are therefore needed. Software design with persuasive and gamification techniques can be used to reform people's problematic attachment to social media. However, ad hoc empowering of social media design by these tools may result in user side effects such as stress; leading to loss of engagement in the behaviour change process [38]. Co-creation methods integrate user perspectives with expert opinion and scientific evidence to develop interventions [39]. Participatory design has been used successfully to improve the dynamics and challenge of serious games for health promotion [40]. Participatory design methods may, therefore, help reduce this conflict by developing platforms acceptable to users, in terms of ease of use and need satisfaction, and developers, in terms of promoting wellbeing, in line with corporate responsibility.

It is also important that designs to target problematic attachment to social media do not lead to other issues. Individuals with problematic attachment tend to be anxious and may report that, e.g., checking notifications reduces their anxiety. Identifying designs of social media platforms that both improve wellbeing and reduce problematic usage is a challenge to be addressed. For example, decreasing notifications to individuals, while reducing checking, might increase anxiety in those who excessively checked social media. Also, limiting groups to certain times, while reducing the pressure to reply to messages at all hours, might lead to increased loneliness in users who have come to rely on the group for 24-7 support. A socio-technical approach could be needed, where human care combines with machine intelligence and software tools.

V. CONCLUSION

In this paper, we explored problematic attachment to social media presented by users' experiences. Our findings reveal psychological states associated with problematic attachments, indicating that problematic users rely on social media to satisfy their social requirements such as relatedness, learning and promoting self-esteem. They suggest that problematic attachment can be managed through tools which help users to reform their online interaction, expectations and online identity in a healthy manner. Design of these behavioural change tools is complicated by characteristics such as denial, relapse and cognitive dissonance. Most of the literature on the problem domain focused on user psychology. Further work will reveal psychological states associated with problematic attachment through real-time data such as sensors to promote cross-sectional study. This will increase understanding and pave the way for clustering people with problematic attachment to

social media by customising countermeasures, e.g. persuasive techniques to fit each group.

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Procrastination on Social Networking Sites: Combating by Design

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Abstract— Procrastination refers to a voluntary postponement that prevents people from performing their tasks and can hurt productivity and wellbeing. Procrastination might occur due to a lack of motivation to perform tasks or due to the low self-control that people might have over their time and task management. Social Networking Sites (hereafter SNS) are designed to enable their users to engage in online interaction for different purposes such as increasing popularity or exploring information. SNS embed influence and persuasion techniques to attract users which can make them a medium for procrastination where some users fail to maintain a desirable level of self-control over their usage. However, we argue that advances in persuasive technology and gamification techniques can be utilised to augment SMS and help users to regain self-control over their procrastination. Implementing these techniques correctly means that users can still enjoy accessing SNS while maintaining a desirable level of control over their procrastination. Building these anti-procrastination tools, however, is a challenging design activity due to their potential of triggering negative side-effects such as reactance and workarounds, and affecting the overall user experience. In this paper, we conduct user studies, consisting of an exploratory stage using focus groups, diary study and interviews and followed by a design stage based mainly on co-design sessions. Our studies' participants self-declared having a problematic degree of procrastination on SNS, to explore procrastination countermeasure techniques that can augment the future designs of SNS and how best to apply them.

Keywords— Procrastination, Social Networking design, Co-design

I. INTRODUCTION

Procrastination refers to the voluntary delay of urgent tasks which might lead to negative consequences such as low productivity or anxiety [1]. Delays caused by procrastination can negatively impact students' academic performance (among other groups) and their learning achievement [1]. However, it has been demonstrated that managed procrastination can help people to relieve stress and improve their mood which can positively increase work efficiency [2]. With managed procrastination, people maintain good control over their procrastination and control excessive negative effects, for example by being able to resume their work at an appropriate time. However, some people fail to control their procrastination due to several factors such as their low self-control and external social pressure. Procrastination is often motivated by the desire to avoid a task and through interaction with others on SNS. Hence, the process can induce stress which might be detrimental to their productivity [3].

SNS such as Twitter and YouTube enable their users to create online profiles and communicate and maintain contact with others. Despite these perceived benefits, some usage styles might turn out to be harmful to those who do not maintain good control over their usage. SNS are designed to encourage further engagement which can eventually lead users to procrastinate if this engagement conflicts with the other tasks. SNS also provide a medium for peer pressure, whereby users feel the urge to engage in developing a positive self-image or because of their fear of missing out (FoMO) [4].

Persuasive technology and gamification are powerful tools that can help users to gain more control over their procrastination. Persuasive technology is used to help change people's behaviour through influence rather than hard coercion and pressure [5]. Gamification is the use of game elements in non-game contexts [6]. Using these techniques can be potentially useful, by motivating users to maintain better control over their usage [7]. For example, users can utilise SNS usage feedback by observing the time spent and the frequency of interaction with SNS daily. This helps to raise user's awareness about their usage and encourage them to take action to control their levels of usage better. Arguably, users might procrastinate because of the rewards that SNS offer to enhance the perceived social interaction opportunities, in the form of "likes" or "positive comments." In such cases, the use of gamification can also help bring the reward that users experience into the tasks being delayed so that users can feel more motivated to keep working on their tasks to gain further rewards such as points.

Elsewhere, persuasive technology and gamification tools demonstrate their power to motivate users to change their behaviour [8, 9]. Importantly, incorrectly embedding these tools in the design of SNS can be detrimental to the user experience and create problems [10, 11]. For example, users might get overloaded when they get detailed usage feedback which might lead them to misunderstand the provided data. Gamification elements such as timers and progress bars can also lead to reactance and encourage a workaround, e.g. using a different account and device. Gamification tools can also negatively affect users' intrinsic motivation and make them more interested in the rewards they can get by following a certain behaviour [11, 12] than in the genuine or initial goal.

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This reinforces the necessity to define users' needs to minimise the negative side-effects that can occur when implementing these tools into SNS.

To achieve that, we conducted an exploratory stage based on focus groups, a diary study and interviews and then used the results as a basis for a follow-up co-design study to explore different countermeasures that can help users to gain greater control over their procrastination. The method allowed end users to participate in deciding what type of countermeasures to introduce to SNS and combat their procrastination and how best to apply them. The participants in our studies declared to procrastinate frequently on SNS. We report on the findings and provide a conceptualisation of procrastination and the socio-technical measures which can combat it. We also compare our findings with emerging tools in this area and propose enhancements.

The paper is organised as follows. In the next section, we present our research method. In Section III we discuss the procrastination types and the socio-technical countermeasures that can combat it and how best to apply them. In Section IV we present the challenges to deal with when applying these countermeasures and compare our findings with existing tools. Finally, in Section V, we conclude the paper and present our future work.

II. RESEARCH METHOD

We adopted a qualitative method to investigate procrastination on social media in-depth and followed the exploration phase with co-design sessions. This helped to understand procrastination relation to the current design of social media and explore and develop socio-technical countermeasures that can be used to combat it. In co-design and participatory design methods in general, end users can participate in creating the solutions based on their requirements, still based on theoretical foundations communicated and utilised by the researcher [13]. Co-design also refers to the creative process that is conducted collaboratively by researchers and end users to reach appropriate solutions. In our study, this process involves discussion and negotiation on how to embed some techniques into the future design of SNS to combat procrastination. However, there was a need to identify the role of SNS in leading or triggering users to procrastinate before identifying the countermeasures that can help combat it. Therefore, we first adopted the exploration stage to demonstrate how procrastination occurred and obtained the participants' views on that.

A. *Exploration stage*

In this stage, we followed a qualitative method to understand the perceived role of SNS features design in encouraging users to procrastinate. The exploration stage was divided into three phases: a focus group, a diary study, and follow-up interviews. The focus group collected the perceptions of the influence of SNS features concerning procrastination. The selection criteria involved participants who had at least one social network account and had also self-declared that they significantly experience procrastination on SNS. We recruited sixteen participants (nine female and seven male, aged over eighteen). Convenience sampling was used to recruit the participants [14]. The focus group was divided into two sessions, each session had eight participants. Subsequently, we designed a diary study that sought to elaborate on the results of the focus group over ten days. The diary method was chosen because it facilitates the collection of participants views at different times and in different contexts, hence enhancing the credibility of the findings of the focus group [15]. Then three participants were called for further clarification of the data that had been provided. This also helped as a member checking technique to validate our analysis with the subjects. This exploratory phase was required as the first step before designing the solutions that can help users to combat their procrastination. Understanding the role of SNS features in encouraging users' procrastination helps us to take a further step to search for solutions. Therefore, we followed this phase by conducting co-design sessions with end users to figure out how we can add an intervention into the future design of SNS to help users gain more control over their procrastination.

B. *Co-Design stage*

In this stage, we set out to identify the countermeasures techniques that can be used in future designs of SNS in order to help users to combat their procrastination. We recruited new fourteen participants (six female and eight male) into two design sessions with each session having seven participants. We used the same inclusion criteria that had been used in the previous stage for participant recruitment. Furthermore, we aimed to explore the modality of how these countermeasure techniques can be seamlessly implemented and integrated into SNS without affecting the user experience. We adopted a co-design method to collect the participant views and preferences on the design and increase the chance of its acceptance [16]. An example of the design suggested by the study participants is presented in Fig.1. The research benefits from using a co-design approach because it leads to better understanding of the end user needs, and can increase the opportunity to provide stronger solutions due to the different ideas that can be analysed, and evaluated before the implementation stage takes place [17].

We adopted three techniques during the co-design sessions in order to enhance the credibility of the study and to ensure that data bias was eliminated. The co-design sessions techniques include a standard personal introduction, storytelling and brainstorming.

1) Standard personal introduction: We gave a short presentation on procrastination and an overview regarding how SNS features encourage users to procrastinate as concluded through the first exploratory stage. This helped to immerse the participants in the research problem and involved a warming-up activity in getting the participants involved in the design sessions.

2) Storytelling: The participants were provided with different stories describing how procrastination occurs and when and why it can be problematic. The stories provided a strong sense of realism of the problem and encouraged the careful consideration of innovative solutions to cater to different contexts and usage styles.

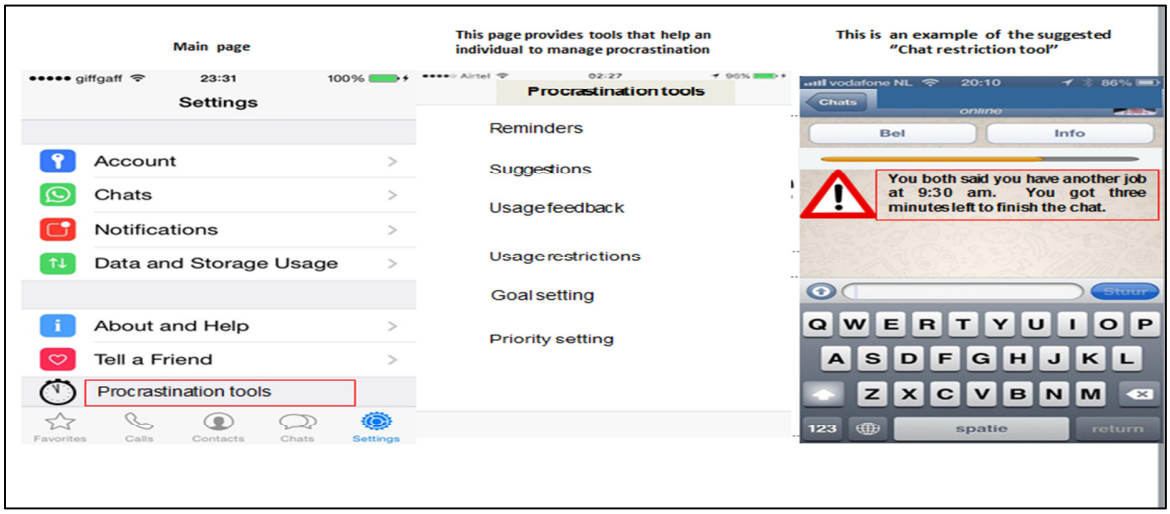


Fig.1: An example of the suggested designs during the co-design sessions

*3) Brain*storming*:* Using scenarios provided by the research team, the participants were encouraged to think and share their ideas openly with others. These ideas were critically analysed and evaluated by the participants in order to formulate robust solutions. The participants were also asked to think about the tools they would like to see in future software designs to combat procrastination. We asked two main questions at this stage:

- What are the different techniques that can be embedded into future designs of SNS to combat procrastination?
- How can we embed the countermeasure techniques into SNSs design without affecting the user experience?

Participants provided solutions based on de-facto techniques used in current technology for different purposes including scheduling software. We abstracted them to families and categories of countermeasures. To this end, we adopted a thematic analysis method to formulate that. Thematic analysis is used to search for themes that emerge with the description of the study problems in qualitative data. We followed the six steps that were suggested in [18] to conduct the analysis. Besides, using thematic analysis helped us to categories the countermeasures techniques into different themes.

III. Design Countermeasures and Modalities of Application

In this section, we categorise the countermeasure techniques into three distinct types: *socio-technical*, *technical,* and *increasing task motivation*. These types help to illustrate the different types of countermeasures that can be embedded in the future SNS design. Technical and socio-technical countermeasures seek to combat procrastination once users start accessing SNSs, while task motivation aims to prevent procrastination from occurring by motivating users to keep working on their original tasks. Moreover, in this section, we discuss how to embed the countermeasure into SNS design without adversely affecting the user experience.

A. *Procrastination: Socio-technical Countermeasures*

In this section, we present countermeasures that can be used to combat procrastination. This includes goal setting and calendar integration, see Fig. 2. Socio-technical countermeasures focus on the relation among the senders, recipients, and the device.

1) Goal setting: it refers to the development of an action plan that motivates individuals to follow and achieve the desired goal [19]. Goal setting is considered an effective strategy for encouraging users to change their behaviour and empowerment in terms of having more control over their SNS usage [20]. Hence, having goals and discovering what motivates users to achieve these goals, will guide users through the process of the goals achievements. Goal setting involves steps which guide users to set their goals and increase the possibility of achieving them. Goal settings process typically follows five main guidelines: setting a specific goal, defining measures, ensuring goals can be attained and relevant to the person and having sufficient time to achieve [21]. Following these steps can reduce the tendency to procrastinate and can help users of SNS to gain more control over accomplishing their goals. However, in the design sessions participants claimed that they usually access SNS without knowing how they are going to spend their time or have a clear idea of how much time they are going to spend on SNS. This leads to procrastination which causes users to neglect their original tasks. One of the participants of the study said that *"the future design of SNSs should include a part to help users set their goals and keep reminding them about their goals to avoid procrastination*." Other participants discussed how setting goals could be implemented within the design of SNS. Based on those suggestions, the design features were divided into two sub-categories: *priority*, and *goal declaration*.

a) Priority: When users have multiple goals to accomplish at the same time, they can decide the time they

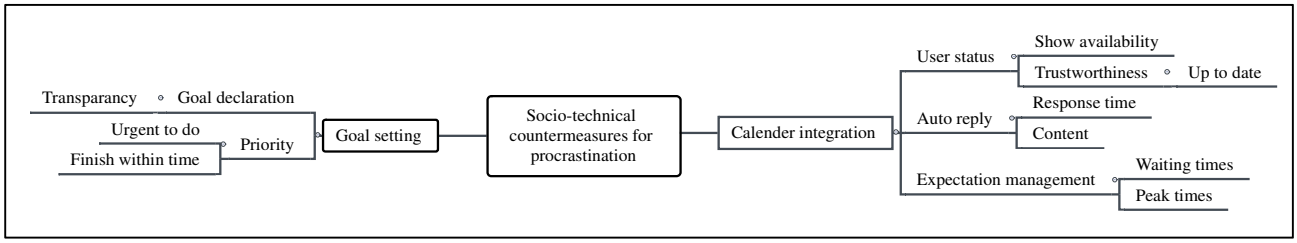


Fig. 2: Procrastionation on SNS: socio-technical countermeasures

need to accomplish each task and determine the level of *urgency* for each task. This can help users to determine which goals are more important and why clearly. Setting goal priorities helps users to track their progress and avoid spending time on non-urgent or unimportant tasks. Goal priority can help users to take control of their actions by determining the design process towards accomplishing their goals. It has been shown that people who have a specific goal to focus on paying more attention to it than a collection of goals, which leads to better performance compared to others who work without setting a specific goal [19, 22]. Therefore, the urgency level and time frame allocated can help to determine the priority of the tasks.

Concerning how to implement the priority technique into the future design of SNS, the findings of the design sessions suggested that the *urgency* level of the goal needs to be considered when setting goals so that users can decide the level of goal *priority* and whether it is an urgent goal. If users have more than one goal, the priority technique can use the urgency level to decide which goal users should receive more motivation to complete. Therefore, based on the degree of urgency, users can receive reminders and suggestions about their goals to motivate them for goals achievement and at the same time avoid information overload and irrelevant or less interesting reminders. A participant said that *"the app can allow users to list their priorities and based on that automated suggestions can be sent"*.

Finishing within time is another factor that was suggested by the participants in the design sessions to help users to determine their priorities. It is also seen helpful for users to accomplish their goals successfully and minimise the threat of procrastination. Setting a suitable timeframe for specific goals can help users to monitor their progress, while it helps to complete the task within the allotted timeframe. It has been found that people who have poor time management behaviour, such as leaving tasks at the last minute, experience work-related stress and low academic performance [23, 24].

b) Goal declaration: Declaring goals to contacts and colleagues can help users to avoid getting pressure when they ignore other users comments and requests on SNS. For example, when a user receives a notification or a message while performing a particular task, it may cause them to procrastinate by feeling the urge to check and respond in order to maintain a good relationship with others and build a positive self-image despite having other active goals and tasks disrupted. Goals declaration as a countermeasure can help users to avoid procrastination by showing user' contacts the availability time of the user. Hence, users can avoid procrastination and still build a positive self-image when they fulfil their promises and respond once they get free time. A user can have the option that allows them to be more *transparent* and provide more details about their goals to inspire trust. One participant said: *"I usually procrastinate by responding to my contacts' requests on SNS to maintain good relations with them. If they realise that I am busy they will not distract me"*

2) Calendar integration: The calendar integration is one of the countermeasures that were proposed by the participants of the design sessions to help them to combat their procrastination on SNSs. The calendar integration technique is divided into three sub-categories: *user status*, *auto-reply*, and *expectation management*.

a) User status: User status represents the present situation of an individual on SNS when those users are active. The status can also be used to share certain information with others such as user availability. However, participants suggested that the visibility of user status to *show the availability* of the user can help to combat procrastination on SNS. User status can indicate to other users whether the user is *available* or *busy*. However, some users tend to use the same status for a long time without making a change which often harms the *trustworthiness* of the status feature. One participant said: *"I have seen people who have not changed their status for more than three years."* This has a significant effect in terms of trusting the status of those users, rendering it irrelevant. Therefore, user status can be integrated with the user's calendar to keep it *updated* to increase the likelihood of others trusting it and avoiding distraction which will, in turn, lead to reduced procrastination.

b) Autoreply: The autoreply technique can help to reduce the pressure that the recipients and the sender to manage their expectations of each other well in terms of response time and also priorities, e.g. "*I am dealing with the high workload at the moment. I may take longer to reply to your message*". This technique manages senders' expectations because they can know when they might receive responses. As a result, the autoreply can help in the optimisation of time management for both senders and recipients. Autoreply is divided into two sub-categories: *response time* and *content*. Both categories have different benefits in terms of empowering the autoreply technique to help users gain more control over their procrastination.

Response time refers to how fast other users can receive the autoreply and whether the autoreply can be sent *instantly* upon receiving a notification or if it is *controlled* by the users themselves. It was debated at length in the design sessions of this study whether an instant automated reply can help both

the sender to avoid procrastination more than the controlled reply due to the time that the user spends thinking about whether or not to send the reply, depending on the message received. One participant said: *"I would not use the autoreply if I received an important notification."* Meanwhile, some participants suggested that *"Using autoreply to tell others about the time that they can get a response help to avoid procrastination and reduce the pressure that senders might have to interact"*. They can still override that if the message is important.

Autoreply *content* and its framing can have a significant effect on the recipients' reaction and belief in the message. The content can be *personalised* or *general*. For example, each user can receive an autoreply that includes their name so that user might feel their request has been given more attention. In the general content, all users can receive the same content on the automated reply.

c) Expectation management: Users who use SNS to maintain or seek popularity might use SNS excessively to meet others' expectations and avoid disappointing them which can result in procrastination. However, managing the sender's expectations can reduce the pressure that the receiver feels when they receive a notification through. For example, when a user receives a notification, the sender is unaware whether the receiver is available. This might put some pressure on the receiver to access their SNS and interact, which might lead to procrastination. Therefore, the sender's expectations can be managed better if the sender knows more details about the time that they can expect a reply. This can be achieved by considering certain factors that include the length of *time to wait* before getting a response, and the *peak time* at which the user is usually busy.

Concerning *the modality* of the calendar integration, the participants suggested that SNSs should be integrated with the user's online calendar or the to-do-list and the goals that users declared and based on that the user status will suggest whether the user is available. This technique can help to manage senders' expectations and reduce the pressure that receivers feel when they receive a notification enticing them to interact. Also, the auto-reply can be customised based on the closeness of contact and other criteria and preferences. For example, the user can customise the autoreply for those who are deemed to be important or close to them but provide more general content for others. One participant said: *"I prefer to generate the autoreply to have some more information about me to some contacts so they will know I appreciate their request."*

B. Technical countermeasures

This section presents the technical countermeasures designed to help users combat their procrastination. These countermeasures focus on the relation between the user and their device. The technical countermeasures were divided into three sub-categories that include *reminders*, *self-monitoring*, and *suggestions* (see Fig.3).

1) Reminder: Is a persuasive technique that can be used to help users tackle their procrastination on SNSs [25]. Reminder techniques can be integrated with the user goals or calendars, to send reminders that motivate users to have more control over their procrastination. When users have planned a change in their behaviour and set up measures and tools for that, including a reminder, it suggests that they have the intention to achieve that change. Behaviour change literature claims that initiating and strengthening the intentional goal is an important factor in transforming these goal intentions into actual behaviour [26]. The ease of implementing these intentions depend on how confident people are about their ability to transform these intentions into actual behaviour [27]. For example, when a user intends to stop procrastinating while working on their original tasks, they are more likely to do so when they are confident about their ability to control their usage. Therefore, the reminder technology helps remind the users about their intentions when they deviate from it, e.g., by sending them an alert or vibration. The strength of the user's intention can be increased when the time of reminders and their frequency are sensitive to the user's context. Users can be reminded about various responsibilities such as a *subject reminder*, *usage reminder*, and *context sensitivity reminder.*

a) Subject reminder: With the subject reminder, users can set a reminder about the tasks that need to be performed. For example, users procrastinating on SNS can receive reminders which help to raise their awareness and motivate them to stop procrastinating. Users can be reminded either about *current tasks*, *new tasks*, or *alternative content*. The participants claimed that users can have the option to decide how they would like to receive reminders, whether in the form of *vibrations*, *sounds* or *changing the screen colour,* e.g. using green, amber, red lights.

b) Usage reminder: The usage reminders can be used to remind users about the time they tend to spend on SNS. For example, when a user accesses an SNS, the reminder technique will monitor their usage and issue reminders accordingly. Users will have the ability to design those reminders and their frequency. Hence, based on usage, the number of reminders can be increased, and the way of delivering those reminders can be changed. For example, users can receive a reminder if they spend more than 30 minutes on SNS and then a new reminder after a further 15 minutes, with another after a further 5 minutes. Increasing the number of reminders would lead to alarming users and result in them focusing on the importance to stop to procrastinate. A participant said that *"the frequency of the reminders and the content can strongly affect users decisions to stop procrastination"*. This can be debated as sending multiple reminders can also lead to ignoring the initial reminders expecting another reminder to come close to the deadline.

c) Context sensitivity: Some users can set a reminder based on their location, such as being on campus and having to attend a lecture. The reminder technique can integrate with the user's location and different reminders can be sent when the user procrastinates. The context sensitivity reminder might appear immediately when a user accesses their SNS in a certain context and let them know that SNS access conflicts with their expected tasks in that context. The users can design the content of the message they would like to receive the reminder when they access SNS in particular locations. The ability to choose what users would like to receive can help to minimise any side-effects associated with the messages and

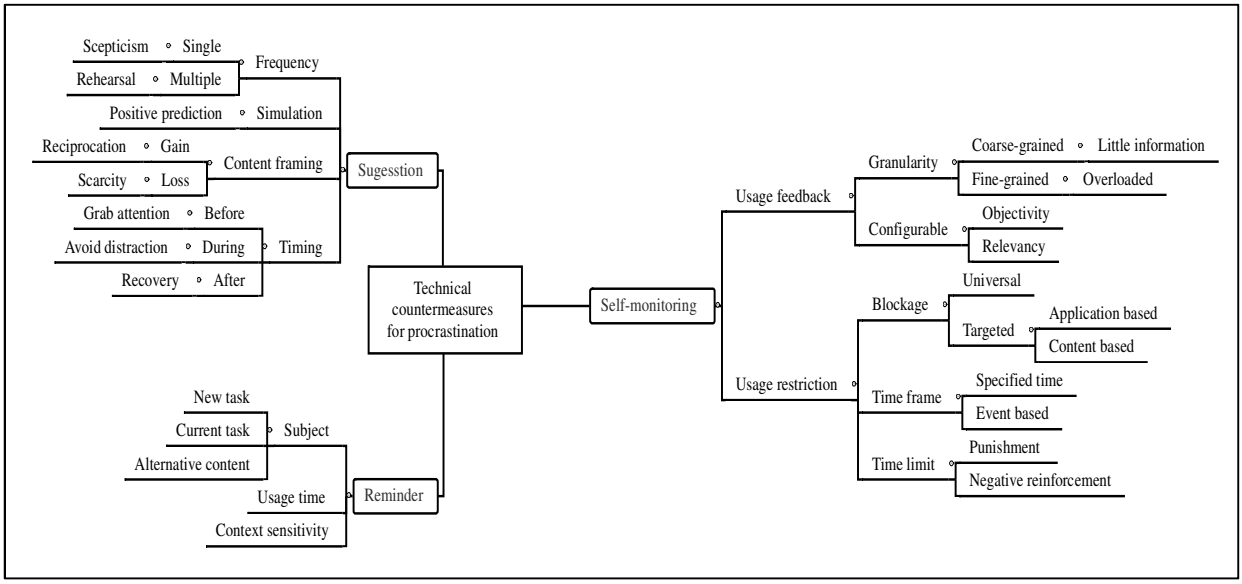


Fig.3: Procrastionation on SNS: technical countermeasures

whether messages are strong enough to motivate users to stop procrastinating.

The participants suggested that users should have the ability to decide the best way to remind themselves about their procrastination, and the *frequency* of the reminders. Some users can stop procrastinating when they receive the first reminder, whereas other needs *multiple* reminders combined with an option to lock certain social media. A participant proposed that: *"the number of reminders should be increased and the time between these reminders should be reduced if the user does not stop procrastinating."* Also, when a user interacts with others, the remainder could be for both users to help them stop procrastinating. One participant said: *"If I got a reminder while chatting, this could increase my stress to stop procrastinating because other users do not know about my procrastination."* Therefore, reminding both users at the same time could help to reduce the pressure that users feel when they withdraw from the interaction. Fig. 1 presented an example of a chatting interface where both parties are shown the timeframe of the chat and its expected end.

2) Self-monitoring: Is one of the persuasive techniques that can be used to motivate users to reduce their usage of SNS which can lead to raising awareness about procrastination [25]. Self-monitoring is divided into two subcategories: *usage feedback* and *usage restriction.*

a) Usage feedback: In this category, users can be provided with details about their usage to increase their awareness of procrastination. Based on these details, users can see how procrastination might harm their productivity, how often they become distracted while increasing user attention to the importance of regulating their SNS usage. Users can receive *fine-grained* or *coarse-grained* usage details. Fine-grained usage data provides richer feedback concerning the type of applications being used, the length of usage, user location and interrupted activities while procrastinating. The coarse-grained format provides fewer details. These include general usage about SNS and which apps dominate user usage. However, the participants proposed to have *configurable* feedback, where users can choose the level of details in the feedback. This can help to get both *objective* and *relevant* data and avoid abundance in data leading to distraction and information overload. In contrast, the lack of feedback on user procrastination might prevent users from taking informed action to change their usage style. This suggests conflicting requirements in users around the desire to have brief information and at the same time be able to take a fully informed decision.

b) Usage Restrictions: Usage restrictions refer to the techniques that can be used to prevent or complicate users' access to SNS once they fail to meet the user restriction conditions. Usage restrictions are divided into three sub-categories: *blockage*, *timeframe*, and *time limit*. Blockage techniques prevent users from accessing SNS once they procrastinate and deviate from their original tasks. The blockage can be *universal* for all SNS accounts or could be *targeted* at a specific application or the content that users view while procrastinating.

Another type of usage restriction is the *timeframe* which represents the period the user has to work on their original tasks. The timeframe can be *specified time* or *event based.* Hence, users are not allowed to access SNS during a given timeframe and will not be able to receive any notifications. Users can decide the *time limit* they wish to set for SNS access, and once exceeded their usage will be limited. This technique can help users to set goals and rehearse them to increase the control they have over their usage. The time limit technique can *punish* users and sign them out, thereby requiring signing in again after a while. However, *negative reinforcement* can also help to prevent users from accessing SNS for a limited time.

The modality of self-monitoring techniques can allow users to decide what kind of monitoring styles and tools they would

like to use in order to reduce potential side-effects resulting from using the feedback and time restriction techniques. Some users can have more controllers over their usage so they just need to know certain information and feedback about their usage. However, some users may experience difficulty in stopping their procrastination when utilising their usage feedback due to their low self-control. Therefore, further actions, such as restricting them from browsing SNSs for some time, will be needed to help them stop procrastinating. One participant said: *"preventing me from accessing SNSs during the class is more helpful because I cannot stop procrastinating by my own"*.

3) Suggestion technique: Suggestion refers to the informative process that shall help people in their thoughts, feelings, behaviour and decisions [28]. Suggestion can affect how people remember things and even how they act or behave based on the expected response. The expected response refers to when someone expects something to happen; their behaviour and reactions will contribute to matching that prediction [29]. For example, if an introvert student expects that rehearsing their presentation in front of the mirror will increase their confidence during the actual presentation, this expectation may play a significant role in increasing their confidence. However, the use of technology to deliver different kinds of suggestions can encourage users to follow these suggestions by being proactive and data-driven [25]. The suggestion can be more powerful when it causes users to do a series of actions through incremental suggestions rather than one suggestion [30]. When implementing the suggestion techniques, the design process should consider four factors: *frequency of suggestions*, *simulation*, *content framing*, and *timing of the suggestion*.

a) Suggestion frequency: The number of times users can receive suggestions might have a significant effect on encouraging them to follow the suggestion and reduce the likelihood of procrastinating. Some participants claim that multiple suggestions can increase their worry to stop procrastinating. For example, one participant said: *"I usually ignore the suggestion the first time like I do with my alarm every morning by pressing snooze."* In contrast, others proposed that a single suggestion works for most people because they take it seriously from the first time since they know there is no possibility of receiving more suggestions. Therefore, a single suggestion can increase user *scepticism* whereby users are afraid of not receiving more suggestions. In contrast, multiple suggestions can utilise *rehearsal* as a technique providing them with scenarios to practice and get them ready for performing the task at hand and also their usage control tactics, e.g. rehearsal on how to tell friends online in advance about time limitation and the framing and phrasing of the language used when opting out from an online dialogue and interaction.

b) Simulation: Refers to the scenarios of usage suggested to the user to see and reflect on how procrastination happens and its effects and alternative usage styles. This shall allow users to think on their own procrastination and make a self-assessment of it and its harm. The content of the messages can be textual in the form of certain sentences that have a strong inspirational effect, aimed at keeping users motivated; alternatively, it is possible to use images instead of text. For example, a metaphor like a tree can be shown to reflect adherence to plans with green leaves for being on time and brown and green leaves to reflect degrees of deviation. Hence, when users are presented with simulation, they can visualise in a more user-friendly way their status around procrastination and *predict* the outcome and perhaps change their strategies.

c) Suggestion framing: Refers to how suggestion content is phrased and the tone used to it. Some people prefer to know that harm and loss caused if they do not follow a recommended practice. Others refer a framing where they can be presented with the benefits that can be gained from following the suggestion. Hence, the suggestions can be *loss-framed* or *gain-framed*. Gain framing focuses on the good things that can happen if users follow the suggestions. Cialdini demonstrated that the rule of *reciprocation* is to try to repay what other people and actions provided to us [31]. Hence, when a user knows that they will achieve something once they follow the suggestion, they are more likely to behave based on the suggestion. For example, if the users do not procrastinate when preparing for an exam, they will have a better opportunity to get a good mark. In contrast, loss framing focuses on the negative things that will happen if users do not follow the suggestions. For instance, users who do not attend lectures might fail the exam. Therefore, framing the messages that users receive in the suggestion can affect their behavioural decisions and encourage them to follow the suggestions. According to the prospect theory, people's choices are sensitive to how information is framed [32]. Hence, the *scarcity* principle suggests that people will follow the suggestion when they feel they have limited resources or options and they can be lost if they do not [31]. The framing of the message can also exploit this by showing people the opportunities and their time-limited nature.

d) The timing of suggestions: One of the important factors that were emphasised by the participants is whether users should receive suggestions *before*, *during* or *after* the original tasks that need to be performed. The suggestion can be sent before the task starts to *grab the user's attention,* and hence lead the user to focus fully on the tasks. Similarly, users can receive suggestions during the task when they receive an ad-hoc interaction or when they try to use SNS so that they remain motivated and *avoid getting distracted* that can result in procrastination. Furthermore, once a task has been completed, users can receive suggestions for a *recovery* time to refresh their mood and prepare them for any upcoming tasks and also to positively reinforce their achievement.

In terms of *the modality of suggestion*, different approaches were proposed concerning how participants should receive suggestions. About the frequency of the suggestions, users could receive single suggestions when they tend to procrastinate, with the number of suggestions increasing based on their level our duration of procrastination. For example, if they ignore the first suggestion, they then receive another suggestion with the same or different content. Receiving multiple suggestions can influence users to stop procrastinating and get ready for their original tasks. Of course, such suggestions should not in themselves become a nuisance and users can have the option to decide what type of

content they would like to receive. This can influence their commitment to the decisions they made earlier when they designed the suggestion [31]. Framing the content of the suggestion can take different approaches. Some participants prefer to receive the suggestion in red to highlight the importance of the suggestion. For example, one participant said: *"the suggestions should be in red to attract the user's attention."* Also, some participants suggested that the suggestion could also be used to remind users to set their goals. Hence, based on the goals that users want to accomplish, the suggestion countermeasure can integrate with these goals and send motivational suggestions to help users continue their progress.

C. Task motivations

In this section, we discuss how users can be motivated to continue working on their tasks before the tendency to procrastinate takes place. Based on our study findings, task characteristics were found to be one of the factors that usually affect the tendency to procrastinate on SNSs. Task-related procrastination happens when users procrastinate because of a lack of motivation or the difficulty of the task whereby users avoid performing a task due to their fear of failure. Therefore, gamifying tasks can be a solution to enhance a user's motivation to complete them. Task motivations were divided into three sub-categories: *commitment*, *Reward* and *milestones* (see Fig.4).

1) Task commitment: Refers to the ability of an individual to demonstrate a focus on undertaking tasks for some time without distraction [33]. Renzulli claimed that it is not possible for an individual to experience high achievement without high task commitment. There is an associated relationship between task commitment and job performance which means that when users have a high commitment to their tasks, this can reduce the possibility of procrastination [34]. Furthermore, users might tend to lose their commitment when they have doubts about their ability to complete the task successfully or have a fear of evaluation which can negatively impact their task commitment [35, 36]. The commitment to a task can be driven by the user's motivation to perform the task. According to self-determination theory, users should have three basic psychological needs: autonomy, competence and relatedness [37]. Therefore, to motivate sufficient commitment should satisfy, to varying extents, those three needs. Furthermore, when users demonstrate their task commitment either to themselves *or via a public commitment*, this appears to have a positive impact on task completion [31].

2) Task reward: It is one of the factors that can motivate users to perform the task. For example, when the task has a sizeable reward, either intrinsic or extrinsic, this reward can have a significant effect in terms of increasing the user's *enthusiasm* to perform the task. The participants of the design sessions suggested that users could even be motivated by simple rewards such as adding points to some tally once users complete a task. Similarly, during the task, some form of motivational feedback was also considered to be useful. Such feedback can help users to maintain their progress and to ensure that they will continue to progress and the motivation will not be affected by the long time spent progressing the work. One participant said: *"when the deadline is far away from the starting point, my motivation starts to decrease"*. Furthermore, the feedback that the user receives when working can also be personalised, to reflect their progress (see 3), to increase its effectiveness, and ensure that they remain motivated to complete their tasks.

3) Task milestone: Describes the tracking of the task's progress to accomplish them. Dividing tasks into different milestones can help to manage better the progress of the task which helps to ensure the quality of the work by reflecting it in different phases [38]. Furthermore, when users accomplish each phase, they can be rewarded to motivate them to complete the new phase. When the task is reduced into small phases and each phase can have a *timeline* to be monitored, this can help users to keep their progress under control and *track their performance* which decreased the chance of procrastination [39]. A task's milestones also help users to build their self-esteem especially when they get motivating feedback. The information about progress feedback can help users to reflect on their performance and planning and have clear ideas about the next stages before the completion of the task [40]. Control theory suggests that people can change their practice when there is a gap between the goal they would like to achieve and their current behaviour to minimise that gap [41]. The feedback that users receive can help to guide and motivate users to accomplish their goals and minimise the gap between their current behaviour and their desired behaviour [42].

The modality of task motivation is around how to gamify the commitment of the task which can help to keep users motivated to complete their original tasks and reduce the possibility of procrastination. In the design sessions, participants suggested different techniques to motivate users to complete their tasks successfully. These techniques include task *reduction* and *reward*. The reduction techniques refer to the action of dividing the task in smaller parts. The reduction can help to reduce the difficulty of the task that users might face when they deal with a particularly large task. Providing users with a *progress bar* was one of the most important strategies suggested by the participants. One participant said: "*while I am performing a task I feel less motivated to complete it because I do not know how long I need to finish*".

Task *reward* is another technique that users wanted to help combat procrastination. The reward can be either during the task or after the task has been completed. During the task, users can be rewarded for each milestone they achieve such as a reminder about the work that has been done. One participant said: *"users can be thanked for the work they have achieved and motivated to complete the rest, such as 'well-done, you've done 70% of the work and still need to do 30%"*. This kind of reminder triggers users' extrinsic motivation by appreciating their work so that they can feel motivated to accomplish the whole task. Another type of rewards that have been proposed by the participants is to compare users' progress with that of their colleagues by showing how many points' users have gained or the number of tasks that have been accomplished. Comparing users' achievement can increase competition between users which can increase their commitment to tasks and reduce the possibility of procrastinating. Also, some

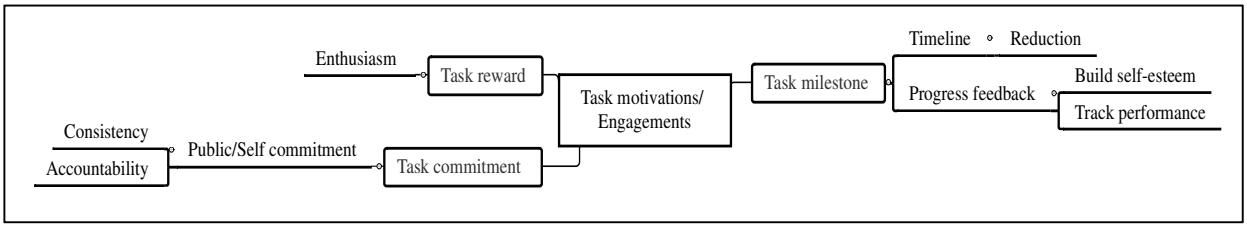


Fig.4. Procrastionation on SNS: Increasing task motivation and engagement

participants suggested that the task reward should be personalised for each user which could have a significant effect on an individual's motivation. Personalisation refers to the adaption of the output to the individual user instead of treating a group of people [25].

IV. USERS REQUIREMENTS VS EXISTING TOOLS

Our suggested countermeasures are meant to help users to reduce and regulate procrastination. However, they may also come with their own risks and side-effects. This also applies to de-facto tools provided by the industry. For example, in iOS Downtime[1], users can schedule a time for muting the phone and avoiding notifications and their distraction. The downtime tools can introduce a risk whereby users keep thinking about whether they have received important notifications; i.e., hidden procrastination and fear of missing out. Hence, such tools should come with richer settings allowing people to decide upon alternative and socio-technical measures such as the one we proposed around suggestion, rehearsal and simulation. Another example from the iOS Downtime tool, users only have the option to select one block time in which they will be unable to receive any notifications. Table I presents a comparison between our proposed procrastination countermeasures in the area of usage regulation and the iOS Downtime tool.

Our suggested techniques and countermeasures allow users to customise the blockage time tool and what to block based on the types of the app and the content of interaction and to be integrated with their own calendar. This allows for greater personalisation and context sensitivity and increases acceptance and relevance. However, this also comes with additional costs in terms of requiring users to set up plans. There is a need for further research to ascertain the readiness of users to take the time to set up such plans, and how they perceive the cost/benefits of the additional effort. We expect this to also relate to several factors such as their technical skills and confidence and their perception of the need to make behavioural changes.

To empower existing tools, our findings suggested that online time management should be more fine-grained and sensitive to the content of the usage, its context and user status. The autoreply suggested in this paper has a richer format and setting to those tools in current communication software. Our auto-reply is intended to support the broader aim of managing user's expectations; both the sender and the receiver in an informative personalised style. We view procrastination as a social pressure problem in part. Importantly, our tools are suggested to reduce the pressure on all communicating parties.

1 https://apple.co/2OW7DG2

We discussed the countermeasures and their modalities of application with the aim of reducing their potential negative side-effects. In our future work, we will use this knowledge to develop a method to help users identify the features and usage styles of SNS that trigger their procrastination and choose and configure suitable countermeasures that can help them to gain more control over their procrastination. We expect this method to be based on persuasive design and personalisation as we also acknowledge the role of personality traits, culture and self-control in the acceptance and efficiency of such tools.

TABLE I: DOWNTIME IN IOS SCREEN TIME VS OUR RECOMMENDATIONS

Comparison criteria	Current Downtime iOS Screen Time	Suggested design
Frequncy of time blockage	Enable users to only have one time block	Enable users to have more than one time block, i.e. schedules and timeframes
Modality of setting time blockage	The user sets the time manually	Manual and automated based on users' calendar and user context
User status	Senders are unaware of the receiver availability	Senders are aware of the receiver's availability, meaning that the receiver can have less pressure to interact
Effectivness on managing others expectations	It does not manage senders' expectations	It contains an auto-reply to manage senders' expectations
Stakeholders	Only focuses on the relationship between the user and the device	Focus on the relation among the user, the device and other contacts

Summary of what users expect from the anti-procrastination tools to be introduced to future social media:

- *Making* users more aware of how procrastination harms their productivity
- *Guiding* users to understand their current situation by providing them with feedback and guidance on how to gain more control over their procrastination.
- *Having multiple stages to achieve results*; helping users to control their procrastination in different stages such as feedback, a more advanced stage with reminders, and then the use of restrictions if required.
- *Flexibility* to enable users to decide the suitable techniques to use to avoid negative side-effects such as reactance. We recognise the risk of bias here.

- *Reducing* the pressure that users feel to respond to notifications while working on their tasks by making other contacts aware of their availability.
- *Managing* other contacts' expectations, e.g. by showing them when they will receive a response and the time remaining for a chat.
- *Supporting* and motivating users to complete their original tasks; for instance, using task reduction and progress visualisation.
- *Gamifying* the commitment to the task to bring the fun that users experience on SNS into the work task environment.

V. CONCLUSION

In this paper, we have sought to gain a better understanding of user needs and how users could combat their procrastination. We also sought to explore the modality of the countermeasures which can be used to combat procrastination on SNS. The study highlighted the countermeasures that need to be considered as part of the future design of SNS to combat user procrastination. Some of these countermeasures are already incorporated into emerging tools such as iOS Screen Time and Google Digital Wellbeing to help users to manage their online time. However, these techniques focus mainly on the interaction between the user and the device; e.g. usage limits and feedback. This study has shown that some users procrastinate because of the pressure they feel when they become distracted, which in turn forces them to respond to SNS prompts, in order to develop or maintain a positive self-image. In doing so, the study paid particular attention to the inclusion of three aspects of countermeasures: the user, the device, and society. This can help to reduce the pressure that leads users to procrastinate and helped them to gain greater control over their usage.

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Infoxication in the Genomic Data Era and Implications in the Development of Information Systems

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***Abstract*—We live in an age where data acquisition is no longer a problem and the real challenge is how to determine which information is the right one to take important and sometimes difficult decisions. *Infoxication* (also known as *Infobesity* or *Information Overload*) is a term used to describe the difficulty of adapting to new situations and effectively making decisions when there is too much information to manage. With the advent of the Big Data, infoxication is affecting critical domains such as Health Sciences, where tough decisions for patient's health is being taken every day based on heterogeneous, unconnected and sometimes conflicting information. In order to understand the magnitude of the challenge, based on the information publicly available about the genetic causes of the disease and using data quality assessment techniques, we performed an exhaustive analysis of the DNA variations that have been associated to the risk of suffering migraine headache. The same analysis has been repeated 8 months after, and the results have allowed us to exemplify i) how fragile is the information in this domain, ii) the difficulty of finding repositories of contrasted and reliable data, and iii) the need to have information systems that, far from integrating and storing huge volumes of data, are able to support the decision-making process by providing mechanisms agile and flexible enough to be able to adapt to the changing user needs.**

***Index Terms*—Infoxication, Genomics, Information Systems, SILE method**

I. Introduction

Infoxication (also known as *Infobesity* or *Information Overload*) is a term used to describe a situation where a decision maker faces a set of information characterized by its amount, complexity, redundancy, contradiction and inconsistency [1].

Infoxication affects especially the decision-making process since having too much information to manage inhibits our ability to prioritize and optimally determine the best possible decision. The term infoxication has been widely studied in Social Science and strongly associated with the evolution of Social Media. Nevertheless, the impact of infoxication has started showing its effects on other fields such as genomics, where data acquisition is no longer a major problem.

During the last decades, the technological advances in the field of genomics have allowed the proliferation of multitude of research projects around the world. Technologies such as Next Generation Sequencing (NGS) allow researchers to read the entire DNA sequence of a human being, known as genome, in a cheaper and faster way. Consequently, NGS has become a routine research tool that makes possible the development of Genome-wide Association Studies (GWAS) to identify inherited genetic variants associated with risk of suffering a disease or present a particular trait. These studies require the sequencing of hundreds of genomes and generate terabytes of data ready to be analyzed by the scientific community. Nevertheless, the management of this increasing amount of data is not a trivial task. The establishment of meaningful associations among the DNA changes and their consequences for human health requires the connection of heterogeneous data scattered in multitude of repositories, represented with different formats and even without an ontological agreement about how the same concept must be represented [2]. In addition to the integration problems, the information has a variable level of quality which requires a considerable effort to separate the wheat from the chaff in order to extract reliable and meaningful conclusions. Therefore, scientists are overwhelmed with the amount of data that is exponentially increasing in a domain characterized by its constant evolution.

The natural way to face the problem of selecting the most adequate option in this infoxication age is to simplify the options by reasoning about the information available. But how can this be done? Scientists know that a typical human genome differs from the reference sequence in 4.1 million to 5.0 million sites and there is a huge difference among populations [3]. These are the DNA variants that must be evaluated in order to determine those that may be potentially pathogenic for a disease. How can the researcher decide which are the adequate variants among all the existing ones?

Reducing infoxication is a great challenge for information systems research in the information age. While an information system can ease the flow of large amounts of information potentially leading to overload, it also has the potential to help decision-makers to organize, store, and process information that is accessible, informative and actionable enough to extract valuable knowledge. This is what we call the *smart data perspective*. But another question arises, how can the

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smart data be processed and evaluated by "smart" information systems?.

According to [4], the identification and management of smart data requires to address four main tasks:

- Search and identification of adequate and reliable data sources.
- Identification of accurate and relevant information.
- Storage in the adequate repository.
- Analysis to extract meaningful conclusions.

Focusing on the genomic domain, infoxication affects each of the above-mentioned tasks in different ways.

A. Search and identification of adequate and reliable data sources

The genomic data sources play an important role in information search, information processing, and decision-making. Thus, this is the first decision to make when managing genomic information. And it is a crucial one because the selection of the adequate repositories can either decrease or increase the effort required to manage the information they store. For example, the selection of genomic repositories that lack of controls for the submitted information, that do not use standard vocabularies or that do not update or maintain the stored data generates distrust in the user.

There are too many aspects to take into account to select the adequate data sources, and combined with this is the great variability in the number of available repositories. This number varies from year to year as can be seen in Fig. 1, to the point that nowadays there is no way of knowing with certainty the number of active data sources.

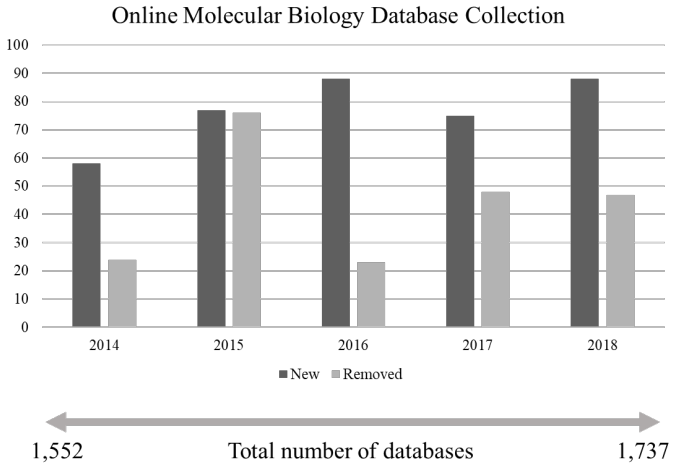


Fig. 1. Number of databases added and removed from the Online Molecular Biology Database Collection.

There are different reasons why this situation occurs:

- The exact number of active resources cannot be determined because the information about these online resources is scattered in several life science journals and around the Web [5].
- From year to year, new data sources appear but at the same time part of them become inactive or dissapear. This is due to the fact that many of them have been developed to store the information derived from specific studies or projects and they are no longer maintained.

Under such complex scenario, researchers must face the uncertainty as to whether they are using the adequate data sources, combined with the effort that requires to determine the validity of the new emerging ones.

B. Identification of accurate and relevant information

On the other hand, each genomic data source stores information that sometimes is conflicting, redundant and based on studies that cannot be considered statistically significant to be used in the clinical practice. For example, Fig. 2 shows the impact of redundant data in the UniProt KB database.

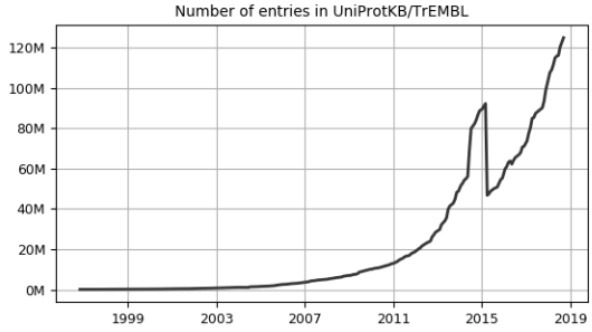


Fig. 2. Impact of the Proteome Redundancy Detector in the UniProtKB database [6].

Furthermore, the identification of the relevant data is not easy because it requires the harmonization of different sources that frequently lack the required metadata to efficiently automate the process. This forces the researchers to head to the literature in order to manually complete the missing information, with the consequent loss of time and increase in the complexity of the decision-making process.

C. Storage in the adequate repository

The increasing amount of genomic data is positioning the domain within the scope of Big Data [7]. For example, the European Bioinformatics Institute (EBI), one of the world's largest biology-data repositories, currently stores over 140 petabytes of data and back-ups about genes, proteins and small molecules [8]. This represents an increase of approximately the 1500% in the last 6 years, as can be seen in Fig. 3.

But, this happens not only in the big centers. As prices drop for sequencing technologies, even small biology labs can become big-data generators. This situation opens many possibilities but at the same time, a series of challenges for researchers that must be sure that their computational infrastructure and software tools are up to the task.

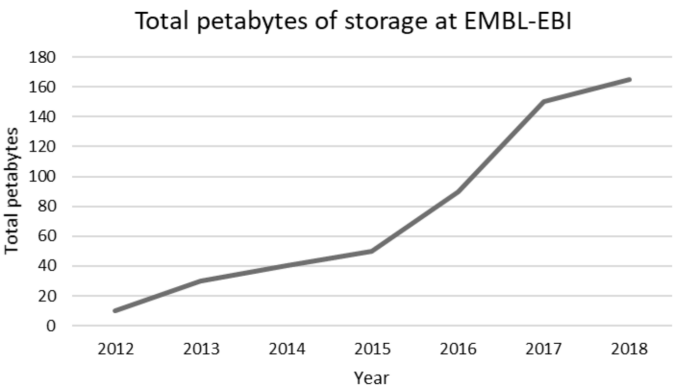


Fig. 3. Storage evolution of the EMBL-EBI database.

D. Analysis to extract meaningful conclusions

When the data acquisition is not a problem, the main concern is what to do with all the collected data. To take full advantage of the data, it is essential to interpret them based on all the relevant prior knowledge. However, in the genomic domain this exceeds the computational capacity of many laboratories. At the end, genomic data is useful only if the scientists can do something with it in their everyday jobs.

In order to understand the magnitude of the challenge, we focused on a specific task that is the core of a genetic diagnosis: the identification of the DNA changes associated to the development of a disease. The size of the problem can be understood if we consider the high number of potential different diseases (phenotypes) to be explored, each one with their particular problems in terms on discovering the correct variations to be used in clinical environments. There are two problems here: one is more "horizontal", associated to the understanding of how generic the variants identification process can be when applied to different diseases (each one with its own particularities in terms of reliable data sources and quality criteria to be applied in the selection process). The other one is more "vertical", oriented to analyze how stable the results are for a given disease when the evolution of the genomic knowledge is taken into account. This is the dimension that we explore and report in this paper. To what extent does the process of determining relevant variants depen on the moment in which the analysis is carried out? Are the resulting variations the same? Do relevant changes appear when the analysis is carried out at different times (assuming that the method that is employed is the same)? It is easy to understand how important this problem is if we remind that we are talking about information to be used in clinical diagnosis. Could it be the case that the infoxication problem (associated to the heterogeneous and diverse data sources) directly affect the results of the applied method?

To this aim, we performed an exhaustive analysis of the DNA changes that have been associated to the risk of suffering migraine headache by using a method called SILE, specially developed to move from the Big Data to the Smart Data perspective. Thse SILE method is a systematic approach that provides a guide on how to find the adequate data sources, how to identify the relevant data, where to load the genomic information and how to extract knowledge from it. Further details about the application of the method is provided in section II. Because of the speed with which the knowledge in the genomic domain evolves, the method was applied again to check the information 8 months after the first use. Considering the implications of infoxication in the genomic context, we could imagine that the expected results would incorporate the appearance of new DNA changes and studies, or the appearance of new evidence that could contradict the results of the first implementation. But what is the real impact of infoxication? This is the question that the work reported in this paper explores and answers.

With this goal in ming, along section II, we introduce the SILE method and the results of its first application. In section III, we discuss the results obtained in the second implementation. Finally, in section IV we draw the conclusions and explain the importance of having information systems that not only support the management of genomic information but also can guide the decision-making process, helping the user to adapt to the different situations that occur in a changing domain.

II. The SILE method and the migraine case: 1st implementation

The SILE method has been developed with the aim of providing a systematic approach to the Search, Identification, Load and Exploitation of high-quality genome data [9]. The method consists in four stages (Search, Identification, Load and Exploitation) that support the tasks required for the management of smart data, explained in the previous section. The core of the method is the Conceptual Schema of the Human Genome (CSHG) [10], which provides the ontological basis required to harmonize the genomic data sources; and a data quality methodology that ensures that the information managed on each stage is of high-quality.

The validity of the method has been initially proved in different case studies with the aim of searching relevant DNA changes (variants) associated to a set of diseases: Alzheimer [11], colorectal cancer [12], Crohn's disease [9], migraine, epilepsy, as well as male and female breast cancer. The results of the method have been corroborated by a group of experts (geneticists and clinicians) in genomic diagnosis.

One of the studied diseases was migraine headache due to it is the 3rd most prevalent and the 6th most disabling illness in the world [13]. A migraine headache can cause severe pain, usually on just one side of the head and it is often accompanied by nausea, vomiting and extreme sensitivity to light and sound. Migraine attacks can cause significant pain for hours to days and can be so severe that the pain is disabling [14]. Despite the impact of this disease, migraine causes are not yet fully understood and new studies are published every year, as can

be seen in Fig. 4. Thus, it is important to study all the available information in order to infer new insights on the mechanisms that causes the migraine attacks.

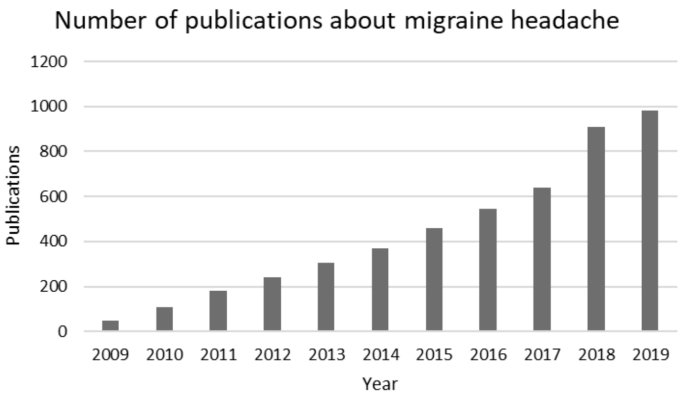


Fig. 4. Evolution in the number of publications submitted to PubMed and associated to migraine headache.

Nevertheless, the effects of infoxication cause the management of all this information to be a great challenge. With the aim of mitigating the impact, the SILE method was used to simplify the number of DNA variants to analyze helping the researchers to focus only on the information that really deserves their attention.

In the first implementation of the SILE method, we started by the Search stage that consists in searching and selecting the sources from which the information is going to be extracted. We identified three relevant data sources: ClinVar [15], Ensembl [16] and GWAS Catalog [17]. These repositories were selected after performing an exhaustive process of selection that included the following quality criteria:

- The information stored must be reviewed by a group of experts in the field.
- There are quality controls to assure the correctness of the submitted information.
- The data source must be supported by a research center, association or institute with national or international relevance.
- The database must be active (less than 1 year from the last update).
- The information must be public and freely accessible.

Once the data sources were determined, we continued with the Identification stage that consists in identifying the DNA variants that can be considered as relevant for the development of the disease.

The quality criteria used to determine which DNA changes are relevant were:

1) There must be at least one article to support the association of the variant with the disease.
2) The study must be performed over 500 participants, at least.
3) The study must be statistically significant:
   a) For protective variants the Odds Ratio must be less than 1.
   b) For pathogenic variants the Odds Ratio must be greater than 1.
4) The clinical significance must be relevant enough (values like benign, likely benign, uncertain or conflicts are not allowed).

The reasons why these criteria have been selected are that a sample size with sufficient statistical power is critical to detect causal variants of human diseases. A large sample size is more representative of the population, limiting the influence of outliers or extreme observations [19]. Following the practices of genetic diagnosis providers, such as 23&Me or Promethease, we stablished the minimum sample size for genome association studies in 500 participants.

Odds ratios are used to determine whether a particular exposure is a risk factor for a particular outcome, and to compare the magnitude of various risk factors for that outcome [20]:

- OR = 1 Exposure does not affect odds of outcome.
- OR $>$ 1 Exposure associated with higher odds of outcome.
- OR $<$ 1 Exposure associated with lower odds of outcome.

According to this definition, pathogenic variants are those which OR is greater than 1, and benign variants are those with OR less than 1. Variants with OR = 1 have the same probability of causing the disease as not causing it and thus there are not statistically relevant.

The clinical significance determines the functional significance of genetic variants with respect to their potential effects on genes and diseases. In order to use these variants in precision medicine and research, the agreement in their clinical relevance is essential. However, the genomic databases often contain variants that are incorrectly classified or have contradictory records on the assessment of pathogenicity due to the different understandings of the existing guidelines and the lack of standard algorithms for implementing them. To minimize the effect of such situation, we consider only those variants that are unanimously classified as:

- Pathogenic: For variants identified to cause a disorder.
- Drug Response: A general term for a variant that affects a drug response, not a disease.
- Association: For variants identified in a GWAS study and further interpreted for their clinical significance.
- Risk Factor: For variants that are interpreted not to cause a disorder but to increase the risk.
- Protective: For variants that decrease the risk of a disorder, including infections.
- Affects: For variants that cause a non-disease phenotype, such as lactose intolerance.

All these critera help to discard the information that are not valuable for the task at hand. Furthermore, the user does not have to care about the different structure of the underlying data sources or the process followed to harmonize the information. His only concern is to verify the results that have been presented as relevant and that in this case study represents less than the 4% of the initial dataset.

At the end of the Identification stage we obtained 4 DNA variants considered as relevant from a total amount of 463 variants and 431 articles. We provide a summary of these results in Table I.

TABLE I
RELEVANT DNA VARIANTS ASSOCIATED TO MIGRAINE HEADACHE

ID	Gene	Chromosome	Location
rs10166942	TRPM8	2	233916448
12388 (ClinVar)	TNF	6	6p21.3
rs1835740	LOC101927066	8	97154685
rs2651899	PRDM16	1	3167148

The results have been validated by a group of experts in genomic diagnosis who have verified the associated literature and have corroborated the association among the variants and the risk of suffering migraine headaches.

The results were loaded into a database that our group has specially designed for its futher exploitation called the Human Genome Database. Using a platform developed to support the genetic diagnosis, a sample from a patient can be checked in order to determine if any of the above mentioned variants are present.

But, as we are aware that the genomic domain is under constant evolution the information stored in the information system must be checked periodically to keep it sufficiently up to date. Nevertheless, there are no suggestions on how long the results remain valid (maybe days? months? years?) and thus the uncertainty about their validity appears. We know that the ClinVar database is updated weekly, Ensembl twice a year and GWAS as long as new information is added to the database. How does this affect the validity of the results? In our case we repeated the process 8 months after the first implementation and the results are explained in the next section.

III. THE SILE METHOD AND THE MIGRAINE CASE: 2ND IMPLEMENTATION

Due to the evolution of the research about this disease, one should expect that the amount of information to be managed -after a so short time period- would include at least the same number of DNA variants and articles in both implementations of the method. Nevertheless, the results obtained was surprising.

In this second implementation of the SILE method, we used the same data sources so we started directly by the Identification stage. After performing the same search in the databases that was done in the first implementation, the initial number of variants to be checked resulted in 552 and the number of articles retrieved was 325. This means that 89 new candidate variants were added to the data sources but surprisingly, 106 articles were missed (See Fig. 5).

These results do not coincide with the expected ones, according to the graphic shown in Fig. 4. As a consequence, the level of uncertainty about the validity of the results obtained in the first implementation increased. How can we be sure about the conclusions derived from these sources if there is such variability?

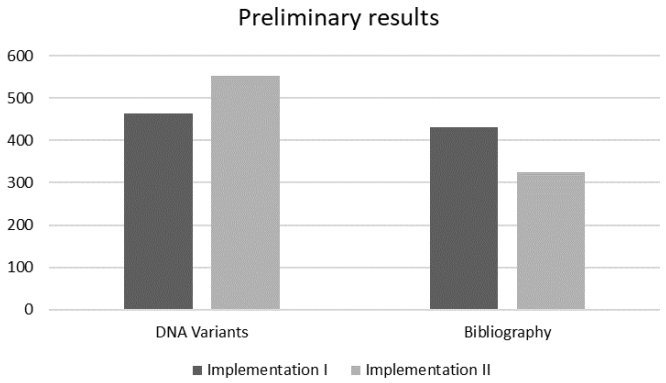


Fig. 5. Comparison of the preliminary results obtained on implementation of the SILE method.

In order to understand the implications of these differences before addressing the Load and Exploitation stages, we performed a deep study of the data obtained from both applications of the SILE method. With the results, we want to prove with concrete data and arguments how complex genome data management is.

A. Analysis of the DNA variants

Concerning the initial number of variants to be checked, there was an increase in the results obtained from all the data sources, as expected. In a working domain that is in constant evolution, it is sensible to expect more variants as a result of the increasing performance of more relevant experimentation, and the use of improved/optimized sequencing techniques. Nevertheless, as can be seen in Table II, in Ensembl only 398 variants are common in both implementations, when the expected results were 404. This means that 6 variants that were found as associated to the disease in the first implementation have disappear, and 40 new variants have been found in the second implementation.

TABLE II
COMPARISON OF THE NUMBER OF DNA VARIANTS OBTAINED IN BOTH IMPLEMENTATIONS OF THE SILE METHOD.

	ClinVar	Ensembl	GWAS
Implementation 1	269	404	196
Implementation 2	351	438	203
Coincidence	269	**398**	196

In order to understand what could have happened and why, we analyzed the differences in the information retrieved and we found that the number of phenotypes (in our case types of migraine) associated to the variants was different in both implementations: in the first implementation 17 phenotypes were retrieved, while in the second implementation only 15 were retrieved. What happened with the information associated to the two missing phenotypes?

But it is even stranger that after comparing the names, we detected that only 12 phenotypes were common, 5 from the first implementation have disappeared and 1 from the

second implementation has been added. So, could it be that the variants associated to these phenotypes were erroneous and as a result they have been removed from the databases?

Our in-depth analysis provided interesting answers. What happened was, that the 5 phenotypes from the first implementation that (apparently) disappeared were renamed to other types.

For example, the variations associated to the phenotype *Migraine Familial Hemiplegic 1 with Progressive Cerebellar Ataxia* (rs121908218 and rs121908225) were renamed to *Familial hemiplegic migraine type 1*. The new phenotype found in the second implementation (*Sensorineural deafness and migraine*) corresponds to a new variant (rs41456348). Globally speaking, this issue affected 29 variants. Table III shows the number of variants affected by these changes.

TABLE III
NUMBER OF VARIANTS AFFECTED BY THE CHANGES IN THE PHENOTYPE CLASSIFICATION.

Phenotype	Action	Num. variants
Migraine Familial Hemiplegic 1	RENAMED	11
Migraine Familial Hemiplegic 1 with Progressive Cerebellar Ataxia	RENAMED	2
Migraine Familial Hemiplegic 2	RENAMED	13
Migraine Familial Hemiplegic 3	RENAMED	3
Sensorineural deafness and migraine	ADDED	1

This underlines the impact of not having an ontological agreement in such important aspect as the name of the disease in a context that is clinical-oriented. The selection of the variants that are associated to a disease has a direct effect in providing a correct diagnosis and it is a serious problem to face these changes just after a few months. Nevertheless, this still does not explain why 6 variants are missing.

In our attempt to find precise answers to the situation that we report in this work, we performed a manual search of the missing variants but there were not results even looking for the identifier of the variant or the phenotype. We found out that Ensembl collected these variants from the dbSNP archive, that merged the information in new records. Multiple submitted variants, when referring to the same location, are clustered into one cluster and are assigned a reference ID number, called rs number. However, if two cluster records are found to map to the same location (i.e. are identical), then dbSNP merges those records and consequently, the IDs become obsolete. Table IV shows the variants that have been merged in new records.

TABLE IV
VARIANTS WHICH ID HAS BEEN CHANGED

Old ID	New ID
rs1012929478	rs886055036
rs1019381145	rs886045424
rs904126858	rs886055040
rs952709556	rs886045438
rs953710910	rs886045423
rs990335919	rs886045428

This process of merging identical records reduces redundancy within dbSNP database. Nevertheless, can cause situations of inconsistencies when searching variants by ID, as happens in our case: the variants had no dissapear, they were redundant. If we cannot trust the provided ID, and the use of standards such as HGVS expressions to name the variants are not an extended practice, the detection of redundancies turns into a new challenge.

B. Analysis of the associated bibliography

We enter now the analysis of another relevant criteria: what is the bibliographical support of those variants that are candidates to be selected as significant for the disease under study?

The associated bibliography is a key aspect when determining the relevance of a DNA variant because it is the original source where the association among the disease and the variant has been stablished. It is in the bibliography where the details about the population, the statistical significance of the experimental results and the technology used to establish the association are explained. Thus, it is crucial to certify the validity of the decisions that are made about the health of a patient based on the existence or not of certain DNA variants. Nevertheless, due to the increasing amount of publications generated every year it is crucial to filter only those that are significant enough. Otherwise, the effort to check the possible contradictory or supportive evidence would be an intractable problem.

As can be seen in table V, there is a significant increase in the number of articles retrieved from ClinVar in the second implementation (245 instead of 98). Furthermore, it was expected that 98 articles were common between both implementations, but this is not exactly the case because one is missing.

TABLE V
COMPARISON OF THE NUMBER OF ARTICLES OBTAINED IN BOTH IMPLEMENTATIONS OF THE SILE METHOD.

	ClinVar	Ensembl	GWAS
Implementation 1	98	223	4
Implementation 2	**245**	**178**	8
Coincidence	**97**	**160**	4

The article with ID = 23757202 has been removed from the database and it does not appear in the results of the second implementation. The article is entitled “Free the data: one laboratory’s approach to knowledge-based genomic variant classification and preparation for EMR integration of genomic data” [18], which is not related neither to the variant or the phenotype.

According to the bibliography extracted from Ensembl, the number of articles has decreased (from 178 to 160) and only 160 are common in both implementations. There is no precise clue to explain why 63 articles have disappear. This situation lunches a disturbing question: Is it possible that publications are being incorrectly associated with variations? If the answer were yes, that would significantly increase the noise that researchers must face. Due to the effort that checking this bibliography implyes, we consider this question as an interesting topic for a future research.

Once the inconsistencies found in the results have been explained we went on study about the relevance of the variants by performing the quality flitering. After this process we obtained the variants considered as relevant for the genetic diagnosis. In the next section, we are going to discuss the results of the method after the analysis of the initial set of variants and the associated bibliography.

C. Analysis of relevant variant/disease associations

In this genomic context, there are relevant questions that need to be treated adequately, such as:

- are these new candidate variants relevant?
- have been variants that were initially considered significant removed?
- are there new evidence (literature) that could affect the results obtained in the first analysis? How to detect and manage this type of new evidences?

After performing the quality analysis we found that the 4 variants considered as relevant in the first implementarion are present in the second one, which suggests that there is not new evidence that contradicts the importance of these variants for the development of the disease. But surprisingly, there are 89 new variants that require manual review. This means that the information extracted from the repositories is not enough to measure all the established quality criteria and a manual review of the associated studies is required in order to determine its validity.

The results are significantly different than the ones obtained in the first implementation. In the first implementation, all the variants had enough information to measure its validity but in the second implementation, all the variants that have been added to the data sources lack of the required metadata. Once again this adds uncertainty about its validty and increases the effort required to verify them.

The reasons why these new variants cannot be fully processed are:

- The variants do not have clinical significance: this happens when the variants come only from the GWAS Catalog database or from Ensembl. These databases do not provide such information that is very important to discard those variants that are proved to be benign for the development of the disease, or present some type of conflict in the interpretation (one study considers the variant as pathogenic and another one considers the variant as benign). If these variants are not stored in the ClinVar database, which provides the clinical significance, the solution is to head to the associated bibliography to try to infer if they are associated with a higher risk or a lower risk of suffering the disease. It is easy to understand how time consuming this task is when the number of articles to be handled is considerable. In addition, this underlines the importance of the source used to extract the information.
- The variants have the clinical significance but they do not have the statistical information about the associated studies: the required information comes from the GWAS database but in this case, all the variants come from ClinVar and Ensembl, that do not provide such data. Once again, the solution is to head to the associated literature and find the data in the article, which can be very laborious.

The logical solution to guarantee the automation of the process is consider only those variants that are stored in the three databases. Nevertheless, this is a risky solution. As can be seen in Fig. 6, the variants are scattered in different databases and only joining all of them we can assure that all the available information is going to be taken into account. So, is there any other information that could be used to discard the variants that have less probability of being relevant?

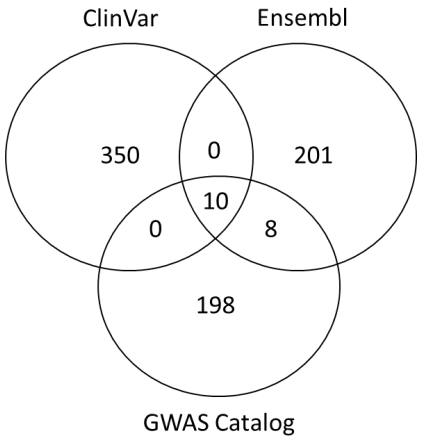


Fig. 6. Number of variants common among databases.

These limitations are known by the scientific community, that tries to provide alternative solutions to mitigate their effect. Nevertheless, these solutions can cause more confusion than help.

D. Alternatives to assess the impact of a DNA variant

There are some tools that help to predict the effect of a variant in the function of the protein. Two well-known tools are SIFT and Polyphen 2:

- PolyPhen-2 is a tool that predicts possible impact of an amino acid substitution on the structure and function of a human protein using straightforward physical and comparative considerations. A variation is classified as benign, possibly damaging, or probably damaging with a score ranging from 0 to 1.
- SIFT predicts whether an amino acid substitution affects protein function based on sequence homology and the physical properties of amino acids. The score ranges from 0 to 1 and is predicted as deleterious if the score is <0.05, and tolerated if the score is ≥ 0.05

Even when these tools are used by the scientific community to have a clue about the effect of a DNA variant prior to the development of a study over a population, there are controversy in the reliability of the results. For example, the variant

rs869025341 is classified as Pathogenic in ClinVar (based on clinical studies), but PolyPhen-2 classifies the variant as probably damaging (there is no clear damaging effect) and SIFT considers the variant as tolerated (benign). Another example is the variant rs28933401 that ClinVar considers as pathogenic and PolyPhen considers as benign. This means that these tools are far from being adequate to provide the clues we are looking for.

Another calculated information is the type of change according to the affected DNA element. Ensembl uses a rule-based approach to predict the effects that each variant may has on the DNA element that codifies the protein. The terms have a degree of severity mapped as an Impact Rating (High, Moderate, Low and Modifier).

- High: The variant is assumed to have a high (disruptive) impact in the protein, probably causing protein truncation, loss of function or triggering nonsense mediated decay.
- Moderate: A non-disruptive variant that might change protein effectiveness.
- Low: Assumed to be mostly harmless or unlikely to change protein behavior.
- Modifier: Usually non-coding variants or variants affecting non-coding genes, where predictions are difficult or there is no evidence of impact.

As with previous tools, the type of change could lead to wrong decisions. For example, it is significant that one of the variants selected as relevant in the first implementation would be discarded using this criterion (rs2651899) due to the variant is classified as Modifier.

As none of the available solutions are useful for our purposes, the only option is to head to the literature and extract the information directly from the articles. This is not a efficient solution and it is logical to think that the problem is going to get worse as genomic research evolves. But, how determinant is the information extracted about these variants. Does the results worth the effort? Is the number of relevant DNA variants changing after manually extracting the information? or, is the same and thus we only have to wait for the DNA variants to be available in all the databases? What if this never happens? The impact of these results is under study and will determine the importance of investing resources and effort in the development of text mining algorithms that improve the information system that support the process.

IV. Conclusions and Future Work

Considering the results obtained, there is a need for information systems capable of managing the information and that, far from integrating and storing huge volumes of data, can support the decision-making process by providing mechanisms agile and flexible enough that can adapt to the changing user needs.

In the genomic domain, infoxication is derived not only from the huge amount of data generated but from the lack of ontological agreements in so critical terms such as the name of the disease. Following this direction, some ontologies have been proposed (e.g. Disease Ontology, Human Phenotype Ontology and UMNS) but even among them there are discrepancies in the classification of the phenotypes. Information systems must be able to manage these underlaying terminology to guide the experts in the search of relevant information associated to the search term used.

Another problem is the volatility of the information. As has been seen, not only new information is added but also discarded, which adds a level of uncertainty that leads to confusion. Furthermore, the metadata provided by the genomic repositories is not enough to make proper decisions. The increasing amount of unreviewed, redundant and contradictory information only exacerbates the problem. The Information systems must be able to provide as many clues as possible and at the same time, reduce the noise as much as possible. Following this approach, machine learning techniques as well as text mining algorithms are a good option only if they help to ensure that only the required information is shown at every stage of the process.

The SILE method in conjunction with an information system have been proved to be a useful approach to manage smart data and deal with the infoxication issue by providing support to the selection of the adequate repositories, the identification of relevant data as well as its storage and further analysis. Nevertheless, the effects of infoxication adds limitations to the automation of the entire process. For example, what should we do with those DNA variants that cannot be fully assessed? Reading the associated literature should be the last option and thus, we are working on the improvement of the method in two levels: i) the identification of new situations that could hinder the process by applying it in different case studies and ii) the study of how to take advantage of the existing predictive tools and available data to help the researchers to make the most adequate decision under each circumstance.

Our final aim is to take advantage of all the genomic data that is currently waiting to be managed in the data silos and stop considering Big Data as a challenge in the genomic domain.

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GDPR Compliance in the Design of the INFORM e-Learning Platform: a Case Study

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***Abstract*—The European Union General Data Protection Regulation (GDPR) governs personal data processing, aiming to ensure privacy in all systems handling such data. All systems that process personal data, including software systems are legally obliged to comply to all articles of the GDPR applicable to them. In this paper, the case study of an e-Learning software platform, namely the INFORM platform and its compliance to relevant articles of the GDPR is presented. The e-Learning platform was developed with the objective to host the educational material developed under the JUSTICE EU-funded project INFORM, targeting judiciary, court staff and legal practitioners, in order to provide free and open distance access to the content. In particular, the paper demonstrates the compliance of the platform with the articles and principles of: Data Minimisation, Lawfulness of Processing, Right to Erasure, Right of Access, Right to Data Portability, Right to Rectification and Security of Processing. By applying these articles, conformance to the provision for Data Protection by design is also achieved; the platform's software development process integrates the articles of the GDPR early in the development steps, from the specification and design phases. We show how the design process progressed and demonstrate the corresponding functionality within the e-Learning platform. The paper extracts a list of lessons learned and conclusions on software GDPR compliance.**

***Index Terms*—Privacy by Design, e-Learning, Case Study, GDPR**

I. Introduction

Personal data privacy protection in information systems is crucial in our era due to the widespread use of mobile, distributed and web applications that store and process personal data of an increasingly large number of users, in order to provide context-aware and personalized services. This need is reflected in the new EU regulation, the General Data Protection Regulation (GDPR) [1], applied since 25 May 2018 not only to organizations established in the EU but also to non-EU organizations that store and process personal data[1] of EU residents. GDPR defines several articles that can be mapped to software functionality and thus, from now on, all new systems need to incorporate such functionality. Furthermore, existing systems should be adapted in order to conform to these provisions.

e-Learning platforms store and process personal information of registered users and may also utilize this information to adapt to the needs of each user providing a personalized user experience [2], [3]. As all other systems incorporating user-management environments, such platforms need to be designed and developed in a way that will lead to their conformance to the data protection regulation and the emerging privacy needs.

However, it is still not clear how the GDPR articles can be precisely reflected in software systems and few works have addressed GDPR compliance. In this paper, we discuss certain GDPR provisions in regards to software and specifically in web environments in an attempt to draft guidelines towards GDPR compliance and personal data privacy protection. We examine the application of our analysis for the design and the development of an actual e-Learning platform, the INFORM Platform, a platform aimed to host and provide access to the content elaborated under the JUSTICE EU-funded project INFORM: *"INtroduction of the data protection reFORM to the judicial system"*. Similar mechanisms can be integrated in any system that includes a user-management module.

This is a first step towards integrating GDPR principles in the system design of some common software features. For many designers and developers these guidelines may be evident, as they may be already applying privacy requirements without being aware that they are essentially applying GDPR provisions. Hence, the objective of this paper is to demonstrate to designers and developers how we embedded some of the GDPR articles into the design of an e-Learning platform in an attempt towards compliance. In the case of experienced developers who have already been designing and integrating such features, our aim is to enable them to understand which of these features should be integrated in order to achieve compliance to GDPR provisions. For those who have no prior experience, our aim is to make them aware of GDPR provisions and their possible application. To the best of our knowledge, this is the first attempt towards mapping GDPR provisions to functionality related to user management in a software system presented from a more practical perspective.

[1]Personal Data is any information relating to an identified or identifiable natural person ('data subject')

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The rest of the paper is structured as follows. Section II presents previous works in the area whereas Section III introduces the GDPR articles we are focusing on. The objectives, the specifications, the design and some details about the implementation of the INFORM platform are presented in Section IV. Section V maps the GDPR articles under consideration to the way they were handled in the INFORM platform giving a view into implementation. Lessons learnt are summarized in Section VI, and, finally, Section VII concludes the paper. An appendix to the paper presents all GDPR articles.

II. Related Work

Information Privacy has been an issue of consideration and discussion for many years. The most widely used taxonomy for privacy based on potential privacy violations has been provided by Solove [4]. The link between the taxonomy of Solove and technology has been performed in [5], where the authors try to relate it with technology and refer to the terms of *data holder* and *data subject*. Privacy in the Internet Age in a more social context is discussed in [6] focusing on philosophical, political, and economic aspects of privacy.

Users' concerns about the privacy of their personal data while using context aware mobile applications are discussed in [7]. Such concerns have been addressed in various previous works that introduce specific mechanisms for protecting user privacy in different domains, e.g., in web applications, so that users define their privacy preferences for HTML5 applications that are adapted accordingly [8], or for reconciling developers' revenue and user privacy, e.g., in mobile applications in the form of a feedback control loop that adjusts the level of privacy protection on mobile phones [9].

A pattern catalog in order to help privacy regulation integration in organizations for systems comprised of business methods, human interaction and software is discussed in [10]. Another work discusses GDPR in the framework of socio-technical systems [11]. The authors also define a goal-based modeling language that can be used to model social aspects of the GDPR, including the relationship between data subjects, employer and employees.

GDPR's provisions for consent withdrawal and the right to forget are discussed in [12]. Privacy by design towards Data Minimisation is discussed in [13]. Privacy Design Strategies towards Privacy by Design are discussed in [14]. In [15], the use of static analysis to assist GDPR compliance of software systems is presented, whereas ENISA[2] has introduced a tool to assess Privacy Enhancing Technologies [16]. A more technical approach can be found in CARiSMA that focuses on model-based security analysis of IT systems [17]. This work has been motivated by the Article 25 of Regulation (EU) 2016/679 that concerns the protection of natural persons with regard to the processing of personal data. A use case on birth certificate registration in Municipality of Athens using the tool is presented. A model-based security engineering framework for supporting the system design based on BPMN (Business Process Model and Notation) and UML (Unified Modeling Language) is introduced in [18]. A case study of an Air Traffic Management system was used. An extension to BPMN 2.0 business process modeling language is also proposed in [19] with the aim of detecting conflicts between security and data-minimization requirements [19].

In relevance to related work, we do not offer a new management approach, but present our insight from the design of the INFORM platform considering GDPR compliance from the initial development stages. Listing and explaining how GDPR aspects are handled in a specific system design is an aspect that is missing from previous works.

III. GDPR Analysis Towards Software Compliance

Since GDPR was published in the Official Journal of the EU in May 2016, it became a subject of consideration and analysis for many disciplines. Many existing studies analyse GDPR, e.g., the work in [20] discusses the regulation principles and compares them to the principles of the previous directive. In [21], a complete analysis of all the provisions of the GDPR is presented, comparing them with previous legislation and providing notes and explanation on the new provisions impact. The Isle of Man Information Commissioner provided a series of guides about the GDPR, such as [22], explaining the Principle of Transparency and the [23] that explains the whole set of principles.

Only a number of GDPR Articles are applicable to Software Systems, and thus in this section we are displaying the analysis we conducted on them, in order to extract conclusion for the needed corresponding functionality in software systems and specifically in the context of an e-Learning platform. We will focus on analyzing this set of provisions specifically in relation to designing and implementing the software system. All other Articles are described in the Appendix in order to document our choice, by explaining what are the rest of the Articles about. Additionally, Article 32 *"Security of processing"*, defining that *"appropriate technical and organisational measures to ensure a level of security appropriate to the risk"* should be taken, will be explained in the context of the platform's design and implementation phases.

A. Data Minimisation

Data Minimisation is one of the principles related to the processing of personal data defined in Article 5 of the GDPR, stating that only personal data relevant and necessary for the processing purposes of each specific system should be asked, collected or in any way processed, except if the user *chooses* to provide more personal data.

This can be reflected in the framework of a web platform handling user data by separating the user profile fields in two subsets: mandatory fields and optional fields. For registering a user and for any subsequent actions, only fields declared as absolutely necessary for the processing purposes of the specific platform should be asked and stored in the system. Additional personal data (e.g., data that might be considered useful for providing a better user experience) should not be requested or

[2]https://www.enisa.europa.eu/

obtained from the user as obligatory. Instead, a user's profile may contain many more fields to be completed as optional ones and their completion will depend upon the user's own will to share the associated data. If the user decides to leave the optional fields empty, this will not block him from using the platform's functionality.

B. Lawfulness of Processing

Lawfulness of Processing is defined in Article 6, providing six potential lawful bases for processing. All systems should declare one of them to be their basis, in order to be able to proceed with storing or processing any personal data. We will be examining the cases of (i) **providing consent** defined in Article 6(1a) as *"the data subject has given consent to the processing of his or her personal data for one or more specific purposes"* and in Article 7, and of (ii) **performance of a contract** defined in Article 6(1b) as *"processing is necessary for the performance of a contract to which the data subject is party or in order to take steps at the request of the data subject prior to entering into a contract"*. The above lawful bases implies that before any storing or processing of personal data occurs, the associated user should provide her consent freely and clearly, or confirm her intention to enter in a contract with the system, i.e., accept to provide the necessary data in order to receive specific services. Both should be evidently provided by their own will, not being at any way deceived e.g. by an already filled-in consent form or confirmation check box. Additionally, both should be provided based on the processing purposes of the platform described in the privacy policy and the terms of use. The notion of *purpose* constitutes a central notion of the GDPR, describing which personal data will be used for which purposes by which entities. This policy should be consisting of a precise and easy to understand, human-readable text, in order for the users to be able to fully comprehend its content before accepting it.

Most web platforms interacting with users should apply, depending on their functionality, either consent or performance of a contract, or both. For example, an e-store providing services and goods to a customer will be functioning on the lawful basis of performance on a contract and it can reflect this provision by not accepting or proceeding with any user's order unless confirmation was provided by the user for her acceptance of providing personal data in order to fulfill the requested services purpose, i.e., in this case, deliver the order. In contrast, if the e-store needs to ask users if they accept to keep their data stored for example for the purpose of informing them about offers, then a relevant consent from them will be additionally required.

C. Right to Erasure

Right to Erasure is defined in Article 17, as *"The data subject shall have the right to obtain from the controller the erasure of personal data concerning him or her without undue delay and the controller shall have the obligation to erase personal data"*. This right can be applied under different grounds.

A software system interacting with users should be able to provide each user with the option to be able at any given time to stop existing as a user of the platform, and to be able to withdraw his or her consent along with all of the personal data that by that time were stored and processed. Furthermore, after instructing a delete action no more personal data of the specific user should be able to be received or in any way processed, unless the user re-provides her consent or confirmation following the Lawfulness of Processing principle as explained in 3.B.

The Right to Erasure requires that all personal data will be removed from the system's database, unless some data is properly anonymised, thus no longer relating to an individual or being able to identify the previously associated person from that data, setting the storage and processing on those data outside the scope of the GDPR as explained in Recital 26 *"Not applicable to anonymous data"*.

D. Right of Access and Right to Data Portability

The Right of Access by the data subject is defined in Article 15 of the GDPR declaring that an individual should be able to obtain a confirmation from a system as to whether or not personal data concerning this person are being processed and, if they are, then the user should be able to obtain access to that data and to the additional information described in 15(a)-15(h). The Right to Data Portability is defined in Article 20 stating that a data subject should be able to obtain all of her own personal data processed in the system *"in a structured, commonly used and machine-readable format"* and that she have *"the right to transmit those data to another controller"*. Concerning a software system, a user that has her personal data stored and processed by that system should be able to easily ask for access to all of these data and with no undue delay the user should receive a packet, e.g., a compressed folder or a document, containing all the information related to her. It is important, that the user gets authenticated before receiving the information. The additional information defined in the Right of Access is considered static, or a mixture of static and dynamic information already known before the subject requests access and can be included in the same packet, or be published in a part of the system, where all users can read it e.g. in the Privacy Policy.

E. Right to Rectification

The Right to Rectification is defined in the GDPR in Article 16 stating that a data subject[3] should be able to require and obtain the rectification of inaccurate personal data or the completion of incomplete personal data. A software system handling user profiles and storing their personal data should provide users with the option to edit all of their personal data, either by providing new values to replace the previous ones, by adding values where no data was previously given e.g. in an optional field, or by removing values out of such fields.

[3]Data subject is any person whose personal data is being collected, held or processed by an organization.

Any changes done should be directly, or without undue delay, applied and presented.

F. Data Protection by Design

The Principle of Data Protection by Design and by Default defined in Article 25 of the GDPR, determines that *"the controller shall, both at the time of the determination of the means for processing and at the time of the processing itself, implement appropriate technical and organizational measures...in order to meet the requirements of this Regulation and protect the rights of data subjects"*. Privacy by Design was referred in [24] suggesting that *"Privacy by design is characterized by proactive rather than reactive measures"*, demonstrating a need for embedding compliance from the first steps of a software development, i.e., from the requirements phase, and a continuation of the efforts throughout the whole software engineering procedure. Following a traditional software engineering development methodology, during the requirements analysis phase, specially elaborated specifications should be drafted in order to describe GDPR necessary functions additionally to the actual software's requirements. Specifications should be reflected in the model created at the design phase, and implemented as functionality in the implementation step, whereas all GDPR-relevant aspects need to be verified and validated.

IV. The INFORM Platform

The INFORM Platform is a web platform for open and distance e-Learning, aimed to host and provide access to the content elaborated under the JUSTICE EU funded project INFORM[4]: *"INtroduction of the data protection reFORM to the judicial system"*. The platform includes functionality open to all users, namely a news blog, as well as additional functionality requiring users to be registered and logged in, in order to have access to it.

By incorporating user registration, it is also required to have a user management mechanism in order to create user accounts and profiles, store and process their personal information, authenticate them, and allow them to use the respective functionality. Functionality that is available only to registered users includes mechanisms for viewing a directory and the profiles of all platform users, as well as having access to all e-Learning material available on the platform including reading tutorials and interactive self assessments.

The material included in the specific platform is comprised of legal e-manuals and content related to the new data protection regulation, regarding the judicial system aimed towards three main target groups: Legal Practitioners, Judiciary and Court Staff. We do not provide more detail on the types of material available via the platform, as it does not affect the functionality we are focusing on in the context of this work. In the rest of the section we discuss the Specifications, Design and Implementation Phases of the platform.

[4]http://informproject.eu

TABLE I
INFORM Platform Specifications

	Specification	Type
(1)	User Registration	Project Requirement
(2)	User Login	Project Requirement
(3)	Password Reset	Project Requirement
(4)	Self-assessment	Project Requirement
(5)	Users' Directory	Project Requirement
(6)	Search for Users	Project Requirement
(7)	View User Profile	Project Requirement
(8)	Blog	Project Requirement
(9)	Access / Download Material	Project Requirement
(10)	Display Privacy Policy	Lawfulness of Processing
(11)	Edit User Profile	Right to Rectification
(12)	Edit User Account Information	Right to Rectification
(13)	Delete User Account	Right to Erasure
(14)	Access own personal data	Right to Access
(15)	Move own personal data	Right to Portability
(16)	Cookies Acceptance/Rejection	Data Min. / Consent

A. Platform Specifications

A basic definition of the required functionality of the platform was described during the proposal stage of the project in the respective document. Thus, during the specifications step, requirements were extracted from the document at first. Additionally, a specially elaborated questionnaire was prepared and distributed to the project's consortium members in order to precisely define a complete set of **project-based requirements**. The responses were gathered and analyzed in order to prepare the System Requirements Specification Document (SRS). The SRS was then enhanced with **GDPR-based required functionality**, extracted from our previous analysis on the GDPR articles and from the Privacy Policy of the platform.

The Privacy Policy[5] was custom drafted by the Law and Internet Foundation legal team, in Sofia, Bulgaria [25]. The policy defines the purposes and the processing of personal data by the e-Learning platform in compliance to the GDPR. It specifically states the Privacy by Design principle. The conformance to the Data Minimisation Article also defines and justifies the minimal data required for the platform to provide a user with a complete functional user experience. The policy explicitly states the purposes of processing and storing personal data in the platform in order for processing to be considered lawful. The erasure strategy and the anonymization strategy of certain data are also defined in the Privacy Policy. Finally, the Privacy Policy lists the Rights of the User in full compliance with the GDPR. These rights include the Right of Access, the Right of Rectification, the Right to Erasure, the Right to Withdraw Consent, etc.

In Table I, we list the software requirements based on: (1) the project specifications as determined by the application document and by the responses gathered from the questionnaires (rows 1-9), and (2), the additional requirements added because of the need for compliance to the articles of GDPR and the Privacy Policy (rows 10-16). Additionally, the principle of

[5]https://www.elearning-informproject.eu/data-processing/

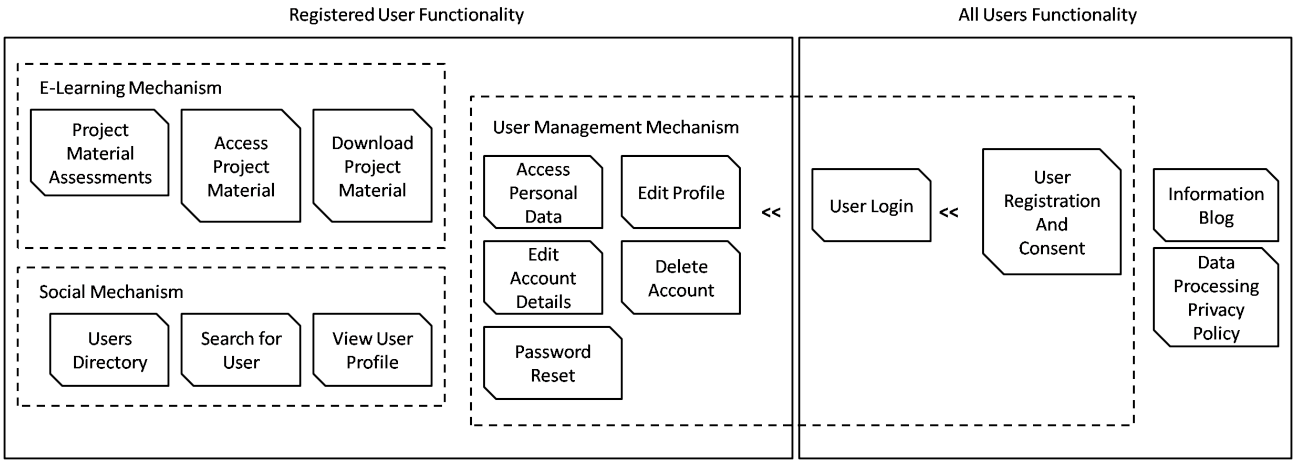


Fig. 1. INFORM Platform Architecture

"Data Minimisation" should be incorporated in all platform's functionality.

B. Platform Design

Architecture. In Figure 1, the architecture of the INFORM platform system is demonstrated. The diagram presents all the functionality of the platform including functionality available to all users, either *visitors* (users that are not logged in) or *registered users* (logged in), and functionality available *only to registered users*. In both sets, common web platform features are incorporated, such as the Information Blog. Further to that, a User Management System is embedded in the architecture in order to hold and manage the accounts of the registered users. In that part of the system, the following GDPR-related modules were added: *Access of Personal Data* (also representing Portability), *Editing of Account Details*, *Editing of Profile*, *Deletion of Account*, and *Consent* (or Confirmation) along with the *User Registration form*. Additionally, the *Data Processing Privacy Policy* is presented as a separate module, easily accessed by any user. In Figures 2 and 3 we use sequence diagrams to present the desired personal data flow from the user towards the platform data management functionality and the database, concerning the GDPR related provisions already discussed. The figures demonstrate the data flow concerning Data Minimisation, Lawfulness of Processing, Right to Rectification, Right to Erasure, Right to Access (and thus Right to Data Portability). Let us note that the User Profile User Interface (UI) entity represents the set of pages related to user information input, update or access.

In Figure 2, the flow is initiated by the User sending a set of data or a request towards the system. We first observe the data flow related to the registration of a new user: the user entity sends the minimal personal data set required along with his/her confirmation for acceptance of the processing towards the registration functionality. The data flow then proceeds towards the User Profile UI, and the Database, which in turn sends the set of profile data back to the User Profile UI. Subsequently, we observe the data flow related to editing the user profile. The user is sending new personal data directly to the User Profile UI, which then forwards them to the Database. A flow from the Database to the User Profile UI and from the User Profile UI to the User acknowledges the rectification. The third data flow sequence in Figure 2 presents the case where the user sends a delete request to the User Profile UI, which forwards it to the Database. The Database continues to send an Acknowledgment directly to the User. In Figure 3, the data flow related to accessing personal data of a user is displayed. The same flow represents both the cases of accessing or moving personal data. The user sends his/her request via email towards the platform admin, who then sends a request to the Personal Data Reporting functionality. The functionality then forwards the request to the Database and receives the data. It then forwards the report created with the data to the admin of the platform, who must then find a way to communicate them to the user, in a non automatic way.

Selected Tools. The Wordpress Content Management System (CMS) was selected to function as the basic core in the development of the INFORM e-Learning platform. The specific CMS was selected because of its user-friendly interface, the multiple responsive themes offered, the numerous available plugins and, most importantly, the possibilities provided by the fact that the CMS is open source: to add functionality on top of it with own coded plugins, or by customising its own code. Additionally, Wordpress sets the foundations necessary for security measures in a web platform. Lately, Wordpress has taken some measures towards GDPR compliance[6]. Nevertheless, the underlying Wordpress CMS implementation and the available plugins are not guaranteed to be GDPR compliant. A form of GDPR compliance for the INFORM platform is based on the assumption of trusting that the plugins of a popular and well maintained CMS, such as Wordpress, do not do anything more than their advertised specification. According to W3Techs[7], Wordpress is used by 33.1% of all websites,

[6]www.wordpress.org/news/2018/05/wordpress-4-9-6-privacy-and-maintenance-release/
[7]https://w3techs.com/technologies/details/cm-wordpress/all/all

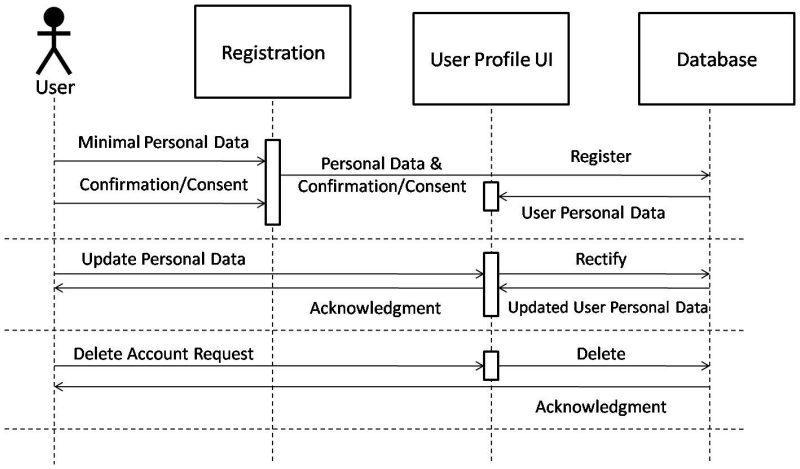


Fig. 2. INFORM Platform Sequence Diagram: GDPR-compliant Register, Rectify, and Delete

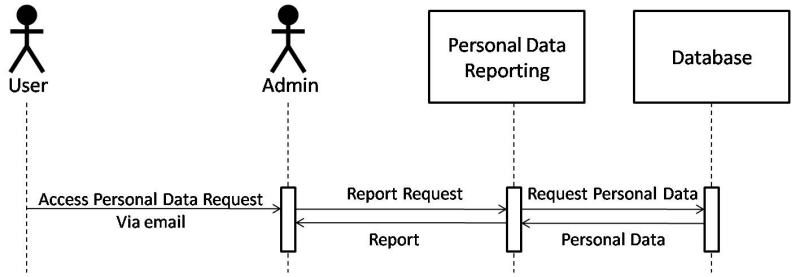


Fig. 3. INFORM Platform Sequence Diagram: GDPR-compliant Access and Portability

nowadays. Wordpress has been also studied a lot in scientific research, e.g., [26].

At this point, a study of the existing state of the art was conducted in order to identify available plugins implementing the required specifications drafted in the previous phase, namely project requirements and GDPR provisions, into Wordpress based platforms. Table II shows the above mentioned research results: in the first column the associated project requirement or GDPR associated functionality is noted and in the second column plugins identified as able and appropriate to cover that requirement are listed. Furthermore, in the second column we demonstrate additionally which functionality is covered by Wordpress itself, as from version 4.9.6. For demonstration purposes, some specifications were grouped, e.g., User Login, User Registration, and Password Reset are named as User Management Specifications. Similarly, User Directory, Search for Users, and View User Profile are named as Users Directory Specifications. Additionally, during the research, the plugins' code were examined to locate the points where the execution of the promised functionality is implemented, along with data offered from the Wordpress Plugins Directory, such as the number of active installations, the last update date, the compatible Wordpress version and the reviews. All above parameters were taken into account when deciding on the plugins to be used.

The Ultimate Member plugin was then selected to be used as the main plugin of the platform, due to the user management functionality it offers covering the main specifications, but also covering some of the GDPR requirements, namely "Edit User Profile", "Edit User Account Information" and "Delete User Account". The latter requirement is also covered by Wordpress in its latest updated version, with the difference that the plain Wordpress procedure is semi-automated: an admin has to manually request the deletion of a user by referring to his/her email address. Ultimate member plugin covers this requirement automatically, by allowing the user to select the "Delete" button in his/her account options. All specifications covered sufficiently by Wordpress and Ultimate Member plugin was decided to be exploited that way. Access to own Personal Data and Data Portability are included in the Wordpress new updated version. Providing and Withdrawing consent is implied by filling-in or emptying the optional fields, respectively. An independent plugin is needed in order to control cookies preferences, as Wordpress stores cookies for logged-in users[8].

C. Platform Implementation

As already described, the Wordpress CMS was used for the basis of our implementation, on which we have built by the addition of existing plugins and the creation of our own coded plugins for implementing all desirable functionality. Using

[8]https://codex.wordpress.org/WordPress_Cookies

TABLE II
STATE OF THE ART

Specification	Wordpress Plugin Name	Resource
User Management Specifications	(1) Ultimate Member Plugin by Ultimate Member Ltd et al.	https://ultimatemember.com/
Edit User Profile/Account	(1) GDPR by Trew Knowledge[1], (2) Ultimate Member Plugin	https://trewknowledge.com/[1]
User Directory Specifications	(1) Ultimate Member Plugin	
Self-assessment	* No suitable plugin	
Access / Download Material	* Wordpress Basic Core by Wordpress	https://wordpress.org/
Blog	* Wordpress Basic Core	
Privacy Policy	(1) Wordpress Updated Version, (2) GDPR	
Anonymize User Posts Information	* Wordpress Basic Core	
Delete User Account	(1) WP GDPR Compliance by Vans Ons[2], (2) GDPR (3) Wordpress updated version, (4) Ultimate Member Plugin	https://www.van-ons.nl/[2]
Access / Move own personal data	(1) GDPR, (2) Wordpress Updated Version	
Cookies Preferences	(1) GDPR, (2) WP GDPR Compliance	
Track Data Flow	(1) GDPR	

the basic Wordpress services we implemented the "Access and Download Material" functionality, the "Privacy Policy" page, the "Information Blog", as well as the "Export Data" functionality.

Furthermore, as decided during the design phase, the Ultimate Member plugin was embedded. All the User Management functionality, the Edit of User Profile and Account Information, the User Directory functionality, and the Delete User Account functionality were enabled and structured through the plugin. Our own coded plugins for the Self-assessments were developed using web technologies, i.e., HTML, PHP and JavaScript. At this point, where most of the desired functionality was already covered we identified a gap: The "Cookies Preferences" functionality. The GDPR plugin by Trew Knowledge[9], was selected for this feature. Using this plugin users can opt in or out of cookies that are being used on the site including Cookies that will be always active or required for the site to function and Cookies that can be activated or blocked based on the user preferences.

The same plugin provides the Telemetry Tracker functionality. This feature displays all data that is being sent outside of the platform's server to any other destination, indicating additionally the plugin or theme responsible, the file and line where the data is being sent, as some plugins can gather data and send them to outside servers. At this point, this is not needed in our platform, having installed only basic versions of plugins, as WordPress Plugin Repository does not allow plugins to do that, as long as they are not in a premium version. According to the Wordpress Plugins Directory guidelines[10] *"A stable version of a plugin must be available from its WordPress Plugin Directory page"*, meaning the basic free and open versions.

Regarding security, some measures additional to those implemented by Wordpress were taken, e.g., an SSL Certificate was purchased and added on the platform's domain for employing HTTPS instead of HTTP, i.e., the secure version of HTTP.

[9]https://wordpress.org/plugins/gdpr/

[10]https://developer.wordpress.org/plugins/wordpress-org/detailed-plugin-guidelines/

V. GDPR PROVISIONS IN THE IMPLEMENTATION OF THE INFORM PLATFORM

In this section we show the previously discussed GDPR articles in practice describing how they have been integrated into the e-Learning environment of the INFORM Platform. Please note that the Data Protection Privacy Policy of the INFORM platform is publicly available for any user to access through the interface of the platform.

A. Data Minimisation

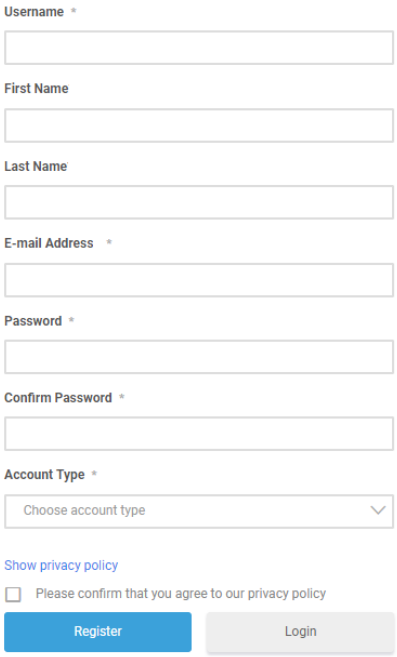
The INFORM platform complies to the Data Minimisation Article, which is applied by asking a user to willingly provide only the necessary personal data required for the purposes and the functionality of the e-Learning platform. These personal data are provided during user registration and are the following: i) username; ii) e-mail address; iii) password; and iv) account type. Username and password are absolutely necessary to enable the log in function of a user into the member's area of the platform. E-mail address is used to confirm the user's identity, necessary to complete registration. Account type, which is considered part of personal data because it declares a property of the user, is also necessary since it enables specific functions based on the user profile. Finally, first and last name can be given as optional information in order to offer better user experience, but not being obligatory thus conforming to Data Minimisation. Figure 4 shows the mandatory fields that request minimal data and are required to be filled for the purpose of registration along with the optional registration fields.

Beyond data minimisation, a user may optionally and willingly provide additional personal information for the purpose of a complete e-Learning profile. This information contains data, such as spoken languages, current organisation, education, biography, etc. There is no mechanism to store additional data (e.g. concerning the user session). Every user can also utilize the functionality available for visitors without providing any personal data. The purpose of storing and processing any of the aforementioned user data is described in the Privacy Policy of the INFORM platform.

TABLE III
MAPPING OF GDPR ARTICLES TO E-LEARNING PLATFORM FEATURES

GDPR Article	INFORM Platform Feature
Data Protection by Design - Article 25(1)	Privacy requirements detailed in system specification
Data Minimisation - Article 5	Minimal required fields for user input and data (e.g. user registration)
Lawfulness of Processing - Article 6	Asking and receiving user consent
Right to Erasure - Article 17	Delete user profile in database and relevant logs
Right to Access of Data - Article 15	Data retrieval and report creation upon user demand
Right to Rectification - Article 16	Profile updated by the user

Fig. 4. Minimum Required Fields in Registration



B. Lawfulness of Processing

As explained in the Privacy Policy, during the registration procedure, a user is considered to be taking steps towards entering a contract in order to benefit from the free provided services. These services are accessed from the e-Learning platform with all of its content and features. The INFORM platform complies to the Article of Lawfulness of Processing by requesting from the user to confirm her acceptance of storing and processing her personal data, in order to be able to use the platform's provided services, thus complying to the lawful basis of performance of a contract. The lawful basis establishment is deployed during the registration of a user to the INFORM platform; a user willingly fills the registration form with the personal data and moreover, the user is obliged to tick a check box declaring the user's acceptance for these data to be stored by the platform and processed as described in the Data Processing Privacy Policy of the INFORM platform. The Data Processing Privacy Policy is enunciated in clear, detailed, and precise human-readable text, and it describes all purposes and corresponding processing the personal data might undergo. If all personal data fields are filled properly and a confirmation is provided by the user by checking the relevant check-box, then by clicking on the registration button the data are stored. The specifications of the INFORM platform ensure that these data will by all means be processed following the Data Protection Privacy Policy. If the user never clicks on the registration button, then the personal data are discarded and they are never stored or processed. The registration form is depicted in Figure 4.

Additionally, when a user fills in the optional information of the registration form of the user profile, then it is considered that she is concurrently giving consent for their storage and processing as defined in the Privacy Policy. Let us note that consent is supported by providing users with the option to delete the optional data at any time. Furthermore, users are aware that their profiles, including the optional information, will be visible to other users, as this is clearly stated in the privacy policy.

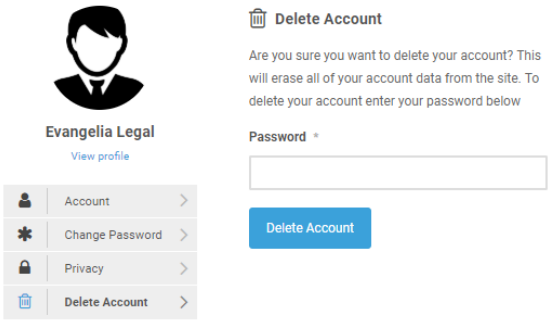
C. Right to Erasure

The Right to Erasure was integrated into the platform by providing the user with an option to delete her account at any given time, as explained in the Privacy Policy. When the Delete Account option is selected, the users are informed that their data will be deleted, and are called to confirm their identity by re-entering their password, as displayed in Figure 5. In order for the "Delete Account" functionality to be offered to the users, the Delete Tab should be enabled by the admin through the Ultimate Member plugin settings, and set to appear in users' account page. After a successful authorisation, the system proceeds with executing a set of database queries on all the relevant database tables, finding and deleting all the stored personal data associated with the specific user. No personal data should be kept after this procedure, unless their processing is for any reason subject to an exception rule, e.g., they are used for the public interest. The process for the erasure of data is described in detail in the data processing privacy policy.

Additionally, our own coded plugins are storing a set of Personal Data for each user, i.e. the text responses given to certain questions in the assessments, in one common database table for all three plugins. Thus, the "Delete Profile" functionality needs to be propagated to our own coded functionality triggering the deletion of any such set of data related to the specific user to be erased. To achieve this, the actual addition of code was done inside the Ultimate Member plugin functionality, where a delete query for the assessments responses

database table was written, in continuation to all other delete queries existing.

Fig. 5. Delete User Account option



D. Right to Access of Data and Right to Data Portability

Access to data provided by Wordpress allows users to export ZIP files containing their personal data, using data gathered by Wordpress and participating plugins. This is included by default in the "Tools" Side Menu, under the "Export Personal Data" option. A Double opt-in confirmation email system is added in this functionality for ensuring privacy protection. In the INFORM platform, a user may directly access a subset of her personal data, namely her profile personal data, stored in the system through the user profile page. However, other personal data are only accessible after a corresponding demand has been performed by the user. The INFORM platform is enabling the semi-automatic process offered by Wordpress for the user to access her personal data. As described in the Data Processing Privacy Policy, a user is required to contact the platform administration team via a specific e-mail format provided by the platform. In the email, the user must clearly state her demand for access, receive a confirmation for her personal data stored in the system, and, furthermore, receive the actual personal data. The administrators are then required to verify the user's identity, through the user's email, and use an automated administrator functionality to extract all the user personal data stored in the platform's database. The personal data are then compiled to a natural language report and are sent to the user. The automated procedure executes a set of database queries, based on the user identity to create the user personal data report.

Software systems with a larger user base are expected to have a complete automatic process, where upon request the process will verify the user, compile a report containing all the necessary personal user data and other information subject to the Right to Access of Data, and inform the user.

E. Right to Rectification

Right to Rectification is ensured by giving to all users the option to be able, at any given time, to edit their profile information as displayed in Figure 6, or to modify their account details as in Figure 7. This Right provides the user with the option to correct and update any information.

A user is able to edit all her personal data stored or asked except from the unique identifier credential, namely the user name. Specifically a user is able to give new values for her personal data information either the mandatory or the optional fields, to delete any previous given values leaving the field empty, for optional data, or complete data left in-completed by that time. Old information will be deleted, and the database tables will be updated with the new data through a set of database queries. All changes will be stored and presented to the user immediately. Similarly to the "Delete Account" functionality, for the "Edit Profile" functionality to be offered the Edit tab should be enabled by the admin on the Ultimate Member plugin settings.

F. Data Protection by Design

By integrating all above mentioned articles as explained, throughout the platform's software development process, from the specifications and design phases towards implementation of the system, conformance to the provision for Data Protection by design is also achieved.

Fig. 6. Edit User Profile Data

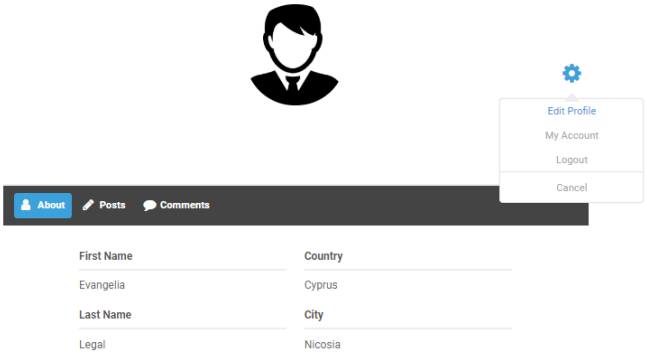
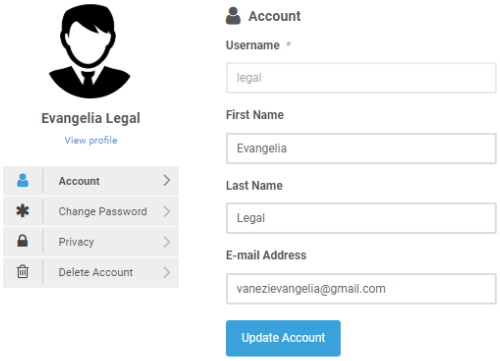


Fig. 7. Edit User Account Information



VI. Lessons Learned

The initial evaluation of the INFORM platform in terms of privacy protection and GDPR compliance has been performed with users in the University of Cyprus, in the Republic of Cyprus, in the framework of undergraduate and postgraduate courses, whereas exposure to the framework was provided to users during dedicated INFORM workshops. Future work will present evaluation results based on the exposure of the platform to a wider audience and external users. Based on the experience obtained via the implementation of the GDPR provisions for the INFORM platform, we summarize the main lessons learned that can be applied in the development of similar software systems:

1) Privacy and GDPR compliance should be considered throughout the whole software engineering process. It is not part of a single component but a required aspect of the system as a whole, serving also as an important quality attribute. In that respect, GDPR compliance planning should be initiated from the beginning of the system development and become part of relevant system functions. This is in essence captured in the Privacy by Design principle.
2) Receiving, storing and processing of any personal data of any user should only occur in the case the associated user willingly enters a contract or consents for the above mentioned, after being clearly informed about the respected processing purposes regarding her data. User consent is a requirement of GDPR, and for this reason it is important for provider to state their privacy policies clearly and in a user friendly manner.
3) Personal data required by the user as mandatory fields in order to use some of the platform's operations should be limited to minimum for fulfilling the described purposes, to which the user has consented or the services that the user entered into a contract in order to access them. Additional fields that may be useful but not essential, may be asked as optional fields. Communicating to the users that they will not be asked for more information than necessary is also important in that respect.
4) When a user needs to withdraw her consent or erase her account, this action should be easily initiated by the user and all data should be either deleted from the database and any other data stores or they should get anonymized, without any undue delay. It is important to provide to the user a way to perform this action via the system.
5) A user should be able, at any given time, to request to view the full set of personal data of her own that the software system is storing and in any way processing, and she should receive those data in a reasonable amount of time. A process needs to exist to support the above in all systems.
6) A user should be able to edit, change, fill or delete any information of those appearing in the user profile. For the mandatory information, the delete action should not apply. Changes should be immediately stored and presented.

Software GDPR compliance is eventually ensured when the code and the runtime environment that handles personal data is tested, verified/validated and eventually audited against the privacy policy requirements of the software. Implementations of platforms that are based on external modules need to provide guaranties of the GDPR compliance of these external modules. The GDPR compliance of the INFORM platform is based on a notion of trust that the plugins of a well-maintain and popular CMS, such as Wordpress, does exactly what their specification is describing.

VII. Conclusions

In this paper, we have presented a discussion and analysis of compliance with certain GDPR provisions towards the design and development of software systems. The under-study provisions have been applied in the framework of an e-Learning platform, namely the INFORM platform, that incorporates a user management mechanism and stores and processes personal data. We have presented the architectural diagram of the system showing the modules affected by privacy issues and GDPR. As an overall conclusion, we have introduced and presented a list of best practices deriving from our experience with the development of the GDPR compliance mechanisms. Let us note that, for more complex design decisions further investigation is required in order to examine and properly apply GDPR guidelines throughout the system architecture at both technical and design levels. Additionally, when a system is more complicated due to applying GDPR exceptions to the processing of data, such as collecting information for research purposes, then additional investigation should be done focused on the legal issues arising from this fact. As future work, we intend to expand on the compliance with more GDPR provisions, including regulation exceptions that complicate the functionality, introducing more elaborated mechanisms, whereas we intend to work on mechanisms that give users more freedom in the specification of their privacy policies, in relevance to service provider privacy policies.

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APPENDIX

A. The GDPR Articles.

GDPR [1] is comprised out of 99 articles. The articles omitted in the analysis of section III are presented in this appendix. An existing online analysis by Intersoft Consulting [27] was used as the basis for the following.

- Articles 1-4 describe the regulation itself and provide definitions of terms referred to in the rest of the regulation, such as *'personal data'*.
- Article 8 refers to offering services directly to a child, and is not applicable for the specific platform target groups. Furthermore, Articles 9-11 refer to processing of special categories of personal data, which are also not applicable in our case.
- Beyond "Data Minimisation", Article 5 defines many other Principles such as lawfulness, fairness and transparency, and purpose limitation all of which are applicable to Software Systems, though not through the implementation, but rather if the system indeed keeps the promises given in the Privacy Policy, e.g. not using the data of the user in any other hidden purpose out of the scopes of the actual functionality.
- Articles 12-14 define the information that should be provided to the data subject. We conform to these Articles by providing this information in the Privacy Policy text.
- Article 19 is out of the scope of our platform, as it discusses details about the case of having third party recipients of the personal data handled by the system.
- Article 21, defining the *"Right to object"*, is applicable only when the lawful basis for processing is based on the public interest, or in the legitimate interests of the controller, none of which is the case in our e-Learning platform.
- Article 22 discuss *"Automated individual decision-making, including profiling"* which is also not applicable in our case.
- Article 23 states that each Member State *"may restrict by way of a legislative measure the scope of the obligations and rights"*. We are also not considering this article and abide to the GDPR text.
- Article 24 and articles 26-31 describe the role and obligations of the Data Controller(s) and Data Processor(s) of a system, in a rather general context, such as their cooperation with the supervisory authority when needed. Data Controller and Processor in our system along with the needed information about them are defined in the Privacy Policy of the platform, in a textual form.
- Articles 33 and 34 state that in the case of a Data Breach, the Supervisory Authority and the data subjects affected should be notified without any undue delay. This provision cannot be taken care of while implementing a system but its only applicable in the case of an actual data breach.
- Article 35, titled *"Data protection impact assessment"*, states that *"the controller shall, prior to the processing, carry out an assessment of the impact of the envisaged processing operations on the protection of personal data"*, if *taking into account the nature, scope, context and purposes of the processing, is likely to result in a high risk to the rights and freedoms of natural persons*. According to paragraph 3 of the Article, and to the UK In-

formation Commissioner's Office Guide[11] the INFORM platform does not fall into the cases likely to result in high risk, and is thus not required to carry out the assessment.
- Article 36 discusses further about the above mentioned assessment.
- Articles 37- 39 discuss the appointment and role of an individual as the Data Protection Officer in an organization. Articles 40-43 define the potential of drawing up Codes of Conduct and Certifications as means *"to contribute to the proper application of this Regulation"* by organizations.
- Articles 44-50 define how the transfer of personal data to third parties should be regulated. In our case, there is no transfer of personal data at all, as all data are handled by the platform.
- Articles 51-76 defines the conditions for the creation of Independent Supervisory Authorities in each Member State, responsible for monitoring the application of the regulation and their responsibilities.
- Articles 77-84 state the conditions, under which remedies and complaints can occur, and defines liability and penalties.
- Articles 85-91 discuss about how the regulation should be applied in specific processing situations. For instance, Article 88 refers to *"Processing in the context of employment"*.
- Article 92 discuss about adopting delegation acts in the regulation, and Article 93 states that *"The Commission shall be assisted by a committee."*
- The final provisions, Articles 94-99 discuss the relation of the regulation with the previous directive and other legal acts, and define the entry into force and application date of the GDPR.

From the above analysis, it is demonstrated how we ended up with the set of selected provisions to discuss in this paper, as applicable in the context of the INFORM e-Learning platform relating to design and implementation of the software.

[11] https://ico.org.uk/for-organisations/guide-to-data-protection/guide-to-the-general-data-protection-regulation-gdpr/accountability-and-governance/data-protection-impact-assessments/

Towards a Prioritization of e-Government Challenges: an Exploratory Study in Belgium

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***Abstract*— New developments in information and communications technologies can enable governments to improve their internal functioning as well as the services they offer to users. This transformation entails several hurdles that have been discussed extensively in existing literature. However, challenges are rarely ranked in terms of importance leaving practitioners in the dark regarding which one to tackle first. This paper analyzes, interlinks and prioritizes challenges that employees in federal, regional and local level experience in the further development of e(lectronic)-government in Belgium. Data was collected through six in-depth interviews and a focus group of three persons. The data was then analyzed following the Grounded Theory method. This allows to understand reasons for the relative lag Belgium has compared to countries leading the e-government charge.**

The findings reveal that coordination and alignment issues (a lack of end-to-end thinking) constitute the main obstacle for Belgian governmental authorities regarding further e-government development. Finally, current policies are reviewed to search for possible leads for solutions for the challenges discussed. This paper contributes to existing research in e-government, by explicitly distinguishing crucial challenges and ranking them on importance. This allows both researchers and practitioners to focus on focusing on the most important hurdles to further development.

Keywords — e-government, challenges, prioritization, coordination and alignment

I. Introduction

E-government has become a general-purpose word for information technology (IT) used by governments [1], [2]. It is a rapidly evolving subject and its scope evolves as information technology changes how citizens and organizations communicate and cooperate. In literature, a variety of definitions can be found. We identified three categorizations for e-government definition: maturity-based, interoperability-based and usage-based. The first one covers an evolutionary approach, where e-government models are classified going from "cataloguing" (first presence of the government on the internet) to "horizontal integration" (fully integrated over different levels of government). Interoperability, on the other hand, concerns the ability to improve collaboration between services, while usage-based is about the purpose of use (service use vs. information use). Based on definitions by [3]–[5], e-government is defined in this paper as the delivery of services towards citizens, businesses or other government entities using IT. The goal of e-government- is not solely the digitization of existing processes and services, but it also strives for an improvement of these processes and a better delivery of services to the targeted stakeholders. This transformation for the better is a crucial aspect, as can be deduced from the frequent occurrence of the word 'improvement' in definitions of the concept [3], [4], [6], [7].

In the existing e-government literature, there have been studies on the possible challenges that may occur, but no studies on the prioritization of these challenges. By researching what are considered crucial obstacles in further development in Belgium today by practitioners in the field, this paper seeks to discover and analyze drivers that explain the situation today. This paper pioneers in interlinking and prioritizing challenges. This allows both researchers and practitioners to focus on understanding the relations between challenges and on the most important hurdles to further development. Section II exposes the research gaps that this paper aims to fill as well as the research questions. Section III introduces the methodology used to elicit concepts, maps them into a network and induce a priority ordering. In Section IV, the different challenges are structured and presented. Section V compares the findings to existing literature and introduces several leads for solutions. Section VI presents the limitations of the study as well as leads for further research. Finally, Section VIII provides closing comments by summarizing the contributions.

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II. RESEARCH GAPS

Many papers on the subject mention a set of challenges that impede further development [8]–[10]. However, little research attention has been given to investigate to what extent these hurdles block further development. Challenges are rarely ranked in terms of importance, as [11] argues. They suggest some measures of importance in their paper, but do not apply these techniques in a case study. This motivates our choice to identify challenges encountered in e-government practice and to not only categorize and interlink them, but also assign a partial ordering to these challenges based on some importance measure. Indeed, a challenge is only worth researching when it is considered important by practitioners.

E-government research should thus focus on the most important issues. A recent paper does so for the city of Dubai [12], but it does not prioritize challenges over another. [13] discusses the state of affairs in China in terms of a relevance criterion, but focus more on broad issues and less so on concrete problems. Finally, the European commission yearly publishes e-government comparisons of its member countries, but these are rather descriptive and do not include recommendations for overcoming obstacles experienced today [14]. As we argue that a ranking in challenges is a gap in literature, this leads us to our research question.

RQ : What challenges are mentioned by e-government practitioners, and how do they perceive relationships and set priorities for these challenges?

Having identified important issues, a logical next step would be how these challenges are tackled nowadays. In the discussion section, we reflect on possible solutions, based on the respondents' comments and insights from literature.

III. METHODOLOGY

A. Collecting Information about Challenges

Challenges were retrieved via six open-ended in-depth interviews, and one focus group of three people concerning privacy. Each was conducted by two of the authors. Details on the interviewees can be found in Table 1. This qualitative method is effective when covering a complex topic in detail, which is not straightforward when using quantitative methods [15], [16]. Moreover, this technique fits the research question well, as it centers around the expertise of the practitioner, and not around the validation of the knowledge of the researcher. However, this method is prone to interviewee bias. Therefore, triangulation is crucial for the validity of the research. For this reason, findings from earlier interviews were submitted for validation by other respondents later in the data collection process.

To avoid bias that stemmed from behavior of the interviewer, respondents were asked to list important challenges at the beginning of the interview. The result obtained became then the roadmap for the rest of the interview. Given the relative importance criterion, challenges need to be defined precisely and situated in a broader context to appreciate their importance. To this end, interviewees were also asked to motivate the choice for their ranking. The arguments used revealed possible measures of importance according to practitioners. Additionally, the content of the interviews was analyzed as well, to extract underlying relationships between challenges. The method itself is explained in detail in the next subsection.

Two different voting methods were used in order to decrease possible bias:

- ***Voting by listing:*** The lists established at the beginning of each interview were collected and combined, resulting in a priority listing based on occurrence. A disadvantage of this method is the background from the interviewee: they will likely list issues that are top of mind for his or her job, but not necessarily for organization. Hence, the choice of interviewees may induce bias.
- ***Voting by mention***: Interviews were coded thematically on the occurrence of challenges. By using the codes attached to interviewee's statements in the transcripts, the relative importance of a code can be measured by comparing the number of words coded with a certain label versus the total number of words coded in a transcript. By doing so, the relative importance of a challenge could be estimated per interviewee by comparing it to the weight of other challenges. Moreover, coding makes a multi-layered approach possible, revealing relationships between challenges and other concepts. For example, it allows to aggregate specific challenges into generic ones and modeling relationships between them, resulting in a network of related challenges. By definition, aggregation means that complex challenges will have a larger relative importance in this method, making a useful comparison against the voting by listing-method with its risk of interviewee-specific bias. The next section explains how this modeling of related codes was performed.

The choice of interviewees is important. Indeed, Belgium, being a federal state, experiences more fragmentation in the e-government field because of its constitutional design. Hence, different perspectives will be present. To bring this into account, multiple interviews were conducted with stakeholders in

middle or senior management positions in the field. All interviewees came from different organizations on local, regional and federal level that play a important role in e-services development.

TABLE I. TABLE OF INTERVIEWEES

Level	Interviewees		
	Function	***Domain of expertise***	***Focus***
Federal	Application Programming Interface (API) manager	Interoperability, intergovernmental collaboration	Operational
Federal	Legal advisor	Privacy	Operational
Federal	Information security analyst	Privacy and security	Strategic
Federal	IT service manager	IT service management	Operational
Regional	Project manager	UX/UI, intragovernmental collaboration	Strategic
Regional	Senior advisor	Interoperability, strategic planning	Executive
Regional	Senior advisor	Interoperability	Executive
Local	President support organization for local e-gov workers	Local e-services, smart cities	Strategic
Local	Chief Information Officer (CIO) of a large city	Local e-services, smart cities	Strategic

B. Analysis method

To analyze the interviews, the Grounded Theory (GT) approach as described in [17] was used. GT is a well-known method in qualitative research. It allows for discovering concepts and a fine-grained analysis of the relationships between them, based on the coding of the interview transcripts. This supports the idea of voting by mention well, by inducing a partial ordering in challenges, as some challenges may exacerbate others. In short, it allows for an empirical analysis where data is coded using keywords. Next, these keywords are being categorized into more general concepts. From these concepts the challenges and solutions were defined. Finally, relationships between these concepts are induced. It is important that this analysis is then validated by further data collection.

To do so, an iterative approach was followed where intermediate results were refined on a rolling basis. At the end of interviews, time was taken for a more closed interview style where previously discovered concepts were validated or rejected. This was done to mitigate researcher dependency, which is considered an important weakness of the GT method. By letting respondents review their predecessor's challenge lists, bias was reduced and new relationships between concepts were discovered.

This analysis resulted in a network of related concepts. These were then further classified into four broad classifications: operational challenges, strategic challenges, solutions and challenge domains.

IV. RESULTS

In this section, the different challenges gathered in the interviews as well as their prioritization are presented.

A. Classification of concepts

When organizing the results of the interviews, classifications were used by the authors to facilitate the analysis by assigning each discovered concept to one of them. The definitions of the different classifications can be found in Table II.

TABLE II. CLASSIFICATION DEFINITIONS

Classification	Definition
Operational challenge	A problem that can be tackled by e-government practitioners or by independent government parties without substantial collaboration with other parties.
Strategic challenge	A problem that can be tackled by governments but requires substantial collaboration from different branches and departments.
Solution	An action that resolves a challenge partly or completely
Challenge domain	Thematically bundled set of challenges and solutions

B. Overview of the principal challenge domains

It is important to note that challenge domains were introduced by the authors during the analysis. Concepts belonging to other classifications (solutions, operational and strategic challenges) were brought up and validated by the respondents. Challenge domains serve to structure the network further by enveloping thematically related concepts in a domain

The Grounded Theory analysis resulted in three principal non-overlapping challenge domains that were identified:

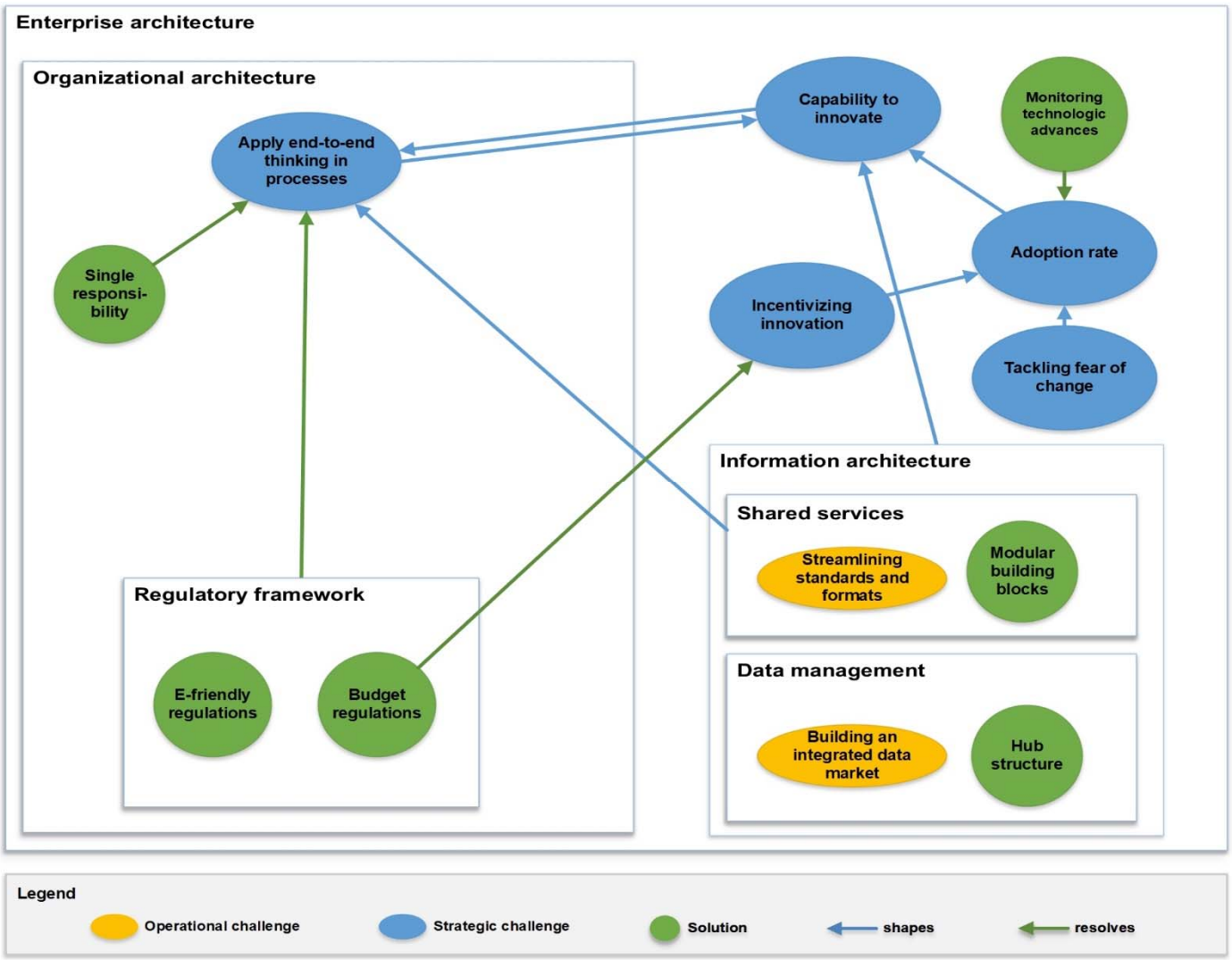
- Enterprise Architecture
- Citizen-centricity
- Privacy

The enterprise architecture (EA) domain is the structure of government that allows for current and future policy development, implementation and execution. For citizen-centricity, we use the definition of [18], meaning "that government is more responsive towards citizen's requirements and being transparent in its service". Thus, when a government practices citizen-centricity, the inhabitants "[…] may take an active role in the […] service design, implementation and operation as part of democratic processes" (p. 601). Finally, we define privacy as the right to be free from intrusion in one's private life.

As a simplification, one could see citizen-centricity as the demand-side perspective of e-government: what makes e-services convenient and useful for citizens? On the contrary, enterprise architecture takes the supply-side perspective: how should a government be organized to function well? Finally, the privacy domain introduces constraints on how supply should meet demand: which solutions respect privacy in both a legal and desirable sense?

In what follows, we will explain the discovered network of concepts in more detail, grouped by the three principal challenge domains. Most of the attention will be devoted to challenges considered important by practitioners (see Section V). Finally, the network relationships that cross the boundaries of the three domains are discussed.

Figure 1: Challenges in the Enterprise Architecture domain



C. Challenge domains

1) Enterprise Architecture

This challenge domain consists of two subdomains, namely "Information Architecture" (IA) and "Organizational Architecture". The first concerns the ability to develop and execute the strategy of the government: it enables the delivery of valued services to citizens and companies in an efficient way. The latter is the organizational counterpart of IA and covers the functional aspects of the government (e.g. the lack of cooperation between departments). The visual representation of this challenge domain can be found in Figure 1.

In what follows, we will briefly discuss the operational and strategic challenges. For strategic challenges, two are considered important by the practitioners: *"capability to innovate"* and *"end-to-end thinking in processes"*.

The first challenge concerns the government's capacity to improve its service delivery. This is largely shaped by the ability of an organization to transform existing processes by adopting new technologies, indicated by the strategic challenge *"adoption rate"*. This is influenced by organization culture (*"Tackling fear of change"*) and how change is encouraged by formal incentive structures (*"Incentivizing innovation"*).

On the other hand, *"end-to-end thinking in processes"* is defined as the ability to design, implement and manage processes from a holistic point of view, by transcending internal barriers. In other words, one should take the final end-perspective into account.

Concerning the lack of end-to-end thinking in processes, practitioners brought up the possibility of giving end-to-end responsibilities. In essence, this boils down to simplify the authority structures. The logic is as follows: as internal barriers and friction can appear between 'competing' departments, rather than striving for optimizations beneficial for the own department, the perspective of the end-user should be better taken into account.

2) Citizen-Centricity

As show in Figure 2, there are two important strategic challenges in this domain: *"user experience"* (UX) and *"digital divide"*. Here, UX is defined as the perceptions of the user when using services that the government provides. On the other hand, *"digital divide"* concerns the lack of ability of some demographic groups to interact with government using digital means. The main solution for these challenges is transparency. By informing users about how the process is executed, uncertainty and distrust can be reduced by informing citizens about processes (and hence, user experience is improved). Some respondents argued that this increased trust and patience in government processes intensifies the usage of digital services. A similar approach is important for privacy as trust plays an important role here as well.

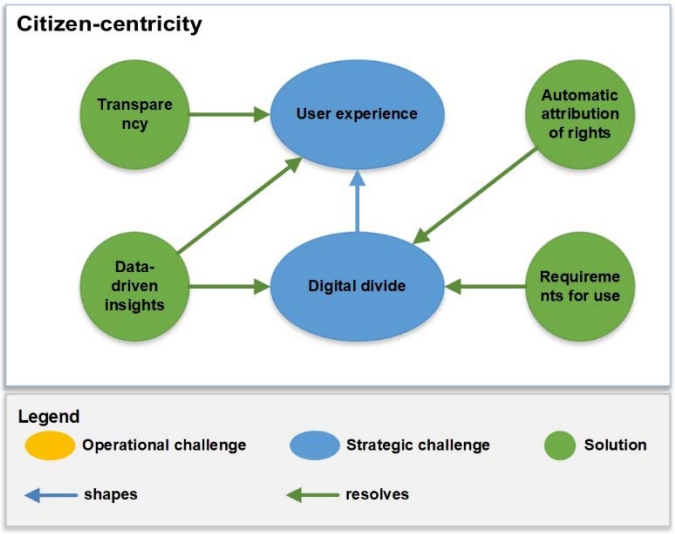


Figure 2: Challenges in the citizen-centricity domain

3) Privacy

Privacy was often brought up by respondents, citing two principal reasons. First, due to the advent of the Internet of Things, the digitization of society, and the pervasive data collection and mining activities of companies, many respondents perceived the privacy of citizens as increasingly at risk. Secondly, they felt that societal consensus about privacy was shifting.

As show in Figure 3, there are two main operational challenges, namely *"handling sensitive data"* and *"control over private data"*. These two are closely related but have an important distinction. The former one deals with how a government can function while respecting the privacy of its citizens in the legal sense. This last aspect is harder to measure, but still crucial: some practices may be legal, but can be considered intrusive by citizens. The latter one concerns some trade-offs the government should make between offering better services and using therefore private data from citizens.

Many respondents pointed out that government has an exemplary role to play in this challenge, as it is responsible for protecting the rights of its citizens. As a result, it would lack credibility if it did not respectfully handle the issue itself. Hence, a purely legal approach to handling personal data is not sufficient. It is as well about giving users the (perception of) control over how their data is used and what purposes it serves.

The European GDPR legislation notably also takes this perspective into account. Balancing the purpose of e-government (public interest) over rights of private citizens is hence an important issue.

Clearly, handling personal data in a correct manner requires adequate and adapted IT infrastructure. Interviewees pointed to an important solution, namely *"privacy by design"*. This refers to the implementation of privacy from the very beginning of application development, e.g. by limiting the access to private data or by rendering data anonymous where possible. Since May 25th, 2018, GDPR makes this mandatory [19].

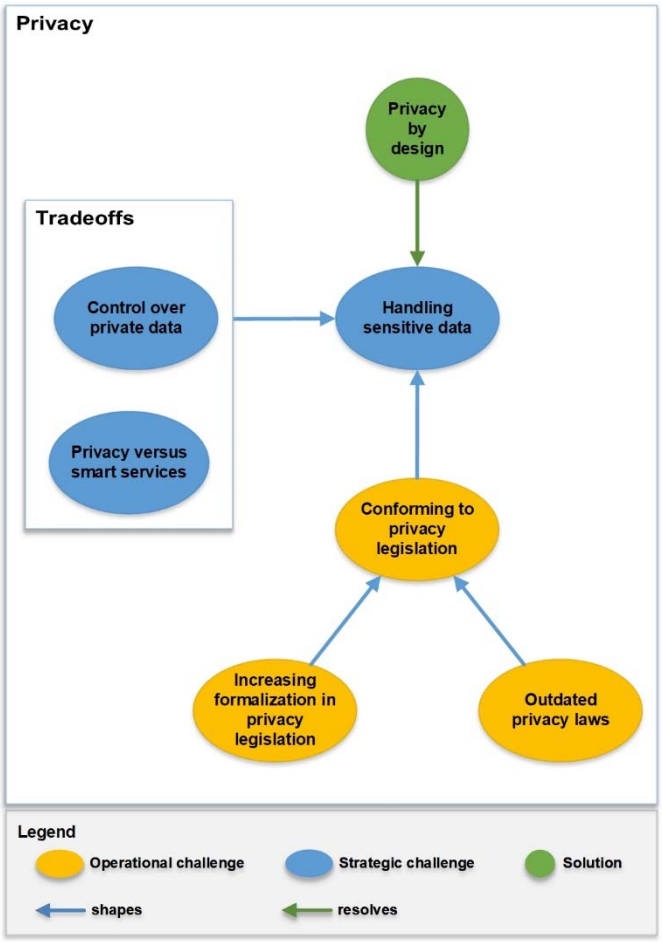


Figure 3: Challenges in the privacy domain

4) Relationships between domains

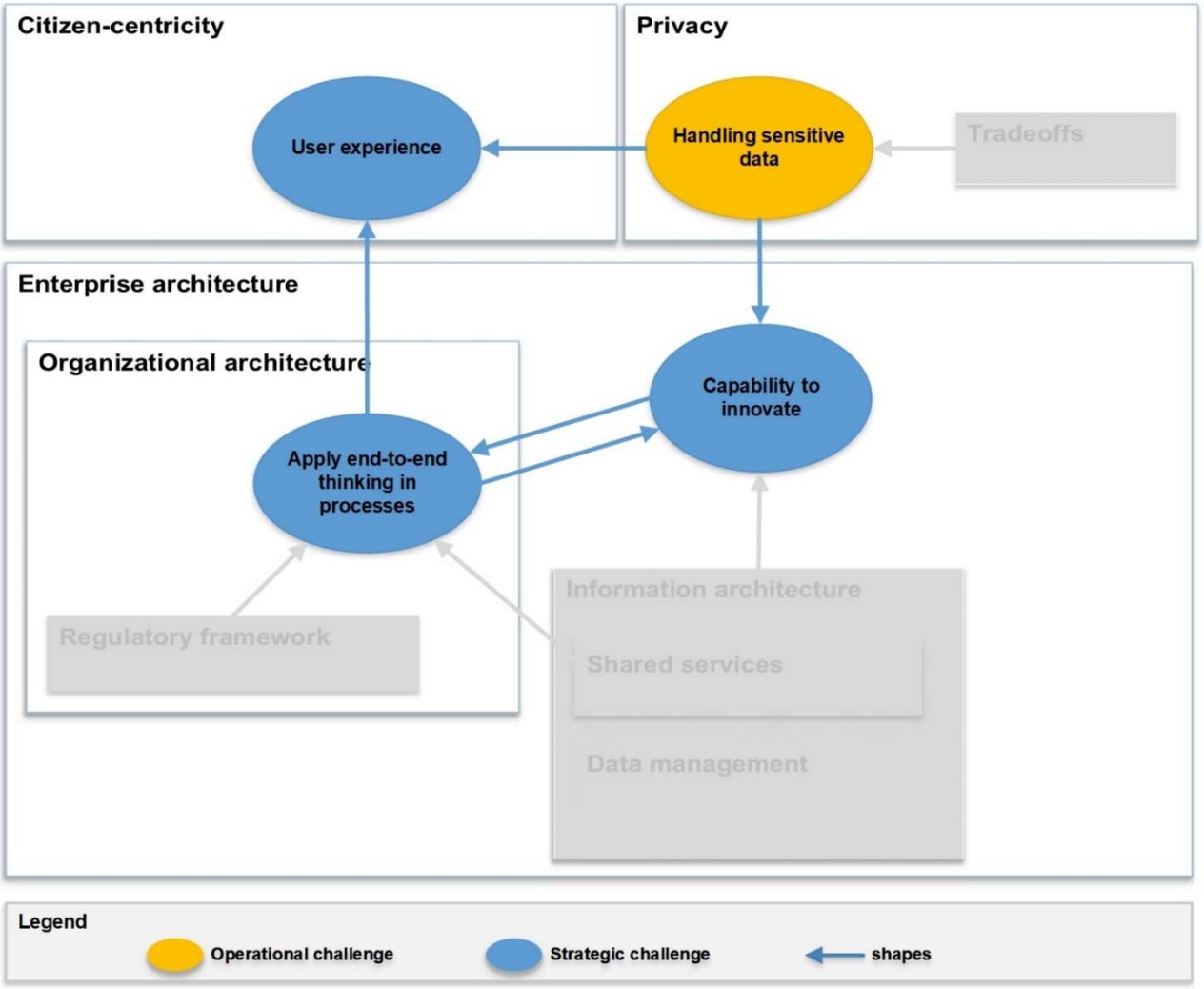
The relationships that cross the boundaries of these three challenge domains were considered crucial by practitioners. Moreover, these related concepts play a central role in their respective challenge domains. The relationships between domains are visually represented in Figure 4.

End-to-end thinking shapes user experience: *"End-to-end thinking in processes"* is taking a holistic approach to processes to optimize service delivery to the end user, thus improving user experience. In other words, to accommodate the end user external to government, this challenge is the internal mirrored translation of this goal. It should be noted that this need for holistic thinking is an argument of stronger collaboration between existing entities in a fragmented government environment.

Handling sensitive data shapes user experience: Increased user data sharing can improve user experience at the cost of increased private data sharing. Indeed, if different departments can easily access private data stored elsewhere, less input is required from users.

Handling sensitive data shapes capability to innovate: This relationship results from the dependency on the availability of data of machine learning algorithms. These hold potential to further streamline e-service delivery. The availability of data again depends on the accessibility of - sometimes private or sensitive – data.

Figure 4: Relationships between domains



D. Prioritization

When comparing the results of both ranking methods (see section II), it turns out that the resulting rankings are largely similar. Out of 25 challenges identified, the top 10 is almost identical, apart from some shuffling (see Table 3 and 4). A summary of the combined votes can be found in Table 5.

TABLE III. VOTE BY LISTING RESULTS

Vote by listing		
Challenge	***Vote by listing***	***Type***
Apply end-to-end thinking in processes	25.9%	Strategic
Control over private data	18.5%	Strategic
Handling sensitive data	11.1%	Strategic
Building an integrated data market	11.1%	Operational

Vote by listing		
Challenge	***Vote by listing***	***Type***
User experience	11.1%	Strategic
Privacy versus smart services	7.4%	Strategic
Streamlining standards and formats	7.4%	Operational
Capability to innovate	3.7%	Strategic
Digital divide	3.7%	Strategic

No other challenges were listed.

TABLE IV. VOTE BY MENTION RESULTS

Vote by mention		
Challenge	***Vote by mention***	***Type***
Apply end-to-end thinking in processes	18.4%	Strategic

Vote by mention		
Challenge	***Vote by mention***	***Type***
User experience	15.3%	Strategic
Control over private data	13.4%	Strategic
Capability to innovate	8.4%	Strategic
Conforming to privacy legislation	8.1%	Operational
Increasing formalization in privacy legislation	7.6%	Operational
Streamlining standards and formats	6.2%	Operational
Privacy versus smart services	4.9%	Strategic
Adoption rate	4.8%	Strategic
Digital divide	4.2%	Strategic
Handling sensitive data	3.1%	Strategic
Building an integrated data market	2.7%	Operational
Incentivizing innovation	2.5%	Strategic
Outdated privacy laws	0.2%	Operational
Fear of change	0.2%	Strategic

TABLE V. COMBINED VOTING RESULTS

Combined vote		
Challenge	***Combined vote***	***Type***
Apply end-to-end thinking in processes	22.2%	Strategic
Control over private data	15.9%	Strategic
User experience	13.2%	Strategic
Handling sensitive data	7.11%	Strategic
Building an integrated data market	6.9%	Operational
Streamlining standards and formats	6.8%	Operational
Privacy versus smart services	6.2%	Strategic
Capability to innovate	6.1%	Strategic
Conforming to privacy legislation	4.0%	Operational
Digital divide	4.0%	Strategic
Increasing formalization in privacy legislation	3.8%	Operational
Adoption rate	2.4%	Strategic
Incentivizing innovation	1.3%	Strategic
Outdated privacy laws	0.1%	Operational
Fear of change	0.1%	Strategic

"Apply end-to-end thinking in processes" emerges as the most crucial challenge (22.2%). This was to be expected, as almost all interviewees brought this up in the voting by listing phase of the interviews. As such, this challenge was discussed thoroughly during the interviews, leading to the highest voting. As second challenge, the privacy related *"control over private data"* (15.9%) follows. The interviews were conducted during the run-up to the rollout of the new GDPR legislation in the EU, which may have been a factor in this result. "-*User experience"* is highly important as well (13.2%). As said before, this challenge is correlated with applying end-to-end thinking: a government model that centers end-to-end thinking leads naturally to proper UX. "*Streamlining standards and formats*", although crucial for cooperation across entity boundaries, is not further discussed for the sake of this paper. Another challenge that was often highlighted during the interviews, is *"Capability to innovate"*, which is the ability to transform processes continuously to achieve operational efficiency. Although this challenge does not appear in the top five, it is still highly important, given its close relationship with e-government itself, which is about improving government services.

V. DISCUSSION

In this section, challenges identified as crucial are discussed and compared with three contemporary studies on this topic [10], [14], [20]. The paper from Chantillon et al. [10] was chosen because the authors performed a similar research in the Belgian context but focuses solely on the federal level. The data used from the Joinup paper allows to compare on European level [14]. Finally, to monitor progress made in recent years, a comparison with a 10-year-old OECD paper was made [20].

A. End-to-end thinking in processes

As described earlier, *"Apply end-to-end thinking in processes"* concerns taking the final end-user perspective into account. In a complex environment where there are different layers of government, each consisting of multiple entities that have closely related or overlapping duties, friction between entities may form an impediment to this holistic thinking. Entities responsible for performing part of the process will optimize the process steps they are responsible for but may fail to take the bigger picture into account. Chantillon et al. mention for example a lack of intra-governmental coordination that they attribute to historical reasons [10].

The Belgian OECD report dating from 2008 already states the need of focusing on user-centricity and coordinating issues, and suggests the following action: "ensure a holistic and depoliticized approach to e-government providing fully integrated services based on common public-sector standards", as "*the cross-*

cutting nature of e-government development and the need to focus on operational implementation requires a whole-of-public-sector perspective and approach" [20, p. 27] . It also notes the need on stronger e-government synergies, by developing common building blocks and shared resources. Finally, the Joinup paper notes that creating integrated services across public institutions is mentioned in the Flemish and federal e-strategies [14].

A solution proposed by multiple respondents in the study was the assignment of a single responsible entity for the whole of the internal process. This boils down to selecting one entity that coordinates the others. However, federal state structures may prevent this from materializing across different layers of government. In that case, a single coordinating entity per government layer could reduce complexity that would in turn improve end-to-end thinking. Nonetheless, one should bear in mind that the lack of a single authority structures at a strategic level is political in its nature, just as the OECD report mentions.

Although over a decade old, some proposals for actions in the OECD report are still very relevant and useful today. It proposes establishing a national coordination entity that "acts as an operational e-government development, implementation, and shared services center focused on providing generic e-government services and components to the public sector as a whole" [20]. Hence, impediments to further development are managerial at heart.
Respondents also often cited generic building blocks as an interesting solution as they provide good public services while leveraging economies of scale, decreasing general expenditure through further digitization, and improving user-centricity as the same logic is applied throughout different processes. With government budgets shrinking, this approach could be fruitful. Chantillon et al. mention G-Cloud, a common cloud with shared services, which is an implementation of this philosophy [10].

B. Control over Private Data & Handling sensitive data

We discuss both challenges together, as they are closely related. *"Control over private data"* concerns how personal data is processed by governments and consists of the control citizens exert on governments to make sure their rights are not infringed. *"Handling sensitive data"* is government's exemplary role when it comes to respecting citizen's rights. In this context, protecting privacy is not limited to enforcing applicable privacy regulation and is more long-term oriented. Governments should also meet citizen requirements beyond legal obligations to ensure trust in public institutions.

With the emergence of the Internet of Things, the array of data sources is rapidly increasing, containing valuable insights about citizens, but at the cost of exposing private life. Unsurprisingly, all respondents agreed that governments should leverage the potential of new technologies and analytics in a smart way while respecting privacy rights of citizens. As citizens have different preferences and standards with regards to privacy, it is of utmost importance how the government positions itself on privacy and how it copes with the changing requirements of citizens on this issue. Both contemporary papers [10], [14] mention common standards for the protection of private data, but do not distinguish between the legal and ethical aspects of handling private data [10], [14]. Not surprisingly, security was highly ranked as well in the recent paper [21], where the challenges of digitalization in Agencies in Sweden were distinguished. This confirms again that confidentiality and integrity are extremely important.

However, interviewees argued that for the federal and Flemish administrations, they disposed of the needed human capital and structures to deal with these issues, citing the presence of security and privacy counselors that oversee e-services development. From this viewpoint, avoiding privacy violations is still an important topic, but not one that hampers or slows the further development of digital government.
It is important to note that the GDPR regulations changed the legislative framework on privacy when it became applicable on 25th May 2018 [19].

There are two closely related topics that are solution-oriented, but these depend on the chosen tradeoff: 'Transparency' (solution in the user-centricity domain) and 'control over private data' (challenge in the privacy domain). Transparency means informing the end-user of how data is stored and processed. Data control is handing control about usage back to citizens. This requires a more profound change as this allows users to cherry-pick which kinds of data storage and processing they accept for which services. Of course, this option is limited and should be balanced against public interests.

C. User experience

In many ways, this is the ultimate goal in delivering public services: optimal service delivery requires bearing user requirements in mind while delivering a service. The first challenge is closely associated with this purpose: delivering a service is the endpoint of a process in which the purpose of the process is considered at every step in the process. In other words, *"end-to-end thinking in processes"* is the translation of the *"user-centricity"* challenge, which is seen from the perspective of the end user, into the perspective of a government worker. In the

presence of a fragmented government, the focus on this perspective risks to be lost.

The OECD argued that Belgian governments have limited experience with assessing and monitoring citizen expectations [20]. The paper distinguishes two important constituting points of action in this challenge: addressing the digital divide, which was not researched in this paper, and providing a 'seamless user experience'. The latter is an important focal point in the federal government's e-government strategy today, as recent reports by ISA² indicate [14]. As stated above, user-centricity and end-to-end thinking in processes are strongly interrelated, because seamless in itself requires coordination and alignment of processes and data within and across government levels.

Chantillon et al. suggest examining the use of participation methods (such as interviews, innovative workshops, living labs, etc) to better understand the requirements and needs of the users so that the developed public e-service is more aligned with their expected experience. Several papers in existing literature expand on this topic [22]–[24].

D. Capability to innovate

This challenge was an often-cited driver for other challenges during the interviews themselves. In this paper, capability to innovate is defined as a means to reach an end (namely improving government processes).

Many respondents felt that there should be a structural approach to leverage opportunities that emerge thanks to technological advancements. Joinup mentions the creation of several new organizations that aim to foster innovation at different government levels in Belgium [14].

Some respondents argued that rethinking existing processes should be a continuous process, because government has the duty to spend its resources responsibly, and a continuous focus on further improving cost efficiencies is part of that duty.

On the other hand, this reasoning already limits the scope for innovation. One respondent stated it as follows: 'Innovation for the sake of innovation is not acceptable for governments. As soon as it becomes unlikely that a service improvement can be delivered, one should consider stopping the project.' Government officials should hence leave room for innovation by setting up pilot projects, but bear returns in mind.

As a solution, respondents indicated that data-driven insights such as artificial intelligence, which concerns efficiently handling data and learning insights from how processes were executed before. These insights may then be used to redesign the process. However, this has repercussions on the privacy of citizens. Chantillon et al. also note that strong limitations on usage of personal data negatively impact user-centricity and effectiveness of e-services and that a balance should be found [10].

Another solution are modular software architectures, where complex functionalities are executed by a network of software modules that interact with one another. Third party developers who use modules, regard these as black box: they do not need to know how their information is stored and retrieved, but just invoke the methods available at the application interface. Modules hence tend to be limited in functionality, resulting in a reduced complexity compared to classic 'silo' applications. This reduced complexity makes replacing modules easier compared to replacing monolith applications (e.g. by running both modules in parallel). Innovative solutions can hence be introduced more quickly in the infrastructure of the organization.

VI. Limitations and further research

In this section, we reflect on the limitations of the present study. Furthermore, we present leads for further research to examine in more depth the findings of this study.

A. Methodology

As stated earlier, the use of both in-depth interviewing and Grounded Theory analysis is interpretative. In other words, the results may be researcher dependent. However, when describing a practice or situation, as was needed to answer the research question it is not possible at all to circumvent this interpretation, unless by direct observation and that Grounded Theory is a standard method for comparable problems in social sciences.

To further validate these findings with a larger pool of practitioners, we would welcome a supplementary quantitative study. For both the explicitly named challenges ('listed') and the implicitly validated ('mentioned') during the interviews, the relative frequency was used as a metric. Again, we stress that each metric will always be a proxy when conducting qualitative research. We welcome running other metrics after doing another analysis of the same subject to validate or reject the findings of this study.

B. Scope of research conducted

First, a total of nine interviews was conducted. This limited number may give a distorted view. Thus, in addition to the interpretability drawback of in-depth interviewing and GT, this makes for limited generalizability of our study to the field of practice in local municipalities, Flanders and Belgium. More interviews are needed to confirm or reject the findings of this

thesis and to detect the root issues that hamper further development. Second, the limited number of interviews makes that government of the French Community, the German-speaking community, the government of the Walloon region and of Brussels-Capital were not consulted and that only local municipalities in Flanders were addressed. Nevertheless, three different levels of government were consulted: federal, Flemish and local, which already provides a palette of different perspectives. A further study could thus extend this research to levels of government that were not consulted for this paper. As the priorities and strategies may differ, other challenges may emerge there. Third, there may be an overestimation of the importance of a concept due to the interviewee's functional and organizational background. This may especially be the case for privacy-related concepts, as privacy experts formed an important group in the respondents. Nonetheless, these issues are clearly relevant, as the new GDPR legislation demonstrates.

C. Recommended further research

1) Qualitative research

To increase the generalizability of this study, we welcome any more intensive study using the same methodology, with or without other metrics that selects a different set of interviewees in the Belgian context, keeping the points noted in 7.2 into mind. To validate or reject the relative importance of challenges obtained in this study, it would be interesting to develop different metrics, that may or may not use different data inputs (i.e. surveys, Likert scales, etc.) and compare the crucial challenges discovered there to the ones discovered in this survey.

2) Quantitative research

We would strongly suggest performing a quantitative study, that could then validate or reject the findings of this study with statistical rigor. Specifically, a factor analysis that studies in detail the significance of the challenges discussed and the relationships between them would be a valuable contribution. Besides, it would be easier to interrogate a large set of practitioners. With respect to the specificity of the Belgian case, this would allow for a set of interesting comparisons, such as differences between different levels of government, both horizontally and vertically. Differences in approach could then be measured and analyzed.

VII. Conclusion

In this paper, current challenges in the e-government field were investigated. These challenges were not only identified, but also interlinked and ranked in order of importance. Finally, these findings were compared with existing literature to suggest some leads for solutions.

Using relative frequency metrics, the importance of challenges was measured. It was found that "end-to-end process thinking" is the main obstacle to e-government development, due to a fragmented government framework. The discovered relationships reveal the consequences of not resolving these obstacles. Research efforts should hence be directed towards bottlenecks that are withholding public service delivery improvement of today and tomorrow.

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The Impact of Impediments on Open Government Data Use: Insights from Users

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***Abstract*—Open Government Data (OGD) is interoperable data that is published on the Internet by public organizations and can be freely used and redistributed by users. OGD is expected to result in several benefits, such as innovative products and services, collective problem solving, and equal access to information. However, several impediments complicate the realization of the benefits. These impediments can impact the process of using OGD that consists of the four phases: motivation, search and evaluate, access and prepare, and aggregate and transform.**

In this paper, we examine the case of a data science project conducted by master's students to understand how impediments impact their use. In order to study this case, we use a mixed-method approach combining a questionnaire sent to the 30 students and nine in-depth interviews.

The analysis of the data allowed us to identify and discuss the impact of several impediments on use, such as difficulties in finding an idea and the lack of longitudinal data. Subsequently, we were able to give recommendations to publishers to improve their OGD portals, infrastructure, and data as well as opening up research directions in the OGD field.

***Index Terms*—Open government data, User process, Impediment, Mixed-method, Impact**

I. Introduction

Open government data (OGD) is interoperable data published on the internet by public organizations to be freely used and redistributed by anyone [1, 14, 17]. The public organizations, who collect and share data, are referred to as publishers, while those who reuse the data are called users [43]. OGD is a change from the traditional system where those who collect and analyze data have been the same [35]. Users can be city managers, businesses, citizens, students, developers, researchers, Non-Governmental Organizations (NGOs), civil society organizations, or journalists [24, 30]. OGD is a collaborative effort to realize several benefits, such as the creation of a new sector, innovative products and services, collective problem solving, and equal access to data [20, 22, 33]. However, both publishers and users can experience impediments in the process, such as low data quality, restrictive legislation, paywalls or loss of income, and no interoperability between systems [10]. The lack of use has been noted as a problem for OGD [16, 19, 23, 30, 37, 40, 41]. This lack means that the opportunities of OGD are not realized, but also a risk for publishers to invest in something that never reaches fruition.

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Central to use is the user process, which can be depicted in several ways. Normally, the user process is depicted together with the publisher process as interdependent [e.g., 1, 42]. In such instances, the processes form a circle where the publisher shares data with the user who later responds with feedback. The process is supported by infrastructure (e.g., application programming interface (API) and OGD portals), which needs to be designed to support users' and publishers' activities. The publishers and the users can experience impediments, such as low-quality data and machine-unreadable formats. Impediments are difficult to solve as they can be connected to each other, be caused by activities earlier in the process, and vary in severity [4, 18, 42].

In this study, the focus is on the user process, as the lack of use and the impediments indicate inadequate infrastructure and a need for further insights into the user process. The inadequate infrastructure can cause bottlenecks in the process, such as unfindable data and inability to combine data [44]. To overcome current impediments to usage, [6] have called for research on the users' motivations, resources, and capabilities. In our research, we take a step towards understanding how impediments impact users, and, therefore, how they can influence users' motivations and need for resources and capabilities.

The purpose of this study is to understand how impediments impact OGD users as they progress through the OGD process. The study seeks to identify crucial impediments and understand how they may change the behaviour of the user. For this purpose, we use a user process framework [9] as a guide for a mixed-method research approach. Our research participants were 30 master's students divided into groups of three, performing a data science project on OGD portals. The study results can give an insight into the current severity of user impediments and inadequacies of the OGD infrastructure. Based on the identification of these impediments, we give recommendations to publishers to improve the OGD portals, data, and infrastructure and open some research directions in the field. The research question is formulated as follows: *"How can impediments impact users as they progress through the OGD process?"*

This article includes the following sections. We first present the background with the user process framework, followed by our methodology. Then, we present the results. Accompanied is a discussion of the results, limitations, and future research.

The paper ends with a conclusion that summarizes this study's contributions.

II. Background

There are several types of OGD, that can be used for different purposes and in different ways. Some common categories of OGD are finance and economy, environment, health, energy, education, transportation, infrastructure, employment, and population [36]. In more practical terms, OGD can be national budgets, environmental measurements, weather reports, public transit schedules, crime incident reports, postal codes, consumer complaints, and information about population [1, 2, 28]. Using OGD is believed to lead to benefits, such as increased governmental transparency, democratic accountability, external problem-solving, and evidence-based policy-making [7, 15, 20, 22, 38]. However, publishing OGD for reuse is associated with various risks: violations of privacy, misinterpretations, and misuse [3, 43]. Moreover, use can come in multiple forms, such as studying voting history for specific facts, making graphs or texts to illustrate data, developing searchable interactive digital maps, and combine and clean data to republish through an API [12]. There is a variation in the data as input, use as process, and information, facts, products, and services as output.

The variations in the process of use have been studied by several authors. An early attempt was to connect the input with the output (with a focus on the latter); data to fact, data to information, data to interface, data to data, and data to service [12]. On the other hand, the process can be depicted as a linear value chain, starting with data aggregation, data analysis, and ending with data services and products [29]. Another approach is to view OGD as a cycle where the publisher process and the user process are interdependent. The user process can then be divided into finding the data, analyzing the data, processing data, and discussing and providing feedback on data [42], or, alternatively, data discovery, data exploration, and data exploitation [1]. Thirdly, it is possible to divide the process into several activities and group them into roles, such as data extractor and transformer, data analyzer, and user experience provider [26]. In conclusion, the outcome-based approach misses the variations in the input and the processes, the process approaches tend to miss the variations in the outcomes and the activities, and the role approach solves the aforementioned issues but is less detailed about the activities. In this paper, the user process is viewed as a linear process with variations in the activities and output based on the purpose and data. This approach follows the user process framework of Crusoe and Ahlin [9]. The authors' framework is a recent attempt to synthesise previous research and empirical data on the user process, as such it contains the findings of [e.g., 1, 12, 25, 26, 29, 42, 43, 44]. Their user process consists of phases with activities and relating impediments: *motivation*, *search and evaluate*, *access and prepare*, and *aggregation and transformation* (see Table I).

III. Methodology

In this section, we first discuss the context of the study. Then, we detail the data collection techniques we applied to measure our constructs and explore practice. Finally, we explain how we analyzed the collected quantitative and qualitative data.

Here, we note that this research is part of verifying and further developing the framework proposed by [9]. From this framework, we selected impediments to be studied based on their perceived possible impact on use.

A. Context

In order to collect information about the impediments that users can experience when using OGD, we examined a specific data science project conducted by 30 master's students between October and December 2018. We argue that these students have high digital literacy and are thus representative of the typical OGD user population. They were asked to use OGD from the cities of Namur[1], London[2], Paris[3] or New York[4] to develop an application valuable for the citizens or the public servants working in the administration. The guidelines for the project were reduced to a minimum to stimulate creativity and the real-life use of the OGD portals. The following constraint was nonetheless imposed on the students. The output of their project should be transferable to the city of Namur, provided that the city acquires and makes available the necessary data. In this way, the projects' outputs consisted not only of solutions directly applicable to Namur but also of prospects valuable for the city officials.

B. Data Collection

To collect data from our case, we followed a mixed-method approach that combines quantitative (one questionnaire) and qualitative (semi-structured interviews) methods. Johnson and colleagues [21] argue that a combination of methods allows having informative, complete, balanced, and useful research results. We chose this combination of methods in order to reach a complete view of the impediments experienced by users. The quantitative insights helped us to understand the importance of some impediments whereas the qualitative insights gave specific details about the impediments. Furthermore, the quantitative insights helped us to frame the interview guide in order to ask questions about the most important reported impediments.

1) Questionnaire: We structured the questionnaire based on the user process previously detailed by [9]. This process is divided into four phases that are described in Table I. In the questionnaire and this paper, the *motivation* phase is referred to as the *start* phase. Figure 1 summarizes the four phases, gives the overall structure of the questionnaire, and details the three constructs we evaluated:

[1]https://data.namur.be/explore/
[2]https://data.london.gov.uk/
[3]https://opendata.paris.fr/explore/
[4]https://opendata.cityofnewyork.us/

TABLE I
THE FOUR PHASES OF THE USER PROCESS FRAMEWORK (BASED ON [9])

Phase	Activities	Sources of impediments
Motivation: The user needs to be aware and motivated to use OGD. In this phase, the user is trying to identify some way to use OGD.	Discover OGD and identify where OGD can be used.	Public advertisement, understand how OGD can be used, and examples of use.
Search and evaluate: The user is searching on the Internet, OGD portals, and publishers' websites for promising data to use. Once promising data has been identified it can be evaluated to determine if it fits with the objectives of the *motivation* phase.	Engine searching, portal searching, browsing the publisher's website, pre-evaluate data on an OGD portal, and evaluate data on the publisher's website.	Search features, presentation of search results, metadata, must download the data to evaluate, tools to explore and analyze data, language, and licences.
Access and prepare: The user has the goal to acquire promising data and transform it into usable data.	Manual access (e.g., download PDF), automated access (e.g., API), and prepare data.	Access method, documentation, filtering, data format, data quality, accessibility, registration, and support.
Aggregate and Transform: The user has the objective to combine data and transform the new dataset into information, a product, or service.	Aggregate data, analyze data for information, and develop a product or service.	Combine data, quality variations, availability variations, supporting tools, longitudinal data, data infrastructure, and domain knowledge.

- **Resource allocation**: this construct evaluates the amount of time allocated and people involved for each phase. Respondents were asked to rank the four phases according to the time it took to complete them, and also according to how much they contributed.
- **Perceived usefulness**: this construct evaluates to what extend the phases of the process are perceived as useful for the project's output by the users. A 5-point Likert measure instrument ranging from *not useful at all* to *very useful* was used.
- **Perceived difficulty**: relying on a 5-point Likert measurement instrument, the questionnaire measures the severity of the impediments reported in [9]. We used the term "barrier" in the questions so that the students can answer more easily.

In order to measure the *perceived difficulty*, the severity of the impediments was evaluated by relying on the instrument previously described by [4]. Indeed, the authors also measured some challenges faced by users with the following measure instrument:

1) **Not a barrier**: it was easy to use the data.
2) **Somewhat of a barrier**: it was still possible to use the data.
3) **Moderate barrier**: it was difficult to use the data.
4) **Serious barrier**: it was extremely difficult to use the data.
5) **Extreme barrier**: it was impossible to use the data.

Besides the constructs, the questionnaire includes contextual questions on the respondents' background, the skills they acquired for their project, and their confidence with programming, data analysis, and OGD portals. The questionnaire ends with a broad open question, allowing respondents to share insights on the class project and OGD in general. The complete questionnaire is available in the appendix to this paper.

2) Interviews: In order to complete and better analyze the results from the questionnaire, we conducted in-depth interviews with the nine students. We applied quota sampling to select the interviewees. The quota was based on students' study orientation (computer science, management, or mathematics). We hypothesized that the impediments faced by students throughout the project might vary according to their background. Working with OGD is an interdisciplinary process that can involve idea development, data analysis, and coding. Due to the differences in their interests and curriculum, students from a given background (e.g., mathematics) could be more experienced in some activities (e.g., data analysis). The questionnaire responses were in line with this hypothesis. We limited our study to nine interviews to respect the sampling method (only three mathematics students were involved in the whole project) and because of their limited availability due to exam constraints.

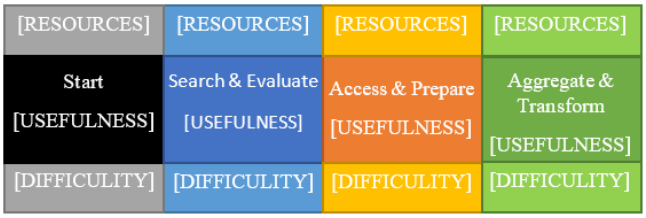


Fig. 1. Questionnaire constructs. For each phase of the user process framework, the questionnaire measures the *perceived difficulty*, the *resource allocation*, and the *perceived usefulness*

The structure of the interview guide is similar to that of the questionnaire. The interview guide starts with introductory questions on the overall user process, as we were interested to compare the user process framework with the activities conducted by students in their project. Moreover, the severest impediments from each phase that were reported in the questionnaire results were discussed with the interviewees in order to collect deeper insights. The interview guide ends with retrospective questions on the project. This latter part includes, among other things, questions regarding the students' motivation to use OGD again and what support they want from OGD publishers. The detailed interview guide is available in the appendix of this paper.

C. Data Analysis

1) Questionnaire: The questionnaire results consist of the items evaluated on a 5-point Likert measurement instrument

for the *perceived difficulty* and the *perceived usefulness*. In order to have a central tendency measure for each of these items, the median was computed since the results consist of Likert-type data [5]. As for the *resource allocation* construct, it was measured by a ranking exercise on the four phases. In order to obtain a representative ranking, the mode was computed for each phase.

2) Interviews: The interviews were analyzed with process and initial coding [31]. The analysis started with summarizing the interviews and then recording them in a data memo. Afterward, the researchers divided the data between each other based on the user process. Each researcher coded a specific phase for each interview. The coding started with skimming the interview to get a sense of the whole, then important sentences were highlighted based on the research question, after the highlights were coded using short sentences to retain context and conceptual relations. The codes were then inserted into a table divided by the interviewees and process phases. As the analysis progressed, researchers could write analytic notes to record insights and thoughts. All coding was conducted in the same cloud-based document, as such the researchers could follow each other's coding process and verify codes if needed.

IV. Results

In total, 30 users completed the questionnaire. 22 of them have a management background, four study computer science, and four mathematics. In the following section, the quantitative results from the questionnaire regarding the three measured constructs are successively presented. Then, the discussion on the *perceived difficulty* is refined with the qualitative insights from the interviews. The findings from the questionnaire regarding the constructs are summarized in Table II.

A. Perceived Difficulty

Figure 2 presents the results from the questionnaire regarding the severity of the impediments. The severity was computed as the median answer of the 30 respondents. One can observe that none of the process phases is exempt from moderate barriers (median = 3). Hence, the users experienced difficulties in some activity of every phase, since a moderate barrier indicates that the use of data was difficult. In the *start* phase, users struggled to find an idea for OGD use. In the subsequent phase, they faced issues with metadata. Metadata is information about a dataset, such as collection methods and freshness. In the *access and prepare* phase, the problems lied in the quality of the data. Lastly, in the *aggregate and transform* phase, users had trouble with combining data, the variation in data availability, and complained about the lack of longitudinal data.

The questionnaire results also show that some expected impediments were no problem for the users (median = 1). This observation is rather encouraging, as it points out that potential impediments can have been solved by the OGD publishers considered in this study. It is, however, worth noting that these are concentrated in the *search and evaluate* and *access and prepare* phases. Hence, every impediment in the questionnaire for the *start* and the *aggregate and transform* phases impeded the use of OGD to some extent.

TABLE II
Questionnaire constructs for the phases of the User Process Framework (based on [9])

Phase	Perceived difficulty	Resource allocation	Perceived usefulness
Start	Find an idea	4 (least)	Useful
Search and evaluate	Quality of metadata	3	Useful
Access and prepare	Data quality	2	Useful
Aggregate and transform	Data cannot be combined Data availability varies No longitudinal data	1 (most)	Very useful

B. Resource Allocation

In the questionnaire, users were asked to rank the four phases by how much time they had invested in each one. The least time-consuming phase was the *start*, followed by the *search and evaluate*, the *access and prepare*, and, lastly, by the *aggregate and transform* phase, which is, therefore, the most time-consuming. The perceived individual contribution reported by the respondents follows this trend as well. The resource allocation and yield per phase thus appear to increase throughout the process.

Furthermore, 26 of the 30 users reported having to learn new skills required for the success of their project. This self-development was expected since most of the users have a management background. The learned skills were mainly about web-oriented languages (Javascript, CSS, HTML, web libraries), Python, and how to connect a Python script and a web page (the Flask framework was recurrent for this matter). This acquisition is one factor contributing to the high time allocation of the late phases.

C. Perceived Usefulness

All phases were perceived as useful (median $\geq$ 2). The *aggregate and transform* phase was considered as very useful (median = 1). This outcome was expected, since the final output of the project is delivered at this phase.

D. Qualitative Insights on Perceived Difficulty

In the following section, qualitative insights on impediments are presented following the phases of the user process framework.

1) Start: The in-depth interviews revealed that the process of ideation was mainly based on the personal needs, uses, or intuitions of the users. Then, users visited the OGD portals, looking for datasets, and, as a result, changed or gave up their first ideas as data was missing. Sometimes this was repeated several times. This process of divergence and convergence, using creative techniques like mind-maps and brainstorming,

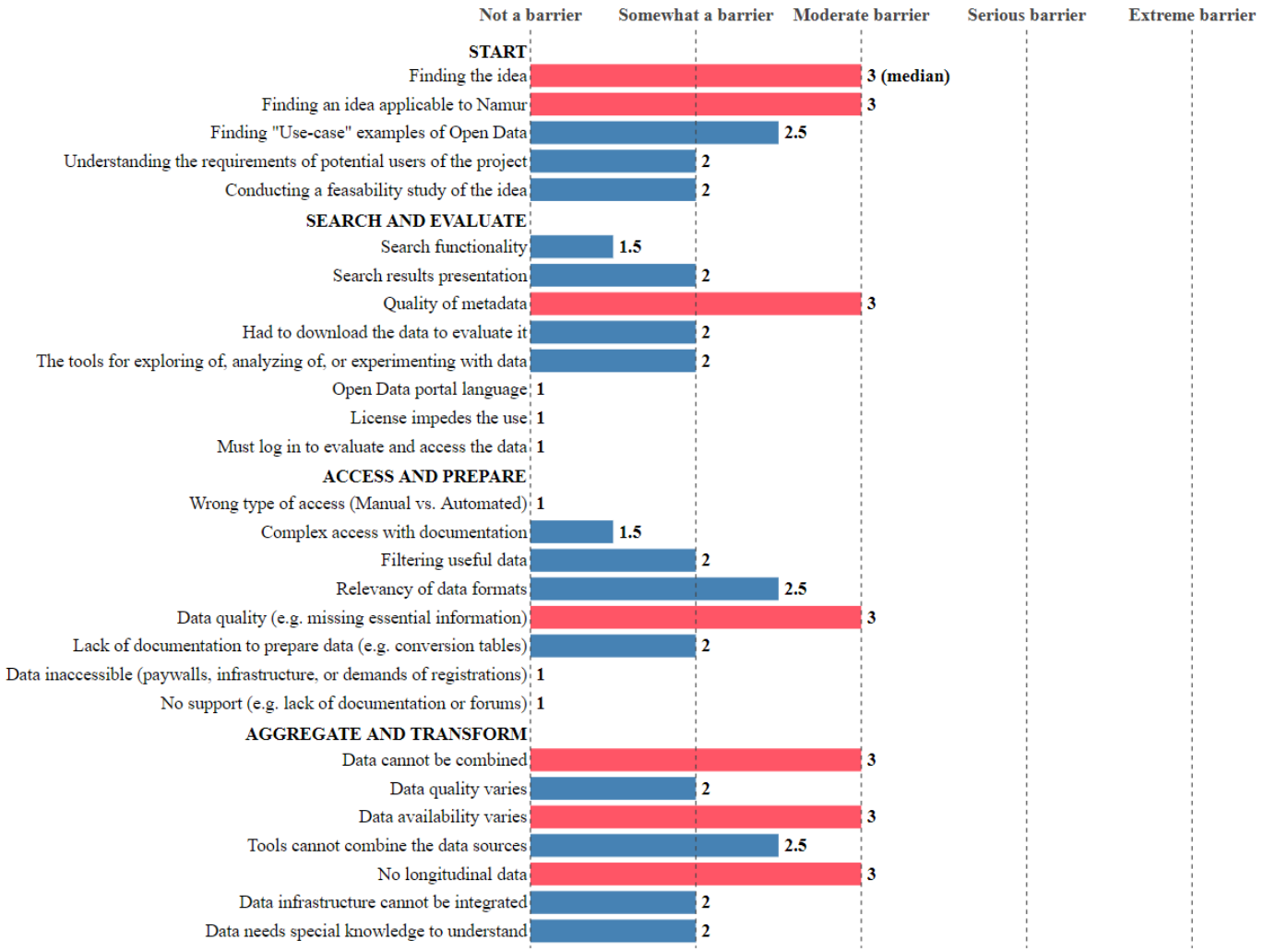


Fig. 2. Median for each impediment computed from the questionnaire results. The impediments colored in red are the most severe for their respective phase.

was constrained by the availability of datasets in the chosen portals. As one user expressed: *"We've got a lot of ideas by looking at the datasets' name in 20 to 30 minutes of brainstorming. But the difficulty was to realize them. When we opened the datasets, important information was missing. Thus, we had to give up some ideas."*

All the interviewees faced this issue, and it shaped their output. Two teams of users started directly from the OGD portal and with the combination of datasets to save time. Seven of them mentioned the limited number of datasets as a major constraint for their project development. They said they had more innovative ideas than data to develop them. As one user expressed: *"I have the impression that the OGD portals were pretty empty in valuable datasets, or the datasets could be usefully combined with other sets that we didn't have."*

Users were frustrated they could not exploit more than the city's OGD portal for their project since the data was too limited and they had little insights into Namur's challenges or priorities, citizens' needs, and market opportunities. The interviewees reported being discouraged by the abundance of existing apps, the lack of domain knowledge and given examples, the absence of precise demand, and the lack of useful datasets. As one user explained: *"It would have been helpful to have ideas from the citizens"*.

2) Search and evaluate: The interviews confirmed that the main impediments for the *search and evaluate* phase are in the *evaluate* activity. No interviewee reported issues with the interface of the OGD portals they used. They found that the portals were well-designed in this regard and provided adequate features for searching data, such as filtering and suggestion of related datasets. The *evaluate* activity, however, was more challenging. The interviews confirmed that the main impediment in the phase is the lack or inadequacy of metadata, as observed when analyzing the questionnaire answers. Six users stated that they encountered issues with metadata. The interviews allowed us to refine this point, and uncovered that the *evaluation* of data can be examined at different granularity levels.

Firstly, three users faced issues with the **data features** (e.g., columns in a dataset) names, which they found uninformative

and badly described. Unexplained columns meant that the user could not use the dataset. For example, one user encountered a population census dataset holding a number of girls and a number of women and he had to make calculations with census data to determine whether the girls are also counted as women. Another user complained: "*In our datasets, half to three-quarters of the features we didn't know what they meant, and it wasn't explained anywhere [...] We completely ignored these columns*".

Secondly, metadata at the **dataset** level were mentioned by three interviewees as an issue. One user was disappointed that "*some dataset titles are awesome, but there is nothing exploitable in them.*". In order to compensate for appropriate metadata, users had to resort to other evaluation methods. One user downloaded the data for further examination. Even worse, one user reported feeling frustrated, as the lack of informative metadata prevented exploiting the full potential of the available data. On the other hand, one user used the API request functionality to explore a dataset. Nonetheless, some features offered by portals were helpful in the evaluation of data. One user noted that the reuse examples comforted him with the potential of the data and increased his motivation to use data. Another user mentioned the usefulness of visualizations showing an overview of data as helpful.

3) Access and prepare: The in-depth interviews allowed us to explore the data quality impediment reported in the questionnaire. On a general note, the data quality was very fluctuating across datasets. There was a lot of data in the datasets that three interviewees respectively qualified as "*missing*", "*irrelevant*" or "*corrupted*". Two interviewees mentioned the lack of longitudinal data as the main impediment for regression analysis. Finally, a lack of consistency in the datasets was also reported by four interviewees. These impediments impacted the output of the work. One user noted the **impact** as *"because of the few relevant datasets our application was not as valuable as we wanted. Our application issues abnormal recommendations, such as: fewer trees will lead to better air quality!"*.

No major issue was reported in terms of data formats as most of the datasets were available in JSON and CSV. Some case-to-case issues were still reported, such as some irrelevant geographic data formats and the presence of the "string" data type instead of "integers" data type.

Also, the interviewees experienced no major problem with the API:s (one API was missing, and some errors were present in the requests). However, three respondents declared they did not use the API but rather downloaded the data directly. This approach may reveal that they did not see the added value of using this channel to access the data. It indeed often seems faster for the users to just download data. The approach may also indicate that the users did not seek to develop a sustainable solution.

4) Aggregate and transform: In the in-depth interviews, the interviewees explained some activities in the *aggregate and transform* phase. For the *aggregation* activity, users can select specific datasets based on criteria, select columns in the dataset, merge datasets to fill out gaps, and use scripts to clean the data. Merging can be time-consuming and involve a "one at a time" error solving approach. As one user told us: *"I spent a very large part of my time just on data aggregation since it was a monster mess."*. For transformation, users can calculate averages, integrate data into web applications, think about the end-user experience, and seek support. For example, for a specific technique, such as machine learning. However, there were also a few impediments. To make data combinable, sometimes keys needed renaming, data needed normalization as datasets were inconsistent (e.g., different metrics), and, in other occasions, several datasets had to be merged to form a complete dataset. As one user explained: *"[Datasets] didn't use the same way of localizing things. They all used neighborhood names, but the issue was that they didn't use the same neighborhood names. [...] It was nearly impossible to do the matching; they didn't use the same partitioning at all."*. In the worst case, data lacked unique identifiers, datasets could use different unique identifiers, or feedback could be hard to leave, making an increase in data quality improbable. On the other hand, *transformation* could be impeded by slow data delivery, a need to add exceptions, and technical complexity. As a result, data needed more preparation to be combinable, which likely contributed to the high time consumption of this phase. One explanation is that when the users once started to transform data or combine data, they noted the work needed to prepare the data. Moreover, the in-depth interviews indicated that it was easier to use one dataset than several, or a single category of data (e.g., photos) than combining several.

V. Discussion

In the following section, we first discuss the quantitative and qualitative data from the users' perspective and give managerial recommendations for publishers.

A. User Process: Theory versus Practice

Following the observations from our study, the user process can be represented as a U shape with the *access* activity at its bottom. The *start*, *search*, and *evaluate* are the left side of the U, while *prepare*, *aggregate*, and *transform* are the right. The U-shape is a representation of the number of and the severity of the studied impediments through the process to gives insight into where users can experience impediments impacting their use. In both the first and final phase (start, aggregation, and transform), none of the measured impediments were reported as *not a barrier*, while there was more variation in the middle. The interviews confirmed that the first and final phases of the user process were the most challenging to the users overall, but different in time consumption and perceived contribution. At the middle of the U-pattern, it is easier to find (*search*) and *access* OGD than to understand (*evaluate*) and make it usable (*prepare*). The impediments reported as *moderate barriers* after the *start* phase seem to come from the data itself or are concerned with the data. Their source is likely the publishers' different practices of data management [10]. Figure 3 illustrates the described U-pattern.

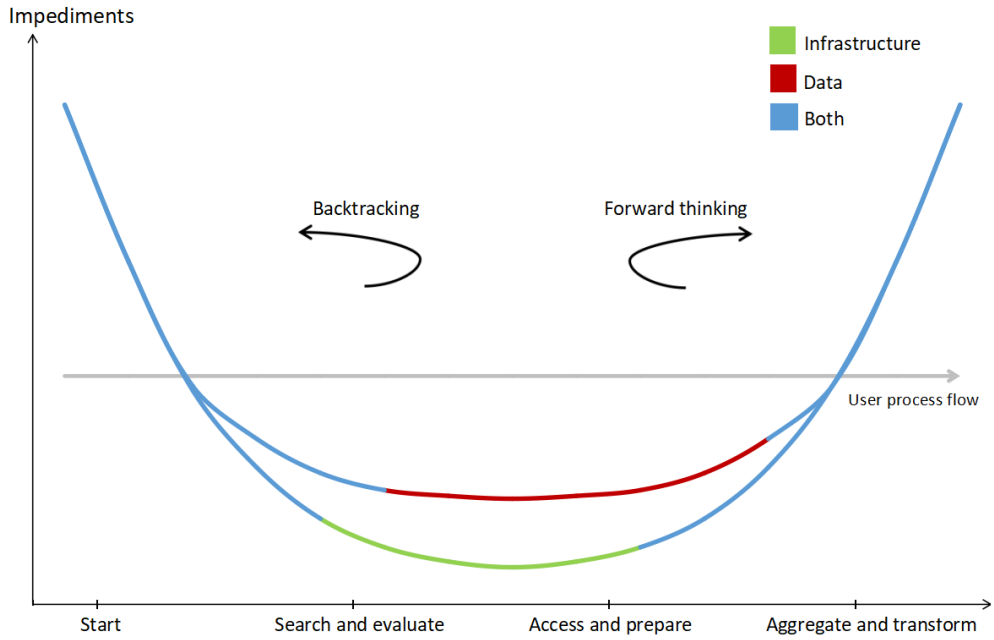


Fig. 3. U-pattern representation of the user process phases. In the first half of the U, users tended to backtrack whereas in the second half they tended to forward-think.

In the descending portion of the U-pattern, users tended to backtrack, while in the ascending part they tended to forward think. Backtracking involves going back from the current activity to a previous activity to resolve an issue in one or both. In our study, we observed users starting with an idea, and then visit the OGD portals for data, only to find none or few datasets fitting with their needs. Then, they returned to the *start* phase to change their idea to adapt to the new information. The lack of data and low quality of metadata are known impediments [10, 44]. Metadata is important for evaluating data and the lack of it can make an analytic investigation impossible [1, 27, 32, 42]. We observed that the availability of large and comprehensive sets of quality data, documentation, and metadata influences the experience and the motivation of the users, especially, in the earlier activities (*start* and *search*). The specific constraints of the class project revealed the importance to able to combine datasets and OGD sources from outside the city's OGD portal to keep stimulating the creativity of the users and maximize the outcome's value.

Forward-thinking involves thinking about what needs to be done in a certain activity to be able to succeed in the next activity. For example, cleaning, merging, and normalizing datasets in preparation for their aggregation. As we observed in our study, the low quality of data meant a need to dedicate more resources to cleaning and normalization of data [27]. The low quality is a known impediment [10, 18, 42] that can make data so difficult to analyze that it is no longer meaningful [39]. The impediments in the second portion of U-pattern likely contributed to the high time consumption we observed for the late phases, as users needed to fix several small problems sequentially and then transform the data into the outcome through development.

A common theme through the user process was the attrition on value experienced from impediments by users. In this paper, attrition is the reduction or wear down of the output's value. Few datasets and incompatible data made certain ideas and solutions impossible to implement, meaning that users had to go for something else or ignore important data (we are not arguing that every idea is a valuable idea). The lack of unique identifiers can impede the ability to combine datasets and scale the product [27]. At the same time, incomplete data, the lack of longitudinal data, and varying data availability caused the outcome to have a lower value. The attrition encourages the use of one dataset or of a single category of data (e.g., photos). In worse cases, it can encourage the use of a few columns in a dataset. Impediments do not always attrit an idea; sometimes the user is able to adapt. The backtracking above is one example, another was when a user downloaded a dataset to further evaluate it as the metadata was lacking, and a third was when a user renamed keys and merged datasets to overcome data quality. However, adoption can still mean changes in the value of the outcome.

In previous research, similar to [4] we have identified that not all impediments are perceived to be equally severe. Impediments are often interrelated and can create such a high threshold that "open" data is still private in practice [20]. The threshold can make certain value creation impossible. In our case, impediments were discovered to also attrit the idea, as such they are more than a binary threshold. Moreover, the phases of the user process are interdependent [42] and we identified that activities in previous phases can be used to negate impediments in the subsequent phases, and not only create them. For the OGD user process, quality of data, availability of data, and infrastructure are important [20, 30], which

our research highlights. The large number of diverse data structures can make comparison and aggregation impossible [1].

B. Managerial recommendations

The results show that the impediments can restrain and discourage even skilled users. A publisher aware of the user impediments can develop strategies to support users or change the infrastructure or data to ease usage - strategies that increase the likelihood of better return of investment. The areas of improvement are not limited to technical aspects. We suggest publishers to perform several actions to enhance the user experience and encourage projects development.

Firstly, we suggest publishers to introduce feedback mechanisms for the users to report incomplete data and lack of longitudinal data or metadata. A more advanced feedback mechanism could empower the users to improve the metadata and the data themselves.

Secondly, publishers can follow common standards in how the data is structured (e.g., formats and content) to allow for easier harmonization between datasets. This approach can lessen the time needed to prepare the data for aggregation and use.

Thirdly, publishers could enrich the portals with datasets from other public actors, institutions, and local organizations. The portals could also be enriched with data collected through sensors by several stakeholders. Enriched portals could enable the creation of more innovative ideas.

Fourthly, publishers can involve the users in the development of the portals. This participation can be implemented through several methods (e.g., workshops, interviews, living labs). The user participation can help publishers better understand the needs of the users and understand what support and features they need (e.g., tutorials, projects examples, reporting systems). This continuous exchange between users and publishers can support the improvement of both the portal and the re-use projects.

Finally, publishers could give users the opportunity to innovate and compete around real problems and needs. This opportunity can increase the match between output and real-world application. OGD can provide an opportunity to build a community around problem-solving in the city. One way to achieve this is the organization of hackathons by the city in collaboration with other stakeholders (universities and businesses).

VI. Limitations

Our study presents some limitations mainly based on the specific sample of 30 students. However, we also argue that this limitation does not introduce fundamental bias in the study as students constitute a re-user group of OGD [24, 30]. Still, the limitations introduced by the selected sample are discussed below.

Firstly, our sample consisted of skilled students with computer science, management, or mathematics backgrounds. Therefore, their digital literacy is quite high. We argue that this sample is representative of the OGD users but not of the full population. Thus, alternative studies with users with low or normal digital literacy could be interesting to perform in order to compare the findings. Alternative studies can also extend the sample to study OGD users at the city level to generalize the findings.

Secondly, the motivation of our sample was biased as it is an imposed class project that the students had to perform. Therefore, we were unable to capture information about what could motivate and drive users to visit the OGD platforms in the first place.

Thirdly, the conditions and rules of the class project itself introduced limitations. The students had limited time, and the project was based only on OGD city portals, which restricted the number of datasets. It does not represent the real practices of users, who can be used to web-scrapping or combining datasets from various publishers. This constraint could misrepresent the perceived difficulties through the process, especially, at the *start* phase. As a consequence of time constraint and educational context, priorities were put on the search, access and aggregation phases. The objective of the students was to deliver on time a visualization or an application to pass the class project, whatever its market viability or power of advocacy. The time dedicated to each phase should consider variables in skills, the profile of the users, objectives of the project and avoid generalization.

VII. Future Work

In this section, we describe solutions that can be performed to solve the issues raised in this paper. Also, the text will open for future research.

A. Questionnaire validation

In the proposed questionnaire, several impediments were measured for each project phase. Although the objective was to identify individual impediments, we wondered if the scores for each impediment of a given phase could be used as a reliable measurement of the difficulty experienced for this phase. For this purpose, we computed the Cronbach's alphas [8] for each of the four phases. The results displayed by Table III shows that the alpha is acceptable for the *search and evaluate*, *access and prepare*, and *aggregate and transform* phases. These numbers encourage us to envision the design and validation of a questionnaire aiming to measure the difficulty for each phase of an OGD project as a future contribution. In particular, a reliable measurement scale measuring the difficulty encountered in the *start* phase needs to be developed in order for the current questionnaire to reliably assign a difficulty indicator for each phase.

B. User Process Framework Refinement

The user process framework [9] is still under development, but has been peer-reviewed by colleagues and in a workshop. However, the framework needs further development. The identified impacts of the impediments need to be integrated into the framework as they are adaptions to impediments, rather

TABLE III
CRONBACH'S ALPHAS FOR EACH PROJECT PHASE

Phase	Cronbach's alpha	Internal consistency
Start	0.466	Unacceptable
Search and evaluate	0.706	Acceptable
Access and prepare	0.760	Acceptable
Aggregate and transform	0.805	Good

than expected activities. At the same time, the interaction of phases can cause new impediments and behaviours, such as backtracking. This relationship means that the phases are more interdependent than a linear process. More importantly, we also found that the phases have different perspectives and different "problem pictures" (e.g., find an idea that is feasible at the start or increased time-consumption at the end).

C. Ecosystem View on Open Government Data

Valuable and sustainable reuse of the OGD not only depends on the users' capabilities or the publishers' infrastructure but on their interactions. The supply-driven approach of the OGD platforms shows its limits. The impediments and feedback reported by the interviewees outline the importance of considering them as stakeholders instead of data consumers. In an ecosystem with OGD as a shared resource, each stakeholder has his own perspectives and expectations: political, economical, technological, or bureaucratic [13]. Research should be conducted on the different support methods needed to stimulate collaboration between actors. What model of partnership or cooperation can enhance the value creation in multiple perspectives? What model of platform can promote interaction in the system? This last question supposes not only new features on a platform but a change in the knowledge and value creation paradigm [11].

D. Support for Idea Generation

The OGD reuse is a project with prospective benefits for citizens, communities, or markets. More research is needed to support the users' needs in the *start* phase since finding a valuable idea was reported as a key challenge by respondents. The application of several citizen participation methods, as described by [34], to stimulate the idea generation might be useful. Indeed, using creativity techniques to stimulate discussions among citizens or taking advantage of ideas submitted in participation software are two relevant examples. With these ideas, needs, and requirements properly elicited, it can allow the development of products and services aligned with actual issues faced by citizens.

VIII. CONCLUSION

The publishing of Open Government Data (OGD) by public organizations has promising possibilities, such as the creation of a new data-driven sector and collaborative efforts toward innovative products and services, with data accessible to all. However, the actual use of OGD remains low [30] and its potential is largely under-exploited.

In this article, we selected a user process framework as a theoretical baseline to study the impediments experienced by 30 students who conducted a class project using OGD. Through a mixed-method research approach involving a questionnaire and semi-structured interviews, we were able to identify the impediments to OGD use students experienced, for each phase of their project. Our results show that finding an innovative use for OGD, the lack of metadata describing OGD properly, and the lack of support to combine OGD datasets are the most detrimental difficulties faced.

In our research, we studied how impediments could impact the user as they progress through the OGD process. We identified that impediments caused the user to adapt by, for example, doing more backtracking and forward-thinking. In cases were adaption was not possible, the end-product would experience attrition (lower or change in value). For backtracking, the user needed to have the capability to be creative with the limited available datasets, while for forward-thinking, the amount of needed resources increased. Together, the impediments increased the need for motivation. Large and comprehensive sets of combinable data, documentation, and metadata are important for the OGD use process.

Subsequently, we discussed the theoretical implications of our findings, and we provided managerial recommendations to publishers in order to encourage them to consider these impediments before publishing OGD, with the goal to foster use by users (e.g., citizens, organizations, and entrepreneurs).

Our findings encourage governments to reverse the local supply-driven approach towards a contextualized OGD strategy as a collective endeavour. A user-driven platform beside a continuous communication of the city challenges and priorities could help to raise interest and engagement (top-down) and sustain spontaneous, efficient, and valuable reuse of the OGD (bottom-up). At the same time, working to find common standards and formats for the data can allow value creation outside a single dataset and region.

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APPENDIX A
FULL QUESTIONNAIRE

Please refer to Table IV.

APPENDIX B
INTERVIEW GUIDE

The interview starts with a brief reminder of the phases. The questions about the phases are answered. The interview is structured in six parts: introductory questions, phase-specific questions (for each of the four phases) and concluding questions.

OVERALL

1) To warm up, give us a brief presentation of your project and how you worked with it.
2) In the survey we had the phases start of the project, search and evaluate, access and prepare, and aggregate and transform. How do you think this fitted with how you worked? Is any activity missing? If so, which?
3) Rank the four phases by difficulty.

START

Main barriers: finding the idea, finding an idea applicable to Namur, and finding "Use-case" examples of Open Data.

1) Was it difficult to find an idea of application for open data? Why? What was particularly tough?
2) If not, did you experience any barriers at the start of the project? If so, what barriers and how did they impact your work?

SEARCH AND EVALUATE

Main barriers: quality of metadata.

1) What was your overall barriers when using the Open Data Portal? Give an example.
2) Did you experience any barriers with the quality of the metadata? If so, how did they impact your work? Give examples.
3) If not, did you encounter any barriers when searching for the right data? If so, what barriers did you encounter? How did they impact your work? Give examples.

ACCESS AND PREPARE

Main barriers: relevance of data formats and data quality.

1) Did you experience any barriers from the data formats or data quality. If so, how did they impact you work? Give examples.
2) If not, did you encounter any barriers when accessing and preparing data? If so, what barriers and how did they impact your work? Give examples.

AGGREGATION AND TRANSFORMATION

Main barriers: data cannot be combined, data availability varies, tools cannot combine the data sources, and no longitudinal data.

1) Did you experience any barriers when trying to combine and use the data in the product? If so, tell us about it. How did they impact your work? Give examples.
2) If not and if you did experience any other barriers, what barriers did you encounter and how did they impact your work? Give examples.

END ON A HIGH NOTE

1) If the barriers persisted, would you be motivated to continue developing a product or service on open data? Why?
2) What is your dream scenario for working with open data?
3) What do you need to get there? How can publishers and open data portals support you?
4) Is there anything you think we have forgotten to ask about? Or something relating to the project you want to tell us about?
5) Did you experience any barriers not captured by the survey or mentioned in the interview? If so, give some examples.

TABLE IV

Part	Question	Measure instrument
Introduction	Can you provide your name or a brief description of the project you worked on? (this will be used to aggregate the answers by project)	Free text
	What is your background?	Multiple choice (management, computer science, mathematics, science, other)
	How confident are you with • Programming • Data analysis • Open data portals	5-point Likert • Very confident • Confident • Neutral • Not confident • Not confident at all
Start	For each of the tasks below, please indicate how difficult it was with the following scale. • Finding the idea • Finding an idea applicable to Namur • Finding "Use-case" examples of Open Data • Understanding the requirements of potential users of the project • Conducting a feasibility study of the idea	5-point Likert • Not a barrier • Light barrier • Moderate barrier • Serious barrier • Extreme barrier
Search and evaluate	For each of the tasks below, please indicate how difficult it was with the following scale. • Search functionality • Search results presentation • Quality of metadata • Had to download the data to evaluate it • The tools for exploring of, analyzing of, or experimenting with data • Open Data portal language • License impedes the use • Must log in to evaluate and access the data	5-point Likert • Not a barrier • Light barrier • Moderate barrier • Serious barrier • Extreme barrier
Access and prepare	For each of the tasks below, please indicate how difficult it was with the following scale. • Wrong type of access (Manual vs. Automated) • Complex access with documentation • Filtering useful data • Relevancy of data formats • Data quality (e.g., missing essential information) • Lack of documentation to prepare data (e.g., conversion tables) • Data is inaccessible because of paywalls, limitations of infrastructure, or demands of registrations • No support (e.g., lack of documentation or forums)	5-point Likert • Not a barrier • Light barrier • Moderate barrier • Serious barrier • Extreme barrier
Aggregate and transform	For each of the tasks below, please indicate how difficult it was with the following scale. • Data cannot be combined • Data quality varies • Data availability varies • Tools cannot combine the data sources • No longitudinal data • Data infrastructure cannot be integrated • Data needs special knowledge to understand	5-point Likert • Not a barrier • Light barrier • Moderate barrier • Serious barrier • Extreme barrier
Resource allocation	Please rank the four phases from most-time consuming (1) to least time-consuming (4).	4-point ranking
	Can you rank the four phases from the one in which you contributed the most (through your skills) (1) to the one in which you contributed the least (4).	4-point ranking
Perceived usefulness	Do you think the time invested in the following phases was useful to the final output of your project? • Start • Search and evaluate • Access and prepare • Aggregate and transform	5-point Likert • Very useful • Useful • Neutral • Not very useful • Not useful at all
Final questions	Have you applied the 4 phases above sequentially or iteratively?	Binary choice
	Did you have to learn new technologies, techniques, concepts to carry out the Data Science project?	Free text
	Which open data portals did you use?	Multiple choice (Namur, London, New-York, Paris)
	Are there any reasons why you did not use specific portals?	Free text
	Do you have additional comments on open data portals?	Free text

Towards a Software Sustainability-Quality Model: Insights from a Multi-Case Study

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***Abstract*—Background. Software sustainability is defined in terms of multiple and interdependent dimensions (economic, social, technical and environmental). Preliminary initiatives have investigated the contribution of certain quality attributes to sustainability dimensions.**

Problem. Despite these valuable efforts, the characterization of software sustainability is still a key challenge. This entails how sustainability can be embraced in the design of software systems by identifying the relevant software quality attributes (QAs) and their dependencies. Both attributes and dependencies vary heavily with amongst others the type of software system and its operational context.

Aim and Method. We followed a multiple case study research method with the main objective ofinvestigating the applicability of the sustainability model in different contexts. We aim also to enrich our model, by means of identifying missing quality attributes or new contributions to the sustainability dimensions. We selected two software projects as cases of our study, where each one was independently conducted in specific situations.

Results. The results of the study show that the relevant quality requirements identified in both projects (cases) are covered by most of the QAs related to the social (82%) and technical (83%) dimensions. Moreover, some QAs that were not addressed in the corresponding projects, their relevance like context completeness, and flexibility were acknowledged. These results suggest that the software sustainability model could support the identification of relevant QAs. The case study also contributed to identify QAs that had not been considered in the economic, technical and social dimensions of the sustainability-quality model.

***Index Terms*—Software quality, sustainability, multiple case study.**

I. Introduction

Maintenance, evolution and adaptation can be extremely costly and painful for organizations due to the continuous and fast evolution of technology (e.g. paradigms, programming languages, etc.), which challenges the of software-intensive systems to be efficiently used in the future [1]. As a result, in recent years, there has been growing interest in understanding what sustainability means in the field of software engineering. In the literature, we can distinguish at least two distinct viewpoints:

1) Sustainability IN software: it is concerned with the principles, practices, and processes that contribute to software endurability (e.g. [2], [3], [4])
2) Sustainability BY software: It is concerned with the achievement of sustainability goals by the help of software (e.g. [5], [6], [7]).

Both viewpoints are in line with software sustainability as defined by Lago et al. [8] and Venters et al. [9]. They agree on defining software sustainability in terms of multiple and interdependent dimensions (social, economic, technical and environmental). According to Lago et al. [8], these dimensions are defined as follows: The *economic dimension* aims to ensure that software-intensive systems can create economic value. The *social dimension* focuses on ensuring current and future generations have the same or greater access to social resources by pursuing generational equity. The *environmental dimension* seeks to avoid that software-intensive systems harm the environment they operate in. And, the *technical dimension* is concerned with supporting long-term use and appropriate evolution/adaptation of software-intensive systems in constantly changing execution environment.

Based on this multidimensional nature of sustainability, current efforts have been put in the definition of a Software Sustainability Model (e.g. [10], [11], [12], [13]). With the purpose of characterizing each sustainability dimension, Condori-Fernandez and Lago. [14] investigated the contribution and relevance of quality attributes from different perspectives. Given a quality attribute can contribute to one or more sustainability dimensions, preliminary direct dependencies among sustainability dimensions were also identified [14]. As the relevance and contribution of these quality attributes are very context-dependent, in this paper we propose an holistic and exploratory multiple case study with the main objective of investigating the applicability of our preliminary sustainability model in different contexts. To that end, we selected two industrial cases from different domains that cover the two sustainability viewpoints discussed above(sustainability IN/BY software).

The contribution of this work is twofold. First, it offers insights regarding the applicability of the sustainability model in different contexts. Second, it generates new insights into the

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characterization of the sustainability dimensions, by means of identifying missing relevant quality attributes and corresponding relations among dimensions.

The rest of the paper is organized as follows. Section 2 introduces the exploratory case study, which includes objective, research questions, data collection techniques, and data analysis. Then we present the results and summarize the main findings in section 3. Section 4 discusses threats to validity of the cases studies. Section 5 presents the related works. Finally, Section 6 concludes the paper.

II. Research method: Case study

We used an holistic multiple-case study ([15], [16]) in order to gain insights for investigating the applicability of a sustainability model for software-intensive systems. Figure 1 shows the main activities that compose the process to perform the multiple case study. These activities are: plan design, data collection, data analysis, and reporting results.

A. Plan design

1) Objective and research questions: The **objective** of our multiple case study approach is to explore the applicability of the sustainability model for identifying relevant quality requirements in different contexts (i.e. organization, type of project and domain).

Moreover, as a consequence of using the model in multiple cases, an iterative improvement of the sustainability model is expected, by adding new quality attributes or extending the definition of the existing ones due to their actual contribution to other sustainability dimensions that were not originally considered.

To achieve this objective, the underlying **research question** is formulated as follows:

(RQ) *"How applicable is the sustainability model in practice for identifying the relevant sustainability-quality requirements?"*

In the context of our study, applicability is investigated by analyzing if the quality attributes (QAs) of the model do cover the relevant sustainability-quality requirements of the software project at hand.

2) Cases and Units of Analysis: In this paper, we investigated two different cases, which were selected by convenience. The companies of both cases were selected from the contact network of the researchers.

Regarding **Case A**, the investigation focused on a project evolving a pre-existing *Customer Relationship Management (CRM) system*. It involved the employees in charge of the project, i.e. business analysts, functional administrators, a project manager, an architect and business managers. The start of the implementation of the CRM system was five years ago. The system was part of a bigger project, aimed at making the whole organization more customer-driven (as opposed to product-driven).

Regarding **Case B**, the investigation focused on devising a new software solution required for reducing *food waste* within a Dutch Airline company. Particularly, such software solution should contribute to improve the business processes from the catering companies, cabin crew and planning department. The goal of this new software system is food waste-reduction and increasing user friendliness.

For each case, Table I summarizes the related context and unit of analysis.

The cases are adequate to investigate whether our sustainability model can encompass a broad range of quality aspects of the respective software system. Through the application of our model, by means of a multiple case study research method, we are going also to be able to identify missing quality requirements, detect incorrect dependencies (contributions), and confirm the contribution of those qualities to each sustainability dimension identified in [14]. In particular, the selected cases allow us to investigate sustainability from two complementary angles:

1) Sustainability *in* software, where the sustainability impact can be observed in the software system itself (e.g. energy efficiency). Case A mainly targets this level of sustainability, since a key objective of the resulting software is to be itself better maintainable.
2) Sustainability *by* software, where the sustainability impact can be observed in the processes supported by the software system. Case B mainly targets this level of sustainability, since a key objective of the resulting software is to help reduce food waste.

B. Data collection

As shown in Figure 1, we used various data collection techniques (see blue arrows in Figure 1). In particular, for Case A the data was collected by using three different techniques (document analysis, user test, and interviews) then combined, whereas A/B testing and interviews were the techniques used for Case B.

1) Data collection techniques used in Case A: **Document Analysis.** The data gathered from the analysis of internal documents was obtained in several iterations in order to understand (i) the organizational goals that motivated the evolution of the pre-existing software system (i.e. CRM system); (ii) the functional and non-functional requirements; and (iii) the design of the software system. One of the authors spent about two weeks on the analysis of the documentation provided by the company. This analysis mostly served to prepare the first iteration of interviews with the team members involved in the project.

User Testing. In order to identify which requirements were addressed in the CRM system, a user test was performed with one business analyst from the company, who did not have any previous experience in using the CRM system while having an interaction with a customer. Thanks to this lack of experience, the user was able to pay extra attention to certain quality aspects of the system. The test took around 40 minutes. The results of the user testing helped to prepare the second iteration of interviews.

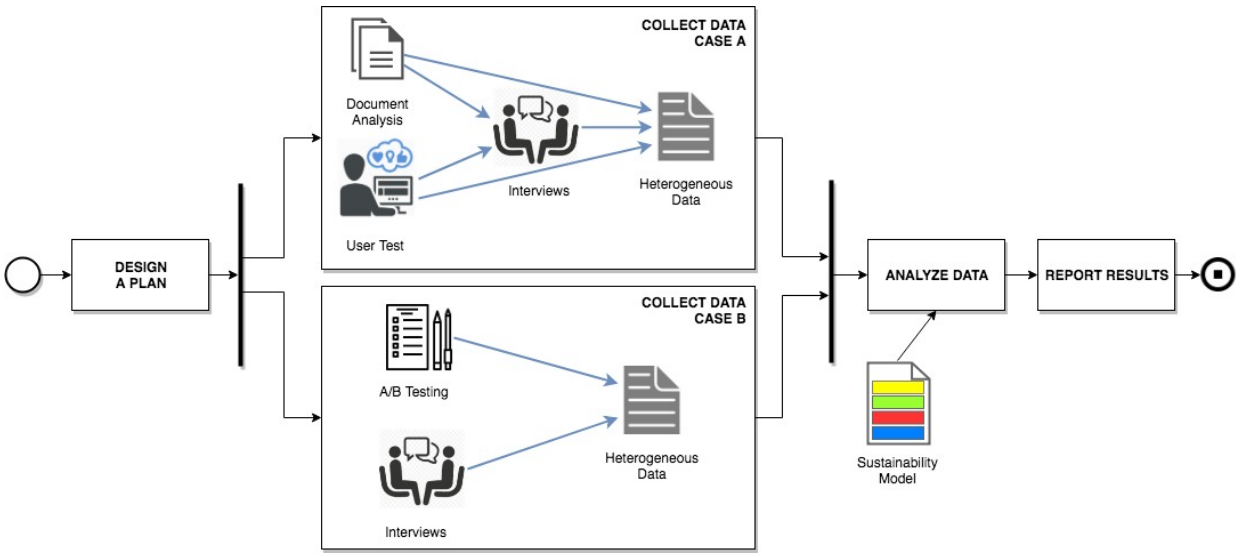


Fig. 1. Process of the multiple Case Study approach

TABLE I
CASES, CONTEXT, AND UNIT OF ANALYSIS

	Context	Sw system	Domain	Sust. angle
Case A	The organization is one of the world leading providers of insurances, asset management and pensions, with more than 170 years of business experience. It counts about 28,000 employees worldwide.	Pre-existing	Customer Relationship Management (CRM)	IN
Case B	The organization is a multinational leader in end-to-end IT and business consulting services. It counts over 72,000 employees worldwide.	New	Food Waste Management	BY

Interviews. The semi-structured interviews served the purpose of understanding how stakeholders interpret software sustainability in terms of quality requirements.

In Case A, semi-structured interviews were carried out with nine employees who were involved in the implementation of the pre-existing CRM system. The duration of each interview was between 30 and 60 minutes. Interviewees were provided with a shortlist of quality requirements identified by Condori-Fernandez and Lago [14]. This preliminary shortlist was made with the results found from the document analysis and user tests. Therefore, the purpose of the interviews was mainly confirmatory in nature.

2) Data collection techniques used in Case B: **Interviews.** Several stakeholders with different backgrounds were involved. The data gathered from *cabin crew members* with 3 or more years of experience allowed us to understand the behaviour of passengers on different types of flights and their buying habits; the data gathered from *managers from catering companies* provided us with an overview of the requirements that should be considered from the side of these catering companies, and hence gain more information about the feasibility of the proposed solution. The duration of the interviews oscillated between one to two hours.

All interviews were conducted face-to-face in The Netherlands between February and May 2018.

A/B testing. As a prototype app was implemented, it was used for validating the requirements of the project by means of A/B testing. This technique is conducted under experimental conditions, where two or more variants of a software product are shown to users at random. A/B testing is used to determine which variation performs better for a given goal. In Case B, two variations of the created prototype app for passenger and cabin crew were used. For instance, variant A showed the products by displaying them as tiles with 2 products per row, where variant B displayed them as a list/table. As part of the A/B tests, an online questionnaire was designed and conducted with the participation of practitioners from different areas of expertise (e.g., aviation, data analytics). The questionnaire took about 5 minutes.

C. Data analysis

In this subsection, we present the data analysis carried out for answering our research question. As shown in Figure 2, researchers in collaboration with stakeholders identified the quality requirements from the collected data. Then, stakeholders related the identified qualities to the sustainability

dimensions (i.e., economic, technical, environmental and social), which could contribute to identify new quality requirements for the project. Finally, these quality requirements were mapped on the corresponding quality attributes of the sustainability model [17].

Next, we list the quality requirements considered in each case.

1) Case A: Customer Relationship Management: According to the data found from the **document analysis**, the selection of possible CRM systems available on the market was based on three fundamental aspects: i) a centralized customer-view, ii) CRM case management, where cases are issues associated with a customer account, and iii) availability of the CRM system. Among the documented quality requirements that were derived from these three aspects are: functional suitability, interoperability, integration, performance, maintainability and availability. The best CRM system fulfilling these requirements was chosen.

Through the **user tests**, additional quality requirements like usability were found. For instance, users considered that the selected CRM system is appropriate for their needs, and it is easy to use. Moreover, as the CRM system is a cloud-based solution, we found security, availability, portability and satisfaction requirements as relevant, too.

Through the **interviews**, we found a list of quality requirements that were considered as relevant to contribute to the social, technical, economic, and environmental sustainability dimensions (see Table II). The interviewees where also asked to prioritize the quality requirements based on how important this requirement was in the selection of the CRM system and its development phase. The five most frequent quality requirements where (ranked from top to bottom) maintainability, usability, compatibility, security and functional suitability.

2) Case B: Food waste management: In contrast to Case A, most of quality requirements were identified through **(group and face-to-face) interviews** conducted with personnel of the airline company. The purpose of the interviews was to elicit requirements of the new software system to be developed. For instance, usability, availability, and fault tolerance were considered as the most important for responsible of the cabin crew. Other requirements considered also as relevant were: scalability, compatibility, performance, privacy, and security. And user satisfaction was tested by means of A/B tests.

Table II shows the list of quality requirements that were identified in the corresponding project and considered as contributors to the different sustainability dimensions from the stakeholders perspective.

In the next section, we present the results of mapping the list quality requirements (Table II) to the quality attributes of the sustainability model [17].

III. Results

As a result of the mapping (See Figure 3), we focus on the findings related to (i) the applicability of the model for identifying quality requirements in software projects; and (ii) the enrichment of the model by identifying other relevant QAs to the sustainability dimensions as well as their dependencies.

A. Applicability of the Sustainability-quality model

According to Figure 3, for the applicability of the sustainability model we highlight two type of findings:

- **QAs covered:** QRs of the software projects (Case A and Case B) that were *already covered* by the QAs of the model are shown in the Appendix, Tables III, IV, VI, and V (see QAs marked by the symbol ✓and listed above the line).
- **QAs discovered:** The QAs marked by the symbol ‡ represent those qualities that were not addressed in the corresponding projects but were identified as relevant after using the Sustainability-quality model.

In the following, both findings are discussed per dimension, by highlighting some of the qualities of the model considered as important requirements in the corresponding projects:

1) Environmental sustainability: Similar to economic dimension, few QAs of the sustainability-quality model(Table V) were confirmed as relevant environmental sustainability-quality requirements (i.e., reusability, modifiability, resource utilization, time behaviour).

2) Economic sustainability: In comparison to social and technical dimensions, several QAs of the economic dimension shown in Table VI were not considered as relevant by stakeholders of both cases (e.g. satisfaction, reliability, economic risk mitigation, functional completeness). It is possible, therefore, that the economic sustainability dimension of our model requires more validation, specially with those QAs that were not considered as relevant as well as the new ones added to the model (see next subsection).

The lack of stability in both economic and environmental dimensions can be due to the lack of competences of ICT experts in sustainability. Social and technical implications of software systems is a much more consolidated practice than the competences related to economic and environmental sustainability, which was also reflected in [14].

B. Enrichment of the Sustainability-quality model

In this sub-section, we discuss i) the new QAs that were *added to the model*; and ii) the extension of QAs's contributions (direct dependencies) to other dimensions not detected in the original model (see QAs listed below the line in the same tables III, IV, V, VI).

1) New QAs in the Model:

- **Data Privacy** According to Barker et al. [18], privacy concerns arise wherever personally identifiable information is collected, stored, or used. In case B, as the app must handle private user data for product orders, data privacy was a requirement to be addressed in the project. Given the contribution of this quality to the social sustainability, Data privacy was also added to the sustainability model.

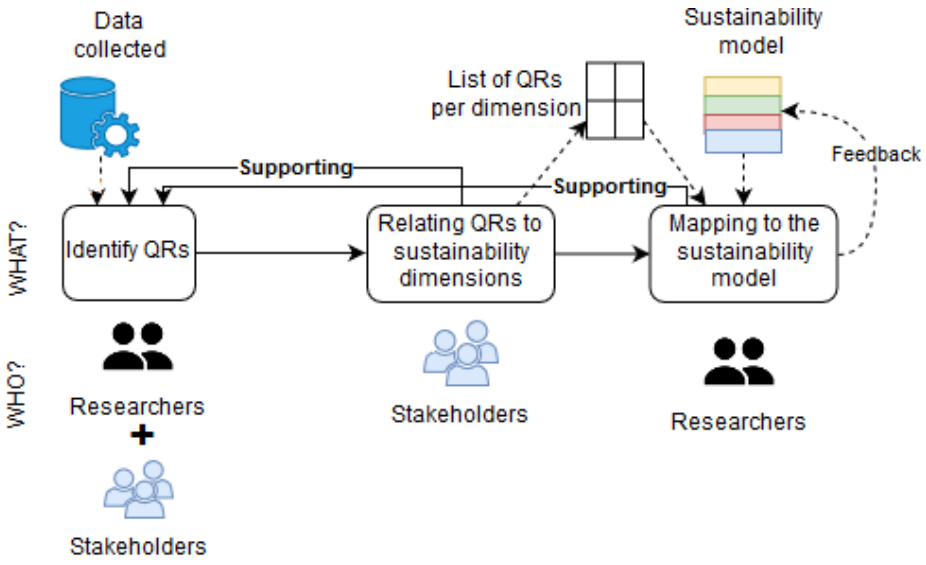


Fig. 2. Data Analysis carried out per case study

TABLE II
CONTRIBUTION OF QUALITY REQUIREMENTS TO EACH SUSTAINABILITY DIMENSION FROM STAKEHOLDERS PERSPECTIVE

Dimension	Case A: Sustainability IN software	Case B: Sustainability BY software
Technical	Functional Suitability, compatibility, effectiveness, maintainability	Compatibility, reliability, maintainability, functional suitability
Social	Security, effectiveness, usability, compatibility	Security, satisfaction, effectiveness, usability, persuasiveness, data privacy
Environmenal	Maintainability	Resource utilization, environmental risk mitigation, performance efficiency
Economic	Effectiveness, functional suitability, replaceability, compatibility, maintainability, usability, portability, capacity	Effectiveness, functional suitability, efficiency, automatable.

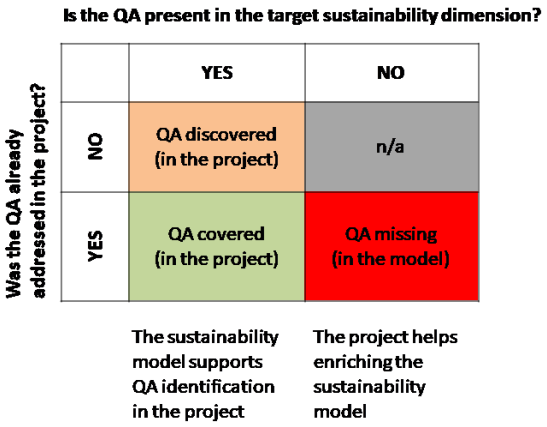


Fig. 3. Main findings from the multiple case study

- **Persuasiveness** In case B, designers aim to persuade end-users to pre-order products before their flight. Thus designing a persuasive mobile app, customer experience is expected to increase by enabling the passengers to order food and beverages upfront with a discount. By doing so, the passengers are sure that their product will be available during the flight, hence improving the current service offering. Accordingly, thanks to its positive impact to the social dimension, we added this QA to the sustainability model by defining persuasiveness as the ability of the software system to persuade its users to take action.
- **Automatable**
The automation of business processes can contribute to the improvement of economic, environmental and social sustainability dimensions in longer term. For instance in Case B, the original business process of an airline company has a standard trolley inventory that is loaded on each plane before flight. However, as the goal is to reduce the food waste, it is no longer possible to serve only standard equipped food trolleys. The business process on the side of the catering companies needs to change.
Although this initially can have a negative economic impact for the organization, the implementation of a predictive data analytics module in the system can contribute to achieve the goal of food waste reduction, by calculating what products and how many of them should be loaded

onto each plane.

- **Replaceability** According to the ISO standard, replaceability is defined as the degree to which a product can be replaced by another specified software product for the same purpose in the same environment. In Case A, this quality was considered as relevant to the *technical* and *economical dimension*. The reasoning of the interviewees was that if the maintenance of a system become so expensive, and harder to fit with the newest systems in the future, replacing the software system that is part of a system of systems can contribute to the sustainability of such systems of systems. Therefore, from this perspective, replaceability could fit to the technical and economic dimensions if we target to replace a software system that is part of a system of software systems.
- **Scalability** This QA was addressed in Case B. The new proposed solution fits in the target architecture, which relies on API-led connectivity. It is an architecture pattern designed for microservices. Although, currently most of the modules to external services are already in place (e.g. the booking- and crew systems), scalability of the system is needed for enabling the connection between the catering companies.

2) Extending the contributions of QAs to other dimensions: In comparison to our original model, we found that the contribution of certain QAs to sustainability could be extended to other dimensions that had not been considered (by respondents of a survey [14]). For example, integrity could also contribute to the technical dimension because thanks to this QA the system can be able to prevent (in certain extent) unauthorized access to the system and prevent that the software system cannot be compromised for example in terms of their functionality or availability.

Other QAs such as compatibility (coexistence), usability (user error protection and learnability), maintainability (modifiability), portability (adaptability) and performance efficiency (Capacity) were identified also as good contributors to the economic dimension.

In order to visualize all the **direct dependencies** between dimensions identified through the case studies, we use a Venn diagram notation (See figure 4). It shows the QAs that belong to the corresponding intersection areas, where a sustainability dimension is defined as a set of sustainability quality attributes. For example, according to the right Venn Diagram shown in Figure 4, the direct dependency between Technical and Economic dimensions consists of seven new ordered pairs whose qualities attributes are: modifiability (A22), coexistence(A16), interoperability (A18), adaptability (A25), capacity (A33), scalability (B4) and replaceability (B3).

Next, we explain the new contributions of these QAs:

- **Security** The relevance of security to social sustainability was confirmed in both cases. However, security was also considered as relevant to the **technical dimension** since the system can be threatened if security is not adequately addressed (Integrity). Therefore, securing the system through the implementation of any mechanism that enables a long-term use of any software-intensive system is also technical, contribution that had not been considered in the original model.
- **Compatibility** In both cases, compatibility (i.e. interoperability and coexistence) was also related to the **economic dimension**. For example, in Case A, before the CRM system was implemented, there was no a central point where all products of a customer could be found. When a customer needed to change her/his address, he or she had to notify all the different business lines separately. Now with the CRM system it is possible that with just one notification, all the connected systems are informed that the new customer´s address need to be updated. As this creates economic value for the organization, both compatibility attributes (A16, A18) resulted as relevant to the **economic dimension**, which had not been identified in the original model.
- **Usability** We found that some of the usability attributes are related not only to the social dimension but also to the economic dimension. The reasoning is that making the system usable (e.g. easy to learn), users will be able to perform their tasks faster, which in turn can help organizations to decrease costs and thus create an economic value, too. For instance, in Case A, the average handle-time of a customer question will decrease since the system can really help in getting the information without errors (user error protection). The quality experience of customers will increase as well, with a positive impact to both **social and economic** sustainability dimensions. The new dependencies correspond to learnability (A13) and User error protection (A12) attributes, which are located in the intersection areas between social and economic dimensions.
- **Maintainability** Maintaining the system is also creating economic value in the organization. If, however, a system becomes a legacy system, the modification of software usually becomes more expensive (e.g. to find the suitable resources to maintain it, lack of compatibility with new systems). This implies a negative impact to the economic and environmental dimensions. Therefore, modifiability (A22) that had been considered as contributor to technical and economic dimensions, now it is extended to the **environmental dimension** as well (See the right diagram in Figure 4.
- **Adaptability** By means of the first case study (Case A), this attribute was acknowledged as good contributor not only to the technical dimension but also to the economic dimension. As the CRM program is a software-as-a-service solution, it is important that the program can effectively and efficiently be adapted not only for different hardware or software, but also for different usage environments (e.g. noisy environments, customers speaking in foreign language, etc.). So practitioners considered that the implementation of adaptation capabilities is technical, but also economic because it also might imply higher costs to the organization. Although we agree

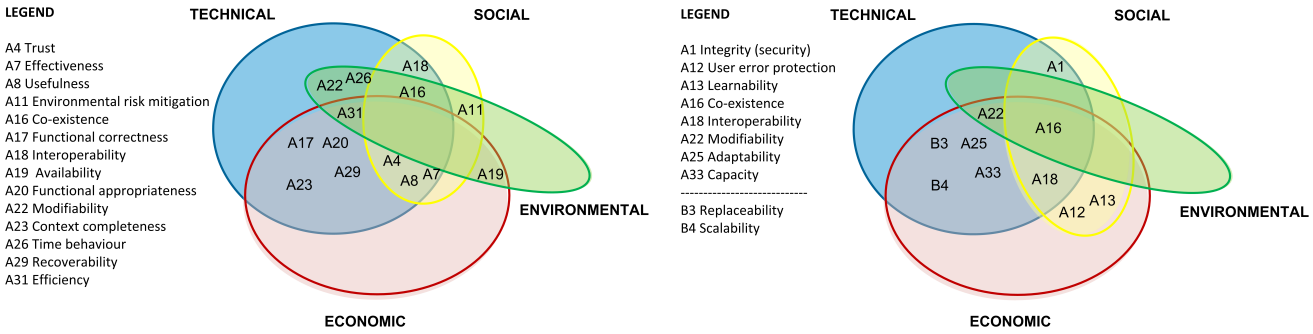


Fig. 4. Direct dependencies identified in the original sustainability model (left), new direct dependencies identified from the cases studies (right)

on such economic implication, we think that adaptability (as technical sustainability requirement) could be related directly to the economic risk mitigation attribute from the economic dimension. However, as this attribute was not considered by any participant of both cases, we decided consider this potential extension for adaptability (A25) as contributor to the **economic dimension** as well, but it still needs more studies to be confirmed.

- **Capacity**
  Practitioners of Case A (CRM project) acknowledged the relevance of this QA to the economic dimension. As in our original model, capacity was only identified as contributor of the technical dimension, we asked the practitioners some examples of situations to verify how capacity was being understood. Some of these examples are: "If the number of users are exceeding the number of licenses that are bought, there is no option to let more users use the system or the organization needs to invest in the licenses. Moreover, If the servers running the system are not having enough capacity, the system will slow down, which will result in more time needed for answering questions and providing the customer with information"; "When a system is running out of capacity, the organization needs to buy extra resources. Creating extra capacity is not possible without buying more resources, like licenses." As a result of these examples, we conclude that whether capacity needs to be addressed, the economic value of the organization will be also impacted. Therefore, although this QA was not acknowledged as relevant for the technical dimension, we decided to extend the contribution of capacity to the economic dimension. As we keep the contribution to the technical dimension, capacity (A33) is located in the intersection between the technical and economic dimensions, represented as sets in Figure 4.

Scalability (B3) and Replaceability(B4), as we discussed in the previous subsection, both attributes were not present in the original model. And as their corresponding contributions were acknowledged to the **economic and technical** dimensions, both are represented also in Figure 4.

IV. Threats to Validity

In the following, we discuss the validity threats of our case studies regarding reliability, internal, and external validity [19], [20].

1) Reliability: It is related to the repeatability of the study. As the execution of the case study was carried out only by one (junior)researcher, the data collection could have been threatened due to the lack of experience of the researcher. To mitigate this threat, both validation and execution activities were always guided by one senior researcher from the university. Moreover, thanks to the several meetings with stakeholders, inconsistencies and misinterpretations were avoided as much as possible.

2) Internal validity: It is related to factors that researchers are unaware of, or cannot control regarding their effect on the variables under investigation. To mitigate the threats related to investigator bias, at least two researchers were involved during the design of the instrumentation. To mitigate threats related to the interviewee bias (e.g. getting false positive answers), people with different roles were interviewed and involved in user tests, which facilitated us to identify possible false positive answers.

3) Construct validity: It reflects how well the measures used do represent the constructs the study intends to measure. In this study, the applicability of the sustainability model is investigated with respect to the QRs identified as relevant in a project. The identification of these requirements is crucial for determining the coverage of the sustainability model. To reduce the threat of missing relevant QRs in the projects, we used different data collection techniques (interviews, document analysis, users tests, A/B tests). This triangulation by method(e.g. interviews, user tests) and data source (data collected from different people) allowed us to reduce this threat.

4) External validity: It is concerned with the generalization of the findings. Since we employed the case study research method, the findings are bound by the context of the selected cases [21]. To slightly reduce this threat, we carefully selected two cases in different companies and different domains, which covered also a different sustainability angle (IN, BY). However, replications of each single-case study is definitively needed for increasing the external validity of our research.

V. Related Work

Being able to assess the impact of quality requirements on sustainability is the first step towards developing software-intensive systems that fulfill sustainability concerns *by design* [14]. The assessment based on the notion of sustainability as a software quality requirement, however, is to date poorly addressed in the literature.

From a purely technical perspective, software sustainability maps on more traditional quality requirements and has been linked, for example, to the notion of longevity [22], stability [23], and evolvability [4]. In our work we cover this perspective by identifying the quality attributes (or aspects thereof) falling under one of the possible sustainability dimensions – namely, technical sustainability.

Through an analysis of the literature, Venters et al. [10] and later on Wolfram et al. [24] discussed the notion of software sustainability. From both analyses it emerges that sustainability is a multi-faceted concept and argue for a quantitative approach [10] that makes explicit the extent to which sustainability concerns are addressed in engineering software systems [24].

Although a dedicated literature exists on approaches for dealing with quality requirements (e.g. [25], [26], [27], [28]), there are still a lack of agreement regarding their definition and classification [29].

Our sustainability model sets a first step in this direction, by offering a toolkit of quality attributes classified along the four sustainability dimensions. To the best of our knowledge there are no sustainability quality models in the literature yet that, similar to ours, address sustainability from a product point of view.

The only exception is the work of Calero et al. [11]: based on the ISO/IEC 25010 Standard, the authors provide a preliminary discussion of which quality characteristics should be considered in addressing software sustainability. As a next step, they propose the definition of a quality model where sustainability is part of the quality of software products. In contrast to our work, Calero et al. defined sustainability only in terms of energy consumption, resource optimization and perdurability (reusability, modifiability, and adaptability). These three quality attributes would map on the environmental (for energy consumption) and technical (for resource optimization and perdurability) sustainability dimensions. Moreover, our work shows that the same quality attribute (e.g. adaptability) does not necessarily impact a single sustainability dimension.

Some research works have addressed sustainability from the perspective of the development process, or even the quality of the whole organization.

Lautenschutz et al. [30] compared and contrasted various Green ICT maturity models. Inspired by the CMM, Hankel and Lago [31] defined the SURF Green ICT Maturity Model (SGIMM) with the aim to assess the maturity of overall organizations with respect to Green ICT. To this aim, the SGIMM includes criteria in four areas, including *greening of ICT* and *greening of the primary processes*. In terms of software systems, these correspond to software energy efficiency and software energy awareness, respectively, which would be mapped on both technical- and environmental sustainability.

Hankel et al. [32] collected factors of influence regarding the environmental impact of ICT, and used them to create a taxonomy, which in turn can be used for quantitative quality evaluations. This work builds upon a pre-existing framework defined by Hilty [3]. This combines the possible orders of impact of Green ICT (namely, direct, indirect and systemic [33]) with whether the environmental impact is positive (part of solution) or negative (part of problem) into a matrix where specific effects are described.

In a similar vein, the GREENSOFT model proposed by Naumann et al. [13] was designed to incorporate quality requirements along the above-mentioned orders of effects. It remains, however, at a mostly process-oriented and very high-level of abstraction, without explicit reference to specific quality attributes.

VI. Conclusion

In this paper, we investigated the applicability of a sustainability model with the purpose of i) understanding how the model supports QA identification; and ii) enriching the sustainability model through a characterization of the sustainability dimensions in terms of relevant quality attributes. To do so, we carried out a multiple-case study, where two software projects from different domains and developed at different companies, were selected by convenience.

The results of this study show that the relevant quality requirements identified in both projects are covered by most of the QAs related to the social (82%) and technical (83%) dimensions, whereas QAs regarding economic (50%) and environmental (38%) dimensions were partially covered. Moreover, despite some QAs of the model were not addressed in the corresponding projects (e.g. context completeness, flexibility), their relevance was acknowledged. These findings suggest that the software sustainability model could support software engineers in the identification of relevant QAs. In fact, practitioners found the sustainability model as very useful not only for identifying requirements but also for prioritizing requirements, by giving higher importance to those that contribute to different sustainability dimensions (e.g. integrity, user error protection, learnability, interoperability, modifiability, adaptability, capacity, co-existence). The relevance of the different dimensions, however, depends on the type of software system [34] or industry sector.

As a consequence of applying the model in both cases, another interesting finding is that the selected projects (cases) helped enriching our sustainability model, by means of:

1) identifying QAs that had not been considered as relevant to the respective dimensions. The results show that most of the new QAs were added to the economic dimension (e.g. automatable, scalability capacity), followed by the technical (integrity, replaceability, scalability) and the social dimension (i.e. data privacy and persuasiveness).
2) extending the definition of some QAs because new relations (direct dependencies) with other dimensions were

identified. Some of these QAs are security (related also to the technical dimension), maintainability, usability, compatibility (related also to the economic dimension).

We consider that more case studies investigating the applicability of the sustainability model in a holistic way are needed for identifying QAs as well as for uncovering the related cross-dependencies. In this paper, we focused only on direct dependencies identified among sustainability dimensions. As a future work, we are going to extend our model with other type of dependencies that can be identified by means of a nichesourcing approach [35].

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APPENDIX

TABLE III
RELEVANT SOCIAL SUSTAINABILITY- QUALITY REQUIREMENTS

Characteristic	Attribute	Case A	Case B
Security	Confidentiality	✓	✓
Security	Authenticity	✓	✓
Security	Accountability	✓	✓
Satisfaction	Trust	✓	✓
Freedom from risk	Health and safety risk mitigation		
Security	Integrity	✓	✓
Effectiveness	Effectiveness	‡	‡
Satisfaction	Usefulness	✓	✓
Usability	Operability	✓	✓
Compatibility	Interoperability		✓
Freedom from risk	Environmental risk mitigation		
Usability	User error protection	✓	✓
Usability	Learnability	✓	✓
Accessibility	Accessibility		
Usability	Appropriateness recognizability	✓	✓
Compatibility	Co-existence	✓	✓
Data Privacy	Data Privacy		✓
Persuasiveness	Persuasiveness		✓

TABLE IV
RELEVANT TECHNICAL SUSTAINABILITY-QUALITY REQUIREMENTS

Characteristic	Attribute	Case A	Case B
Functional suitability	Functional correctness	✓	✓
Compatibility	Interoperability	✓	✓
Reliability	Availability	✓	✓
Functional suitability	Functional appropriateness	✓	✓
Satisfaction	Usefulness		
Reliability	Fault tolerance		✓
Maintainability	Modifiability	✓	✓
Satisfaction	Trust		
Context coverage	Context completeness	✓	‡
Effectiveness	Effectiveness	‡	
Robustness	Robustness		
Portability	Adaptability	✓	
Performance efficiency	Time behaviour	✓	
Maintainability	Modularity	✓	✓
Maintainability	Testability	✓	✓
Reliability	Recoverability		✓
Compatibility	Coexistence	✓	
Reliability	Maturity		✓
Efficiency	Efficiency		
Survivability	Survivability		
Performance efficiency	Capacity		
Security	Integrity	✓	✓
Replaceability	Replaceability	✓	
Scalability	Scalability		✓

TABLE V
RELEVANT ENVIRONMENTAL SUSTAINABILITY-QUALITY REQUIREMENTS

Characteristic	Attribute	Case A	Case B
Maintainability	Reusability	✓	
Maintainability	Modifiability	✓	
Performance efficiency	Resource utilization		✓
Freedom from risk	Environmental risk mitigation		‡
Performance efficiency	Time behaviour		✓
Reliability	Availability		
Efficiency	Efficiency		
Compatibility	Co-existence		

TABLE VI
RELEVANT ECONOMIC SUSTAINABILITY-QUALITY REQUIREMENTS

Characteristic	Attribute	Case A	Case B
Effectiveness	Effectiveness	✓	✓
Reliability	Availability		
Satisfaction	Trust		
Satisfaction	Usefulness		
Freedom from risk	Economic risk mitigation		
Context coverage	Context completeness	✓	‡
Context coverage	Flexibility	✓	‡
Functional suitability	Functional appropriateness	✓	✓
Functional suitability	Functional correctness	✓	✓
Reliability	Recoverability		
Efficiency	Efficiency		✓
Functional suitability	Functional completeness		
Automatable	Automatable		✓
Replaceability	Replaceability	✓	
Compatibility	Interoperability	✓	✓
Compatibility	Coexistence	✓	✓
Maintainability	Modifiability	✓	
Usability	Error protection	✓	✓
Usability	Learnability	✓	✓
Portability	Adaptability	✓	
Performance efficiency	Capacity	✓	
Scalability	Scalability	✓	

A Nichesourcing Framework applied to Software Sustainability Requirements

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***Abstract*— [Background] A software sustainability model is commonly defined in terms of social, economic, technical and environmental dimensions. A key challenge is its characterization regarding sustainability requirements and their dependencies since it depends on, and varies with, the type of software system, and changes in operational contexts. [Aims] With the purpose of facilitating the definition of a context-dependent software sustainability model, we introduce nichesourcing as a type of distributed problem-solving paradigm, named crowdsourcing. [Method] First a set of nichesourcing requirements were identified, and an existing nichesourcing methodology, originally used in the cultural heritage domain was analyzed with respect to its applicability in Software Engineering. [Results] As a result, we propose an adapted methodology for nichesourcing the knowledge on sustainability requirements and their dependencies. Strengths and challenges for crowdsourced software engineering are also identified.**

Keywords—crowdsourcing, dependency, sustainability requirements.

I. INTRODUCTION

Software systems are becoming more ubiquitous as people rely on them in their daily life, work and societal functions [1]. Accordingly, software sustainability is quickly becoming one of the key and urgent challenges of the 21st century.

In the last years, significant effort has been invested in providing principles and common basis of software sustainability (e.g. [2-4]). However, both assessment and design based on the notion of sustainability are still emerging [5-7]. A key challenge for software sustainability is its characterization as a software quality requirement [3]. Being able to identify the impact of quality requirements on sustainability is a first step towards developing software intensive systems that fulfill sustainability requirements.

ccordingly, and from a purely technical perspective, sustainability has been linked to the notion of software evolvability or longevity, e.g. [8]. However, software sustainability has a much broader scope. It is commonly defined in terms of economic, social, technical and environmental dimensions, which are tightly interdependent as argued in [3], [9].

This does not mean that all sustainability dimensions must be always addressed together to guarantee sustainability. In fact, the relevance of the different dimensions depends on, and varies with, the type of software system, and changes in operational contexts (e.g. depending on stakeholder goals). Hence, the identification of relevant sustainability requirements and their dependencies is not trivial since it often requires domain-specific knowledge. In order to gather people that can contribute from several perspectives, a possibility could be based on crowdsourcing, which is an emerging distributed problem-solving paradigm that has been successfully applied in certain software engineering activities [10].

Most crowdsourcing initiatives have been centered around users performing many but simple tasks, and their overall target was focused on "achieving quantity rather than quality" of participants. However, as we require groups of people with high expertise for contributing in the definition of a context-dependent software sustainability model, we introduce nichesourcing to address the growing demand for solving complex knowledge-intensive tasks without decreasing the quality of the final results. Nichesourcing is a specific type of crowdsourcing where complex tasks are distributed amongst a small crowd of experts rather than the faceless crowd [11].

In this paper we adapt a nichesourcing method, called Accurator [12], originally used in the cultural heritage domain. Our contribution is the adaptation of this method for crowdsourcing complex and indecomposable tasks highly demanded in the development of software systems. Specifically, we have applied it to support the definition of a software sustainability model for software-intensive systems, and we envision it can be applied to other relevant complex decision-making tasks (e.g. requirements prioritization, trade-offs analysis).

The paper is organized as follows. In section 2 we discuss the related works. Then we introduce the topic of software

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sustainability in section 3. Section 4 presents the nichesourcing method, which has been applied for supporting the identification of sustainability requirements and dependencies.

In section 5, we also discuss the advantages and challenges of implementing nichesourcing solutions, which give us an opportunity to extend the agenda of crowdsourced software engineering, when higher a knowledge-level is needed.

II. Related Works

In the last years, crowdsourcing has been intensively investigated. Some themes have been regarding the definition and characteristics of crowdsourcing in different fields (e.g., [17], [19]), taxonomies for crowdsourcing (e.g., [15], [16], [24]) platforms for crowdsourcing (e.g.,[18]). For example, crowdsourcing in requirements engineering (RE) has demonstrated to be a useful tool for eliciting requirements (e.g., [21],[22]) and conducting user studies within experimental contexts (e.g., [23]) for validating requirements. However, most of these types of activities have typically been limited to those tasks that are low in complexity, independent, and requiring low cognitive effort, and little time to complete them.

Although it is well-known the limitations of crowdsourcing platforms when complex tasks are deployed [10],[24], in this section we present related works on approaches that aim to address the solvability[1] feature in crowdsourcing.

CrowdForge [18] is one of the first frameworks developed for dealing with the complexity and interdependency of crowdsourced tasks using micro-task markets. However, CrowdForge is based on the assumption that complex tasks can be broken up into relatively small and independent pieces. This assumption can be violated when some work may not be easily decomposable. Another limitation is that CrowdForge does not support iteration.

Zheng et al. [20] proposed a general-purpose crowdsourcing platform, which is based on state machine workflow technology. This platform provides an automated support in the process of resolving and merging complex tasks, and also assumes the decomposition of task.

Lyu and Kantardzic [19] proposed the use of multiple views for complex tasks through crowdsourcing. The applicability of this multiple view strategy was investigated in evaluation tasks of programming projects or research papers.

Although all related works provide valuable contribution for providing support to solve complex tasks, most of them have yet some limitations regarding iteration, concurrency, and decomposition to address solvability of complex tasks.

Given that certain activities of the software systems development process might demand specific type of knowledge and skills due to their complexity, in this paper we aim to address the solvability feature of those complex tasks that cannot be broken down into more simple tasks, but they are still feasible for humans, by following a specific type of crowdsourcing called nichesourcing.

With the purpose of illustrating the application of nichesourcing, in the next section we briefly explain why the identification of sustainability requirements and their dependencies is a complex task.

III. Sustainability Requirements and Dependency

Sustainability is defined as the "capacity to endure" and "preserve the function of a system over an extended period of time."[25] The most frequently used definition of *software sustainability* refers to dimensions of economic, social, technical and environmental sustainability [9], [26]. According to Lago et al. [26], a sustainability model should include both traditional (system-related) quality requirements and sustainability-related ones. This does not mean that all sustainability dimensions must always be addressed together to guarantee sustainability. In fact, the relevance of the different dimensions depends on the type of software system. For instance, a software system designed to remind patients whether or not a medicine has been taken typically requires to address requirements of the social sustainability (like usability, safety, persuasion and health risk mitigation) and of the technical sustainability (like adaptability and availability, which are important to ensure user satisfaction and hence incentivize patients to use the application). Of course requirements of the environmental dimension could be met as long as required.

The identification of relevant requirements that are related to each sustainability dimension of software-intensive systems is not trivial since a variety of stakeholders with different background and specific domain knowledge is required (e.g. experts from climate science or experts from social sciences regarding psychology). The challenges arise when the stakeholders are not collocated since a close cooperation and collaboration is needed.

On the other hand, *requirements dependency* is addressed in different activities that demand a higher cognitive effort, such as requirements prioritization, software product release planning, change impact analysis, etc.

About 25 requirements dependency types were identified through a systematic review [13]. Table 1 shows some

[1] Solvability is the capability to be solved.

examples of requirements dependency types that can be addressed in different requirements engineering activities.

TABLE 1. EXAMPLES OF REQUIREMENTS DEPENDENCY TYPE

RE activity	Requirement dependency type
Change impact analysis	similar_to; resource; refined_to, generalize
Requirements evolution	replaces; satisfies; based on; changes_to
Product releasing	Positive_value; negative_value; requires: And; OR

According to Zhang et al. [13], requirements dependency identification is a subjective process impacted by people's understanding of requirements and relationships. Dependencies among sustainability requirements can exist at two different levels: i) among the four sustainability dimensions (i.e, economic, social, technical and environmental), and ii) between the sustainability requirements within a dimension [9]. Due to the interplay of both levels, the identification of both dependencies types is even more difficult.

IV. NICHESOURCING REQUIREMENTS AND METHOD

We first present the nichesourcing requirements taken into account for adapting the Accurator method [12].

A. *Nichesourcing requirements*

- *Iterative.*- Given its complexity, the nichesourcing task can be executed as many times as the requester considers necessary to reach the campaign goal as long as deadlines are met.
- *Skills matching.*- It is important to match the knowledge required by the nichesourcing task with the skills of the selected niche communities. In contrast to crowds, these communities have a common purpose, members have an identity and affinity with the purpose at hand, and regular interactions engender social trust and reputation [11].
- *Computer mediation.*- Similarly to crowdsourcing, tasks must be remotely executed using the Internet for communication and coordination.
- *Continuous interaction.*- In the execution of nichesourcing tasks, experts can use different channels of communication with i) requesters, when they, for instance, may require more explanations to understand the tasks; ii) peers, when for instance they need to reach each other. The communication can be asynchronous (e.g. email, forum) or synchronous (e.g. chat).
- *Blindness.*- In contrast to crowdsourcing, requesters must know the identity and skills of the contributors. They can monitor contributors' performance. However, anonymity should be kept when contributors interact among them (*single-blind*). This allows to avoid that strong contributors might influence others.
- *Flexible planning.*- Although we can count on contributors with similar domain knowledge, both planning and scheduling should adapt to the availability of the experts without affecting the achievement of the goal.
- *Trustness.*- For the assignment of tasks, requesters trust on contributor's capability to deliver solutions with good quality in terms of effectiveness[2].

B. *The Nichesourcing method*

Figure 1 shows the nichesourcing method adapted for the completion of complex tasks, such as the identification of sustainability requirements dependencies, for which decomposition is non-trivial and high domain-specific knowledge is required.

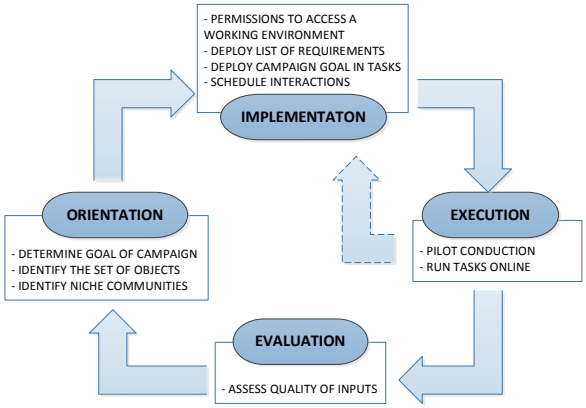


Fig 1. Nichesourcing methodology, adapted from[12]

It consists of four phases: Orientation, Implementation, Execution and Evaluation. All phases must be supported by a software tool.

1) Orientation:

a) Determine goal of campaign. The requester first determines what he or she wants to achieve with the sustainability requirements and dependencies identified during a nichesourcing campaign. It is important to remark that the goal has to be formulated in such a way that contributors deem it worthy to invest time into, fitting with their domain interest. E.g., the goal of a campaign could be as follows:

"Contribute to the definition of a software sustainability model for assessing software –intensive systems"

b) Identify the set of objects to analyze. The requestor carries out this step manually. However, as a dependency

[2] Degree to which something is successful in producing a desired result

identification task can be time consuming and require specific domain knowledge, requesters must consider a preliminary set of (candidate) requirements to address sustainability. For instance, traditional quality requirements that were identified as relevant for each sustainability dimension through a survey research method [9] could be considered as objects to analyze. Moreover, with the purpose of getting a common understanding among contributors, definitions of sustainability dimensions and requirements must also be given.

c) Identify niche communities to select potential contributors. To ensure the feasibility of a nichesourcing study, the set of objects to analyze (i.e., sustainability requirements of software-intensive systems) should match with the expertise of a niche community. It will facilitate to select potential contributors (professionals, senior researchers with background in Software Engineering and Sustainability). Examples of niche comunities in this topic are: members of the Karlskrona Manifesto for Sustainability Design [14], senior researchers from the Requirements Engineering community working on requirements for sustainability IT projects, etc.

According to Dijkshoorn et al. [12], a common feature of niche communities is that they can be divided into even more specialized sub-niches. It is useful to identify such sub-niches because it will help select most knowledgeable contributors. Table 2 shows examples of sub-niches (SN) that can be identified based on who can contribute the best professional knowledge needed for achieving the campaign goal. Each sub-niche consists of a set of candidate experts, contributing to at least in two of the four sustainability dimensions defined in previous works [9], [26]: Technical (T), Economic (E), Social (S) and Environmental (Env).

TABLE 2. SUB-NICHES DISTRIBUTION PER DIMENSIONS

	T	**E**	**S**	**Env**
T	0	SN1	SN2	SN3
E		0	SN4	SN5
S			0	SN6
Env				0

2) Implementation:

In this stage, as shown in Figure 2, tasks are designed and assigned to the selected contributors. This stage consists of the following steps:

a) Permissions to access a working environment. Permissions are granted to all contributors who accept participating in the nichesourcing campaign. According to the expertise of the contributor, the corresponding working environment is loaded. For this, it is very important to ask an explicit confirmation for addressing the "skills matching" requirement.

b) Deploy list of requirements per sustainability dimension in Tool. In this step, the tool is deployed and all relevant requirements identified in the orientation stage are loaded. All definitions of sustainability requirements and dimensions are also loaded.

c) Deploy campaign goal in Tasks. During this step, the goal of the campaign is translated into a set of tasks. With the purpose of ensuring the quality of solutions/inputs, the campaign is organized in a set of sessions. For example, by applying the Delphi technique, the requester can organize the campaign in three sessions as shown in Table 3.

TABLE 3: NICHESOURCING TASKS PER SESSIONS

	Purpose
Session 1	Identify dependencies among each pair of requirements (x,y) that belongs respectively to the sustainability dimensions (A and B)
Session 2	Review your dependency matrix by paying first attention to possible missing or incorrect dependencies
Session 3	Reach a consensus by discussing with your peer(e.g. via chat) to solve conflicts.

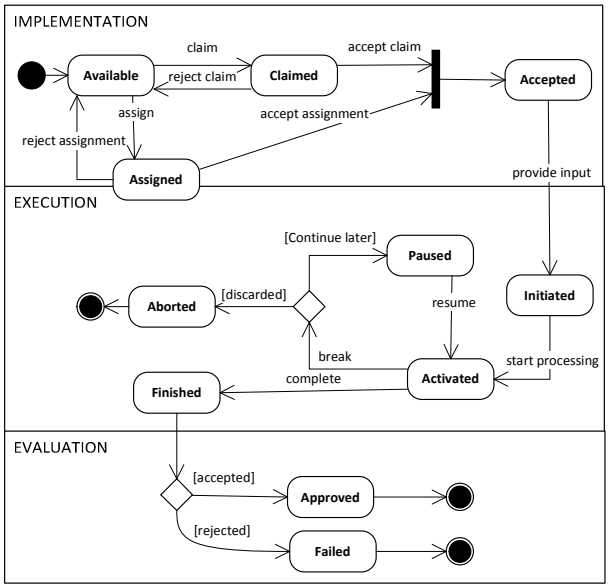


Fig. 2. Possible states of tasks during implementation, execution and evaluation stages of nichesourcing

d) Schedule interactions between contributors and requesters. To facilitate the interaction between contributors and requesters, the nichesourcing tool must support both synchronous and asynchronous communication. Scheduling synchronous communication is harder because of different

time zones and the diversity of work. However, scheduling this type of communication upfront with each sub-niche is needed especially for some sessions (e.g. session 3).

3) Execution:

a) Pilot conduction. To test the nichesourcing tool, the formulated tasks, and the corresponding planning, a pilot is conducted with a limited number members of the targeted niche community.

b) Run tasks online. Once contributors accept a task, they can start providing their inputs in an asynchronous way. With the purpose of avoiding/reducing aborted tasks, continuous support should be provided to contributors. Moreover, as shown in Figure 2, interruptions might occur during the study. If so, the tool should enable to resume suspended tasks in case requesters decide to pursue it later. Reminders to meet the set deadlines of the campaign should be sent for the task completion.

4) Evaluation:

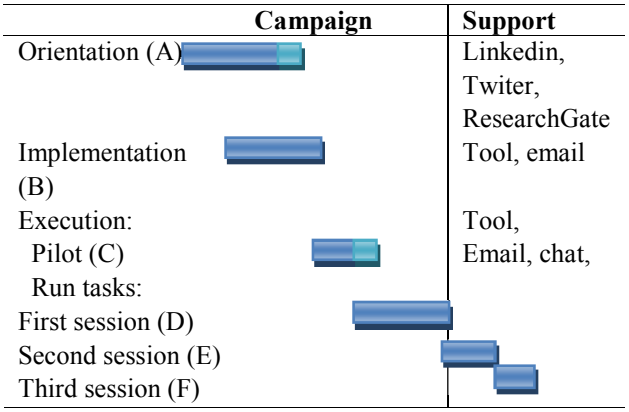
Once a task is finished, the quality of the inputs provided in each session should be verified by the requester. This assessment can be manual or automated. An example of automated assessment is the identification of conflicts in the third session.

The requester decides, based on the assessment, to approve or to reject the solution(responses). It is failed if the contributor is unable to deliver the desired output. A task is successful if most of the outcomes of a contributor are approved by the requester.

Table 4 shows examples of external applications that can be used for supporting each nichesourcing stage. Moreover, based on our own experience in running a pilot study with 12 experts that implemented the method presented, averaged estimated durations are also proposed.

The length of the blue bars corresponds to 8 (A, B, D), 4 (E), and 3 (C,F) working days. The lighter blue bars represent the additional time that should be considered at i) orientation stage when more contributors were needed to be included; ii) execution stage when issues detected in the pilot may require more time to be solved.

TABLE 4. ESTIMATED PLANNING OF A NICHESOURCING CAMPAIGN



V. ISSUES AND CHALLENGES

Mao et al.[10] identified a series of issues regarding the application of crowdsourcing in software engineering. Nichesourcing is a natural evolution of crowdsourcing that emerged to address some of these issues shown in Table 5.

TABLE 5. STRENGTHS AND CHALLENGES FOR IMPLEMENTING NICHESOURCING IN SOFTWARE ENGINEERING

Crowdsourcing Issues [10]	**Nichesourcing**	
	Strengths (S)	**Challenges(CH)**
Task decomposition	S1: The assigned complex tasks are carried out in an iterative way.	CH1: Tools or platforms should provide continuous communication and coordination support for making right assignments of complex tasks, and monitoring contributors during the "n" iterations of the study. One question that arise is: How many iterations would be enough for considering a task as successful?
Skill barriers	S2: Involvement of contributors with specific knowledge selected from niche communities.	CH2: Matching skills of potential contributors with specific knowledge required for solving a task can demand a lot of effort. Platforms/tools should provide (semi-)automated support for identifying "suitable contributors". Considering additional selection criteria can be even more challenging, such as availability, enthusiasm or motivation on the theme, that would ensure high levels of engagement.
Motivation	S3: Social trust and reputation are key drivers of niche communities. S4: Traditional motivation techniques from crowdsourcing like remuneration are not needed anymore.	CH3: Keep the motivation of contributors in long-term studies is a well-known challenge, especially when they are locally distributed (cultural aspects should be considered). It is needed to empirically investigate the applicability of new motivators for nichesourcing.
Careful planning	S5: A flexible planning makes feasible the completion of tasks.	CH4: Adapting continuously the planning and schedule according to the availability of contributors could affect to other ones. So, some mechanisms to facilitate agreeing on deadlines and schedule for synchronous communication should be provided.

Crowdsourcing Issues [10]	Nichesourcing	
	Strengths (S)	**Challenges(CH)**
Quality assurance	S6: Higher quality individual results because nichesourcing tasks are performed by members from socially-trusted communities,	CH5: Determination of minimum level of skills and knowledge to ensure an enough group of skilled contributors for each required sub-niche. CH6: Provide opportune support and positive feedback to contributors for increasing the quality of individual results.

It also summarizes corresponding strengths and challenges for implementing nichesourcing studies in software engineering. The conduction of the pilot has been helpful on realizing these strengths and challenges. It is also important to remark that although our method has been applied specifically to support the identification of sustainability requirements and dependencies, we consider that the method might be applicable to any type of complex knowledge-intensive task. As a future work, we are going to analyze the collected data from our pilot and apply our method for identifying sustainability requirements of a specific healthcare software.

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Model-driven engineering support for social and environmental accounting

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***Abstract*—Social and environmental accounting (SEA) is becoming commonplace in organisations that want to assess and report on their business ethics and sustainability performance. While there is an abundance of methods and standards that define how to perform such practice, tool support is much more limited and does not fully match the needs of organisations. In this paper, we present a model-driven engineering approach to support SEA. We are engineering a domain-specific language that allows creating models of SEA methods and we are implementing a tool that interprets such models at runtime, effectively supporting the accounting, and providing basic model management operations. This paper presents the preliminary results and, as a running example, we use UniSAF, a SEA method to assess the sustainability of universities. The results are promising, according to two SEA experts we have consulted, and have triggered the interest of the Fair Trade Software Foundation.**

Keywords—social and environmental accounting, sustainability reporting, model-driven engineering, domain-specific language, method engineering, software for responsibility, ICT for sustainability

I. Social and Environmental Accounting is Becoming Commonplace in Organisations

Social and environmental accounting (SEA) is the process of assessing and reporting the social and environmental effects of an organisation's actions to particular interest groups and to society at large [1]. This practice is becoming commonplace in companies, universities and non-profit organisations, who are publishing the results as sustainability reports, sometimes referred to as non-financial, integrated, or corporate social responsibility (CSR) reports. This trend is also reaching the information technology industry, where even best practices in CSR are starting to emerge [2]. In the European Union, reporting non-financial and diversity information has become mandatory for large companies [3]. Moreover, beyond the mere reporting, many organisations apply SEA with the intention to provide input to their strategic management, as part of a continuous improvement process that makes them increasingly responsible (say, sustainable, ethical) over the years.

There is an abundance of methods and standards that define how to perform SEA (e.g. ISO 26000 [4], ISO 14000 [5], and Global Reporting Initiative -GRI- Standards [6]). Sometimes, applying a SEA method is a requirement for the membership of networks of responsible enterprises (e.g. B Impact Assessment [7], Common Good Balance Sheet [8], and XES Social Balance [9]). As a result, there are organisations who follow two or more of these methods simultaneously (e.g. Nestlé applies the ISO 26000, ISO 14000 and GRI Standards). While large companies can afford investing in the application of more than one method, smaller organisations often lack the resources to conduct several accountings. The extent to which these methods overlap is largely unknown but, since they all typically follow accounting principles and practices (e.g. measurement and reporting), several method activities are expected to be equivalent. Moreover, the business ethics and sustainability topics being assessed overlap across methods (e.g. the theme "D3. Impact on the environment of the use and disposal of products and services" of the Common Good Balance Sheet and the disclosure "302-5. Reductions in energy requirements of products and services" of the GRI Standards are related).

Existing tools are often coupled with one single method (meaning that they only support such method) and lack features to extend the accounting with organisation-specific topics or indicators. Therefore, companies may need to resort to using several tools. For instance, a company willing to perform the B Impact Assessment and also deepening into the gender equity in their organisation (e.g. assessing the staff ratio and pay gap across different job functions) needs to apply yet another tool to assess this topic, even when it would be enough to add a few questions to the B Impact Assessment questionnaires. Moreover, now that new sector-specific SEA methods are being proposed (e.g. UniSAF for universities [10] and Green IT Maturity Assessment for data centres [11]), we are soon to be confronted with an overwhelming SEA method and tool landscape. A versatile tool able to support virtually any SEA method and which provides features to extend methods or even merge overlapping methods would alleviate the effort of organisations immersed in SEA practices.

This paper presents ongoing research to design and implement a model-driven SEA tool, where SEA method specifications become the input that configure the tool. We present the research method in Section II. Our main contributions are a domain-specific language (DSL) for SEA methods -explained in Section III- and its corresponding model interpreter tool called openSEA -presented in Section IV-. We have opted for an agile and incremental approach, and this paper presents preliminary results after several iterations. So far, we consider the current status a minimum viable product. As a proof of concept and running example, we use the UniSAF method. In Section V, we discuss the assessment we conducted with two SEA experts. Section VI discusses the results of our work and its limitations. Finally, Section VII concludes the work and discusses avenues for future research.

II. Research Method

In this research we aim at producing two artefacts (the DSL and the model interpreter) and knowledge around them. Therefore, we adopt the Design Science paradigm [12] (see the first, coarser level of activities in Fig. 1) and we structure our work according to the DSL engineering method proposed

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by Mernik at al. [13], later updated in [14]. In particular, we apply their first five DSL development phases; namely, decision, domain analysis, design, implementation, and testing (see the second and third levels of activities in Fig. 1). We have also been inspired by the agile approach proposed by Karagiannis [15], and we have embedded SCRUM practices in the implementation and testing of the interpreter tool.

In the following, we clarify aspects of the research method and explain the main decisions we made during the development of the DSL, referring to the DSL engineering patterns by Mernik et al. [13] (labelled in *italics*). This section already reports on the first activity of our research method.

Firstly, we have indeed decided to engineer a DSL, over other options, and our rationale matches the *system front-end* decision pattern; that is, we expect to facilitate the configuration of the openSEA tool, so it becomes versatile and is able to support multiple methods. Additionally, we expect that treating SEA methods as first-order citizens will later pave the way to a number of benefits that model management can bring [16]. For instance, creating repositories of SEA methods that are freely available to practitioners, comparing methods to discover their commonalities and differences, and merging automatically two methods to create a new one that fulfils the conditions of two certification bodies. However, these goals are out of the scope of the current paper.

During the domain analysis, we have collected sources describing SEA methods and tools. With respect to methods, we already had a list of sources that resulted from previous research [1]. We have collected basic information about 26 SEA methods, out of which we only consider 13 methods; that is, those for which we found enough detailed information to metamodel them (see the list of methods in Appendix A).

As stated by Čeh et al. [14], the DSL domain analysis process goes beyond collecting existing information and can produce new knowledge and requirements. In order to complement the body of knowledge on SEA practices, which is mostly centred on larger companies, we have issued a survey to 6 SEA practitioners from small and medium enterprises (SMEs)[1].

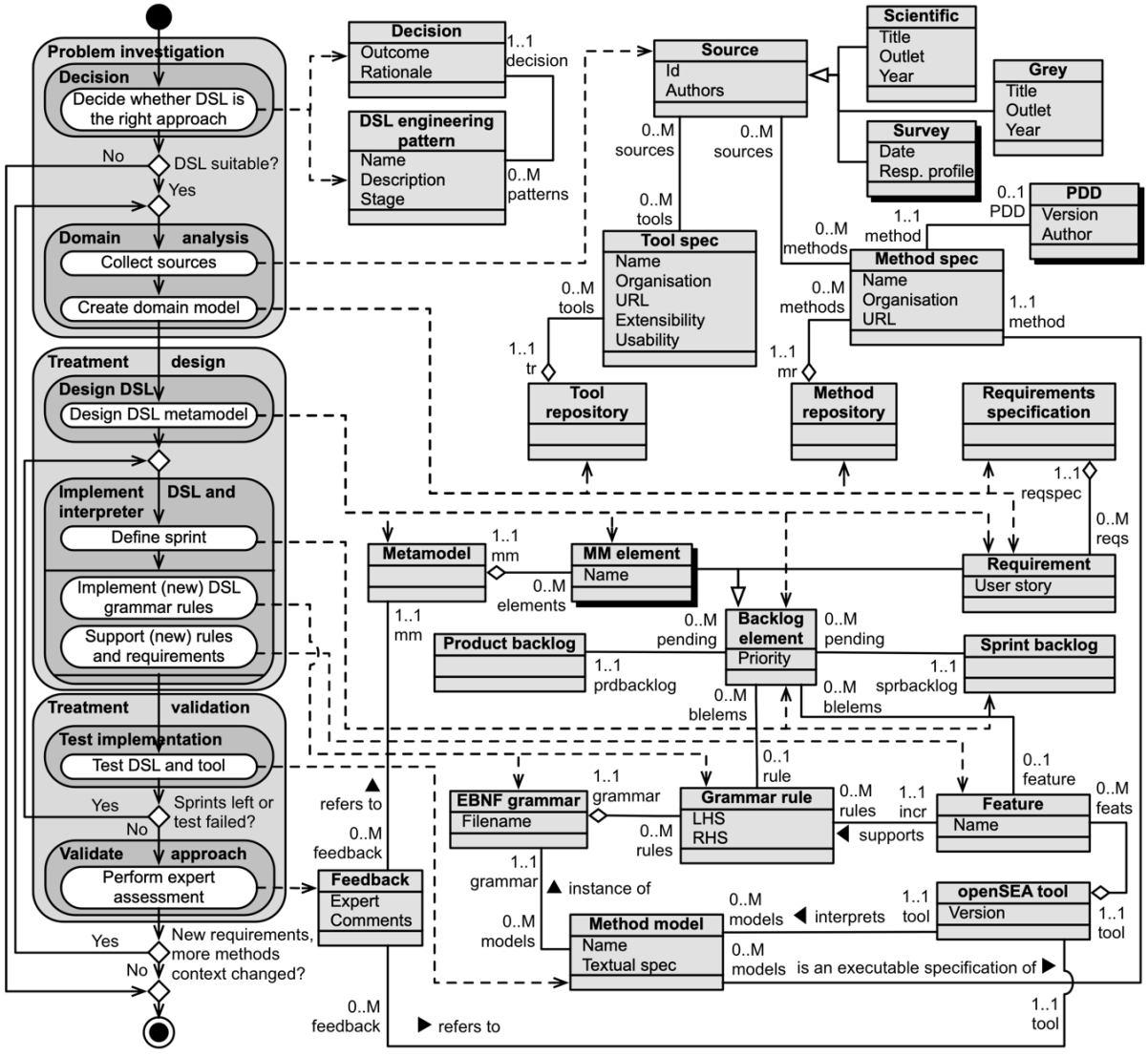


Fig. 1. Overview of the research method, using the PDD technique [17]; the class relationships have look-across multiplicities and use M for "many", instead of *. We illustrate how DSL development can be seen as a design science endeavour and how agile practices can be incorporated in this context, hoping to inspire other researchers undertaking similar projects.

[1] The online survey can be found here: https://goo.gl/forms/idXVhfU5eRY8B2go1 (in Spanish)

This survey was opportunistic rather than originally planned, since the first author assisted a consultant during a XES Social Balance training session and participated in a workshop where several of the organisations developed an improvement plan after reviewing the results of their SEAs. We do not intend to claim a strong validity of the results but to have preliminary knowledge on SME SEA practices.

With respect to tools, we have performed a multivocal literature review [18], in order to collect scientific papers and practitioner-oriented literature (e.g. manuals) describing SEA tools. We use both Google Scholar and Google to search for all combinations of the search string "(environmental OR social OR sustainability OR socio-environmental) AND (impact assessment OR audit OR auditing OR reporting OR impact measurement) AND (tool OR system OR software)." We only consider the first two pages, resulting on 1800 studies, discard the duplicates, and check the sources to include only those that describe tools. As a result, we collected basic information about 57 tools, out of which we only consider 10 tools; that is, those that offer sufficient details and we are able to access (see the list of tools in Appendix B).

We have collected information about the methods and tools (see Fig. 1). For tools, we have collected the name of the tool, the organisation responsible for offering it, the URL where the tool is offered, the extensibility and the usability of the tool. With respect to the extensibility, we checked whether the tool can support more than one method or allows the user to extend it with additional topics or indicators. With respect to usability, we performed a heuristic inspection checking the ease of use, whether metrics and indicators offer explanations, their layout seems logical and proper visual metaphors are used; we then determined a score from 1 to 5, with 5 referring to the highest usability. For methods, we have collected the name, the organisation that has created it, and the URL where the method is promoted and explained. Also, we have applied the *formal* DSL analysis pattern, by using metamodelling; for those methods whose sources clarified the process and products, we have created a PDD [17]. We have also produced a set of user-story requirements, based on our review of (and experience with) existing SEA tools and methods, and our vision of the features that openSEA should provide.

With regard to the language design, we opted for the *language invention* design pattern, in order to start designing a simple language from scratch that has the minimum core of modelling primitives. Of course, metrology standards informed our language design decisions [19]. We had a preference for specifying the DSL *formally*, for which we use a metamodel, using a UML Class Diagram [20]. This metamodel provides an overview of the primitives of the DSL; that is, it specifies the abstract syntax of the DSL. We also use it to define the product backlog; that is, the product backlog contains those metamodel elements and requirements that have not been implemented yet.

For the time being, the concrete syntax of the DSL is specified using an Extended Backus–Naur Form (EBNF) textual grammar [21] and the models of the SEA methods are textual YAML files [22]. For the implementation, we have opted for developing an *interpreter*, which is a tool that recognises DSL constructs and behaves accordingly, using a standard fetch-decode-execute cycle. The implementation and testing were performed in sprints; the sprint backlog was defined by prioritising the elements from the product backlog and picking a subset, also using the results of the survey and the later interviews with experts to inform our decisions better.

The validation activity consisted of testing the tool and performing an expert assessment. Besides conventional debugging and functional tests, we have also modelled a SEA method to check the extent to which the DSL is expressive enough to specify the method elements, and we assessed whether the tool interprets the model in the intended way. The result is a minimum-viable-product that we are now transferring to industry. The expert assessment has consisted in two separate interviews with two SEA practitioners, as a means to validate our minimum viable product and elicit further requirements for the next sprints.

III. Engineering of the openSEA Domain-Specific Language for Social and Environmental Accounting Methods

Our domain analysis has revealed that SEA is referred to with a number of names. For instance, social balance, social (and environmental) auditing, social (and environmental) accounting, social audit, non-financial reporting, integrated reporting, sustainability reporting, environmental reporting, corporate social responsibility reporting, environmental, social and governance reporting, social impact statement, corporate sustainability performance measurement, corporate social disclosure, or triple bottom line reporting [23-28]. This plethora of terms also reflects a variability in the scope and practices of the accounting but, as pointed out by Gray [25], all variants coincide in "the preparation and publication of an account about an organisation's social, environmental, employee, community, customer and other stakeholder interactions and activities and, where possible, the consequences of those interactions and activities." Also, as suggested by Gray, we adopt the term social and environmental accounting.

Many investigations have been conducted on the motivations underlying the practice of SEA [29-31]. According to Gray [25] there are two broad categories of motivations (not necessarily tidy): (i) management control purposes (i.e. supporting the achievement of organisational objectives), and (ii) accountability, democratic and sustainability purposes (i.e. supporting society in the pursuit of its objectives). The management control perspective assumes that an organisation is a fundamentally benign creation, while the accountability focus puts society first and does not make such assumption. In any case, we observe that such investigations are typically oriented towards larger companies, so our survey is intended to offer a glimpse on why and how SMEs apply SEA.

According to the survey results, the main motivations of SMEs for performing SEA are: assessing the compliance with their organisational values, identifying areas of sustainability and business ethics in which the organisation can improve, and using the results to perform strategic management (see Fig. 2). Given the fact that all respondents belong to social enterprises whose mission is to have a positive social and environmental impact, the results bring no surprises. They are also encompassed within Gray's broad categories.

A common practice after conducting a SEA is the authoring and public disclosure of a report. SMEs also publish their reports; 4 out of the 6 surveyed organisations disclose the results publicly, while the remaining two make it available only to the members of the organisation, for the time being.

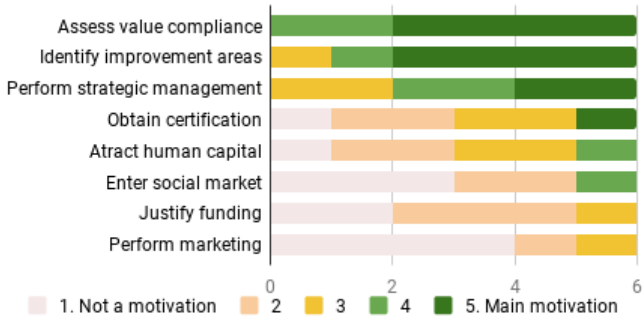


Fig. 2. Motivations for performing SEA practices in a sample of 6 small and medium organisations. Since they are all value-driven social enterprises, assessing the extent to which they live by their values and principles is the main motivation. However, they also perceive the usefulness of SEA for continuous improvement and strategic decision-making.

Of the 13 SEA methods we have analysed, 11 are industry sector-independent, 1 is focused on universities (the University Sustainability Assessment Framework [10]), and 1 is focused on the ICT sector (the Fair Trade Software Foundation certification method [32]). Some of the relevant sector-independent methods are the B Impact Assessment [7], which certifies B Corporation companies, the Common Good Balance Sheet [8], which has been recommended by the European Economic and Social Committee [33], the XES Social Balance [34], promoted by a network with which we collaborate closely, and the ISO 26000 [4] and ISO 14000 [5] standards, focusing on social and environmental responsibility, respectively. Interestingly, several methods offer a certification that is the entry requirement for a network of responsible enterprises: e.g. B Impact assessment for B Corporations (2665 members at the time of writing this paper), Common Good Balance Sheet for the Economy for the Common Good (2259 members), and XES Social Balance for the Network of Networks of Alternative and Solidarity Economy (REAS, over 500 members, in Spain).

For our running example, we will use the University Sustainability Assessment Framework (UniSAF), proposed by rootAbility, a non-profit social business that promotes sustainability projects and initiatives in higher education, the Green Office movement among them. We also use a fictional organisation, named Happy University, for illustration purposes. Happy University does not belong to any network.

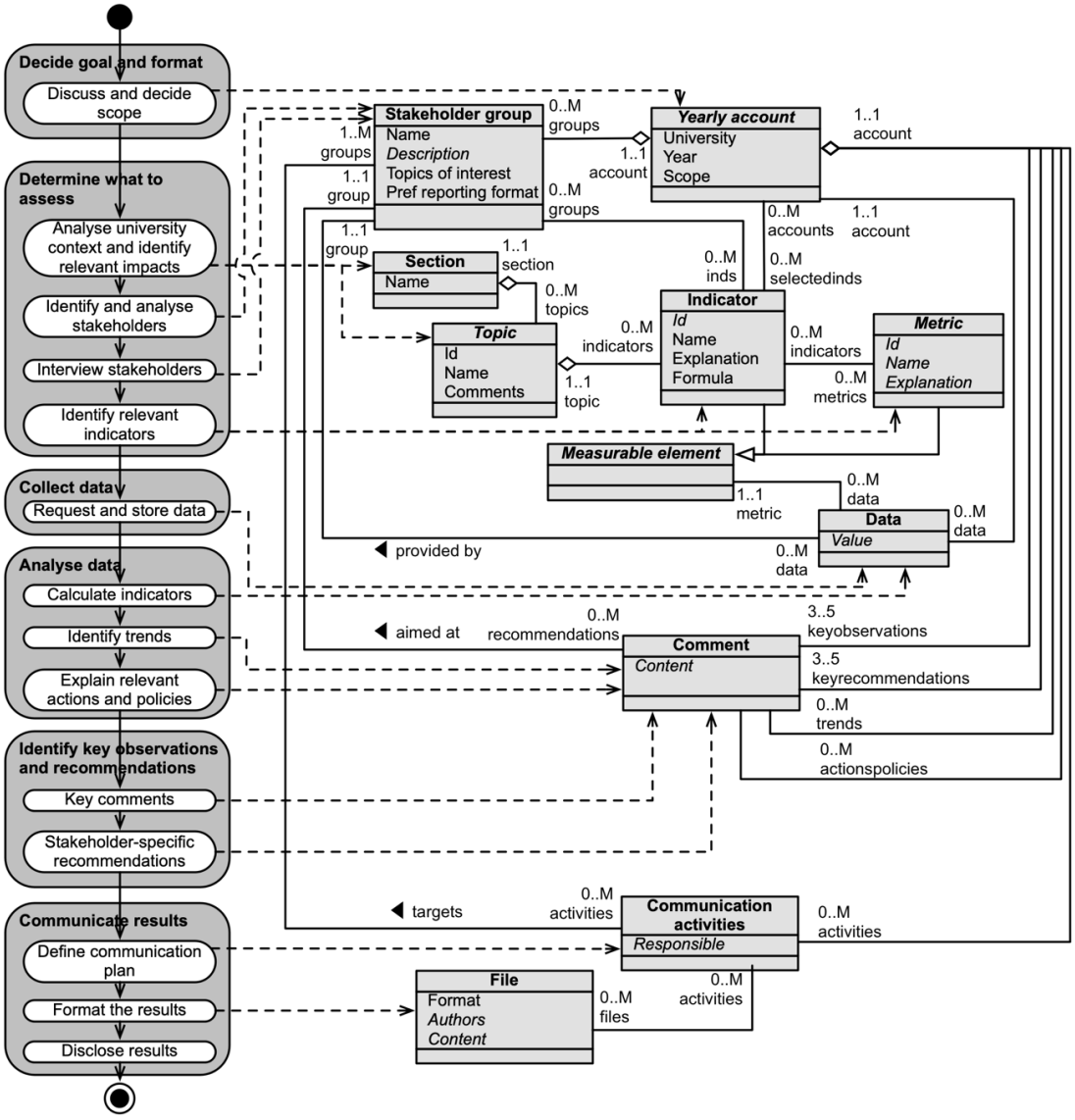


Fig. 3. PDD of the UniSAF method [10], created by analysing the method documentation and tools. Elements in *italics* denote that the concept was implicit an unnamed in the method documentation. For. Instance, the method manual does not mention Topic explicitly, but they refer to occassionally impacts and issues; the Excel tool collects the names of topics but does not label the concept itself. Similarly, Metric is not explicictly distinguished from Indicator.

While most organisations typically apply a single SEA method, some have reasons for applying more than one; for instance, (i) belonging to two networks for the purpose of collaboration, identity or lobbying, (ii) applying two complementary methods (e.g. one sector-independent and one sector-specific). For instance, all our survey respondents are applying the XES Social Balance. One of them is applying an additional method (namely, the Common Good Balance Sheet), and another one is applying two additional methods (namely, SPG Alacant, a participatory guarantee system that proves their agroecological practices, and the auditing required by their ethical bank when they ask for a loan).

Additionally, organisations might need to extend a method by adding topics to be assessed or indicators to be measured. Among our respondents, 4 organisations reported that they measure additional indicators that are not supported by the method tools. When we combine results, 5 out of the 6 respondents (83.3%) apply more than one method or consider additional indicators. This preliminary evidence shows that, not only large organisations could benefit from a model-driven tool capable of supporting several SEA methods and extending them, but so could SMEs.

So far, we have analysed 10 tools. We have only found evidences of scientific validation for 1 of them; namely, ToSIA, with a number of practical applications and testing [35]. Based on our analysis of the tool features, their extensibility is low. ToSIA offers no software support, and is likely to be supported with paper forms or a user-created Excel sheet; therefore, the user could add more indicators. The Common Good Balance Sheet [8] and UniSAF [10] are supported by Excel-sheet templates that could, in principle, be adapted to the needs of an organisation. The rest of the tools do not offer features to extend the methods. With respect to usability, the B Impact Assessment tool [7] stands out, for it has a carefully designed user interface, followed by XES Social Balance [9] and Green IT [11].

We have metamodelled the methods using the PDD technique[2]. This allows us to identify which are the most common activities among the SEA methods, as well as their corresponding concepts (i.e. the input and output products of the activities). See the specification of the UniSAF method in Fig. 3. All the methods include the activities intended to perform the following actions with more or less rigour:

- Registration of basic organisational data (e.g. during UniSAF's activity "Decide goal and format", basic information about the university is registered).
- Assessment of the organisational performance by collecting data related to the sustainability and business ethics topics. The data is sometimes directly provided by organisational representatives, such as C-level executives, or it is collected via stakeholder surveys to employees, clients, suppliers, etc. (e.g. "Collect data").
- Production of a report containing the results (e.g. UniSAF "Communicate results"; proposes to complement the report with infographics, presentations, policy briefs).

Therefore, we have selected those activities for the first version of the DSL and the interpreter. Examples of activities that do not appear in all methods are the definition of an improvement plan, and the attestation of the results by means of an independent auditor. These activities received a lower priority and were not yet included in any development sprint; they remain in the backlog and will be implemented into openSEA in future sprints.

The core concepts related to the above-mentioned activities are shown in the openSEA metamodel (see Fig. 4). The concepts related to certification (i.e. *Certification level* and *Requirement*), although they did not receive an initial high priority, were added to be able to support the Fair Trade Software certification method, so as to take an opportunity to collaborate with this organisation.

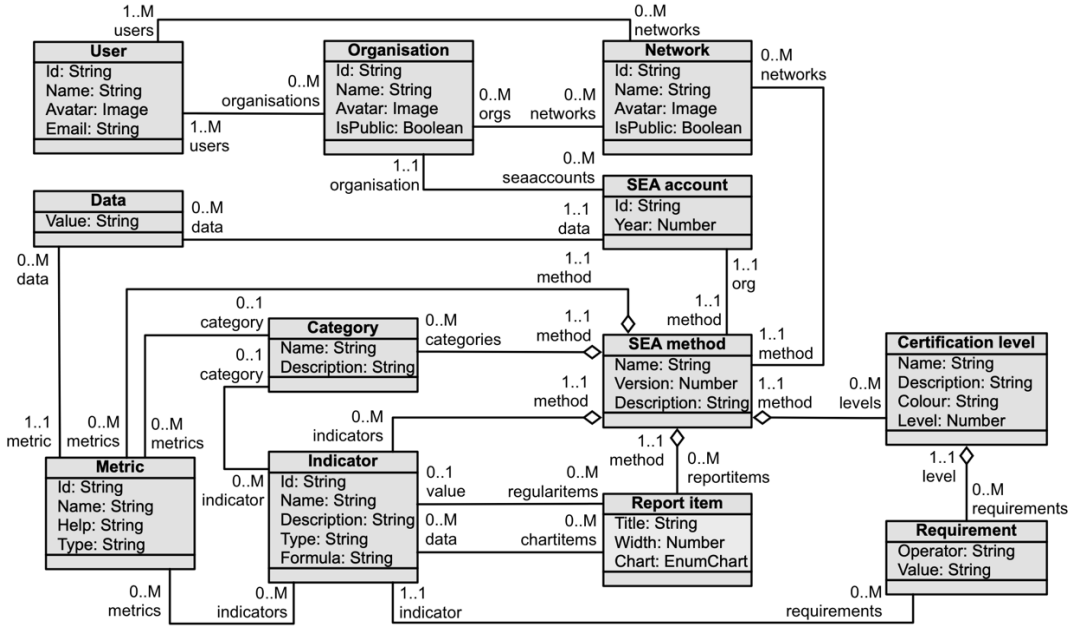


Fig. 4. openSEA DSL metamodel (i.e. underlying model of the openSEA tool). We have added some concepts and relationships that are not related to the DSL per se, but are needed to manage and use the tool (e.g. the concepts *Organisation*, *Network*, *User*, *SEA account* and *Data*)

[2] Until we create a full-fledge method repository, method metamodels can be found in an online folder: https://goo.gl/2ZPcpK

The meaning of the concepts is the following:

- **Organisation** refers the group of persons having a legal entity and sharing a common goal. Organisations can belong to networks. An example is Happy University, a fictional organisation we use for the running example.
- **Network** is a group of organisations with a common identity and that cooperate (e.g. sharing good practices). A network defines a SEA method that their members need to be certified with; that is, members must apply the method with the frequency specified by the network and, often, a minimum performance is required to acquire or renew the membership. Examples are B Corporations, the Economy for the Common Good, and REAS-Network of Networks of Alternative and Solidarity Economy. Happy University does not belong to any.
- **User** is a person that is registered in the openSEA tool and may have been granted permission to edit information about networks and organisations. An example is a representative entering the information of an organisation during their yearly accounting, or an external consultant hired to do that on behalf of the organisation. An example is Sergio, a user in charge of producing the yearly accounts of Happy University.
- **SEA account** is the product containing the results of a SEA accounting. Typically, organisations produce a SEA account per year or biannually. A SEA account follows a given SEA method. An example is the 2018 SEA report of Happy University.
- **SEA method** is the specification of how organisations perform the social and environmental accounting. A method can be prescribed by a network as the official certification method that gives entry to the network. Organisations can define their own method from scratch, use the method prescribed by the network they (want to) belong to, or tailor and extend an existing method (adding new metrics and indicators). An example is UniSAF.
- **Category** is an optional and arbitrary grouping of metrics and indicators, for the purpose of providing structure to the method. A method designer can use categories, for instance, to the define broad dimensions or more concrete sustainability and business ethics topics that are relevant for an organisation. UniSAF has defined *Education, Research, Community, Operations,* and *Governance*.
- **Metric** is a type of information that the organisation has to provide in order to assess their performance. The metric has an identifier (later used in formulas), a name, a text that helps the user understand what information they need to provide, and the data type the tool should expect (e.g. a number, text). Examples from UniSAF are *Women academic staff of the university*, *Men academic staff of the university* and *Greenhouse gas emissions*.
- **Data** is a piece of information that contains the value of a metric, provided as input by a user, for a specific SEA account of a given organisation. For instance, the Greenhouse gas emissions of Happy University in 2018 were *6025* tons of CO_2.
- **Indicator** is a type of information that is meaningful for understanding organisational performance and that is calculated from the values of metrics, by using a formula. Indicators can be grouped into categories. In UniSAF, the category Operations has the indicator *Greenhouse gas emissions per capita* with the formula "`GHG_emissions / (students_total + staff_academic_women + staff_academic_men + staff_non_academic_women + staff_non_academic_men)`". The value in 2018 is *0.79* tons of CO_2 per university member.
- **Report item** is a type of information that the organisation (or the network who defined the method) wants include in the SEA account; that is, information that needs to be included in the final report. Typically, report items present the value of one indicator, either textually, numerically or using charts. In the case of charts, several indicators may be presented simultaneously. Examples are the shown in Section IV, Fig. 5.

Then we designed the EBNF [21] grammar that defines the DSL. We chose to author the models using YAML [22] (see the rationale in Section IV), so the EBNF grammar slightly adapts the openSEA metamodel to enable this support. The complete grammar is presented in Appendix C; it contains the rules that govern the authoring of YAML files specifying the SEA methods, that the tool can interpret. Appendix D has a fragment of the UniSAF model used as an example.

IV. A Minimum Viable Product of the openSEA Model Interpreter

After several development sprints, we have issued a minimum viable product that interprets models created with the DSL and serves as a proof of concept of the overall model-driven approach. Released under the GNU General Public License v3.0, the tool can be found in a GitHub repository[3]. The rationale for the main architectural decisions follows.

Platform selection. Modern-day web technologies are extremely versatile, being possible to write native applications using JavaScript and CSS; for instance, React Native and Electron for mobile and desktop native applications respectively [36, 37]. The decision was made to base openSEA on these technologies in order to publish the tool as a web application initially, but to allow for later publishing native applications on platforms such as Windows or Mac.

Language selection. openSEA is written in Type-Script, a superset of JavaScript, using the React framework [38, 39]. React applications consist of components that exist independently from others, allowing for changing, adding, and removing components without affecting the rest of the application. We valued this versatility.

Back-end solution. Firebase is a mobile and web application development framework that synchronises to connected clients in real-time, and that provides web hosting for free. Maintainability was the main factor for selecting it. Of the Firebase suite, openSEA uses Firestore, Authentication and Hosting. The potential vender lock-in to Firebase has been mitigated by developing middleware functions decoupling openSEA's core functions from Firebase, allowing openSEA to use generic functions that may be replaced to communicate with any other back-end technologies in the future.

Model parsing. The YAML files [22] are parsed using a JSON schema[4]. The rationale for using YAML files for the

[3] The code of the interpreter can be found here: https://github.com/nielsrowinbik/open-sea

[4] Find the JSON schema here: https://github.com/nielsrowinbik/open-sea/blob/master/src/util/schema.json

models, instead of using JSON files directly, is that YAML is a superset of JSON, it is more readable and easier to author, since it relies on indentation rather than brackets, and it allows extensible data types and referencing [40]. The rationale for parsing them to JSON is the availability of useful libraries.

Derived values. openSEA only stores the values of metrics in the database (see concept *Data* in Fig. 4). The values of indicators are calculated on request, using the values of metrics; they are not stored in the database. At the moment, this keeps the code simple. In the future, for the sake of efficiency, we may need to also store indicator values.

Basic model management. There are several ways to manage models. The tool has a simple model repository that collects models (i.e. YAML files) and allows users to download them for reuse. This way, networks can share the model of the method they prescribe. When uploading a model to use it during a given SEA accounting process, the user can create a model from scratch (e.g. if they chose to define an organisation-specific SEA method) or use a model from the repository (e.g. when they -want to- belong to a network). Currently, basic model management operations can be performed. Before uploading the model, the user can edit manually the text file to remove, alter or add model elements, such as categories of topics, metrics, indicators, report items or certification rules. This allows tailoring a network-prescribed method. It is also possible to merge two different models; once a model loaded in the tool, the user can upload subsequent models that will be merged with the existing one.

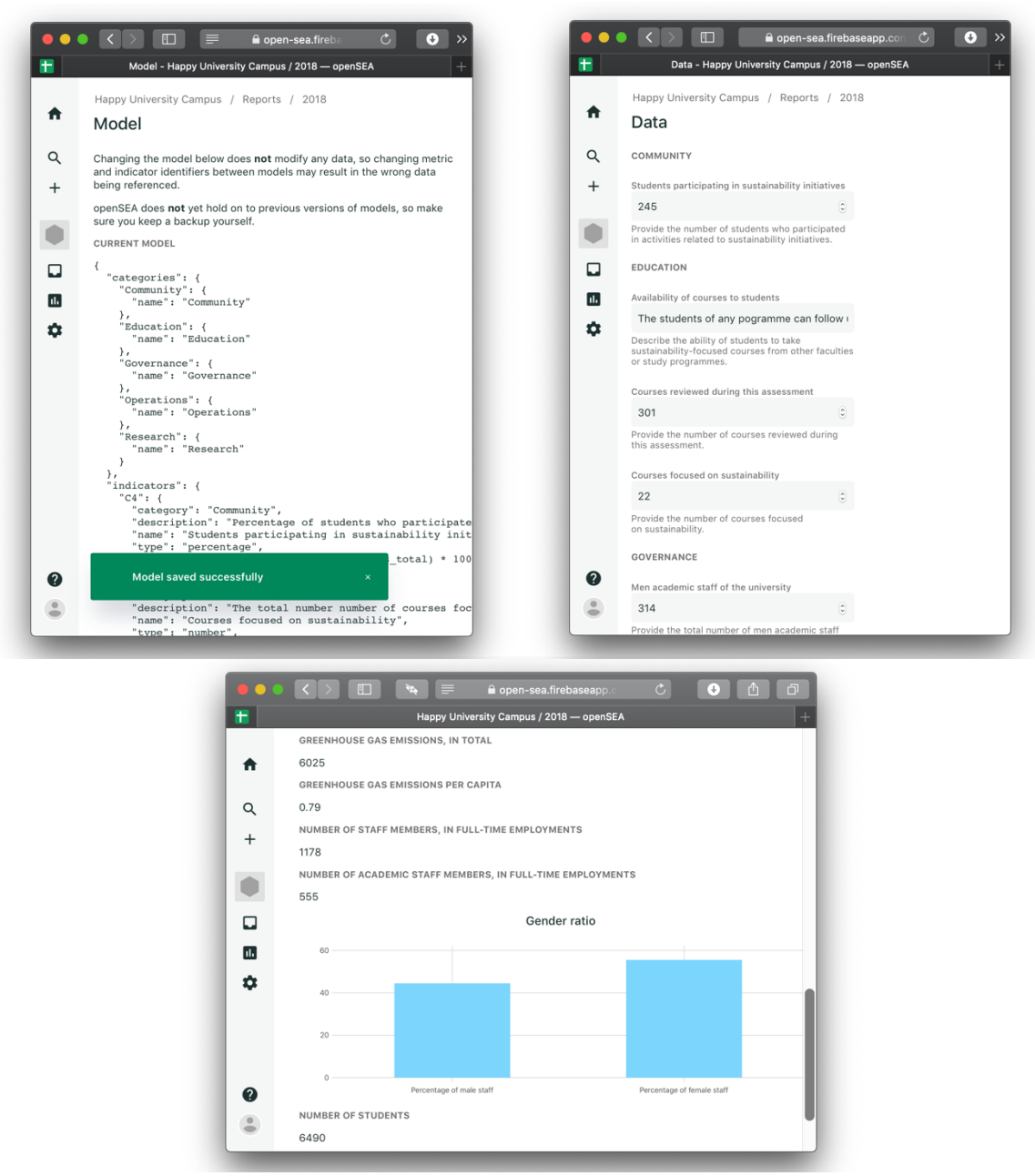


Fig. 5. Three screenshots of the openSEA tool. On the top-left, the tool informs that the model chosen for the UniSAF accounting of the (fictional) Happy University has been successfully loaded; find a fragment of this model is Appendix D. Every time a user uploads an updated version of the model (or an additional model), the tool interprets it (merging the models if required) and updates the other screens accordingly. On the top-right, the screen supporting the "Collect data" activity of UniSAF, based on the specification of metrics; see the field corresponding to the metric *Men academic staff of the university,* mentioned earlier. On the bottom, the screen reporting the results of the SEA account. The *Gender ratio* report item is displayed as a bar chart, whereas the rest are displayed as numbers, as specified in the method model.

V. VALIDATION

We conducted two expert assessment sessions with representatives from two responsible organisations, with the intention to validate the openSEA metamodel (see Section III) and the interpreter (see Section IV). The first organisation, Competa, is a member of the Fair Trade Software Foundation (FTSF) whose certification method does not have tool support yet. The second, rootAbility, have created UniSAF.

The format was a non-structured interview. We first discussed the metamodel. Both experts were positive about it, and only the concept of *Network* yielded some debate. The FTSF indeed plans to structure their members in a network, and their certification method will be a membership requisite. But rootAbility do not consider themselves or plan to promote a network; they simply offer the method to universities who voluntarily want to apply it. However, the tool also supports this scenario, as demonstrated in the running example.

Then we showcased the tool, by loading models of their own methods. The models were authored before the interview (the FTSF certification method was modelled completely, whereas only a part of UniSAF was modelled[5]). We used fictional data during the demo. The experts could try the tool themselves. Then we invited them to provide us with feedback. With respect to the FTSF, the support offered to all 74 indicators, their metrics and three certification levels were considered satisfactory. Competa's representative mentioned that "this is exactly what we're looking for" and that they would begin using the tool soon. rootAbility was in favour of supporting UniSAF with openSEA and offering it to the Green Office community. However, this method is not in the focus of their current strategy and are aiming at gamification mechanisms to promote sustainability improvements within universities, something that is out of the scope of our tool.

Finally, we demonstrated how an organisation that belongs to a network can load an additional model. As explained in Section IV, the tool integrates the metrics and indicators of both methods and supports them at the same time. However, neither of the experts' organisations ever faced the situation of having to conduct two accounts, so they find it a convenient feature but not a critical adoption factor, in their case. However, Competa saw the value of allowing other FTSF members to extend the FTSF certification method with additional indicators if they feel the need. Overall, the results were satisfactory. Moreover, the FTSF has shown interest in the tool and we are currently in the process of transferring the technology to them.

VI. DISCUSSION

A. Discussion of Results

The survey provides preliminary support for some of our assumptions; it shows that organisations sometimes apply more than one SEA method concurrently, and often extend the SEA method(s) with additional topics and indicators that suit their informational needs. This brings complications due to the need to use more than one tool, since all the tools we analysed only support a single method and (disregarding paper- or Excel-based tools) they are not extensible. Using separate tools does not allow saving time, even though methods often have overlaps in terms of activities and metrics; the same pieces of data have to be entered more than once. While this might not be a deterrent for larger organisations, SMEs often have limited time and resources, what acts as a barrier for SEA adoption [41].

After analysing 13 SEA methods, we have found a common core of three activities that all of them contain. This has informed our first version of the DSL and the corresponding interpreter tool. The tool, so far, supports registering the organisations, assessing the performance over a given period of time (typically a year), and visualising the resulting report. Additionally, we included another feature that was deemed as an opportunity to encourage its adoption by the Fair Trade Software Foundation; namely, the definition and checking of rules that determine what certification level an organisation achieves, based on the values of the indicators. We are certain that other SEA methods also require similar functionality; for instance, the B Impact Assessment calculates a number of points based on the responses of the organisation to their questionnaires and, if the points are above a given threshold (80 points out of a maximum of 200), then the organisation earns the B Corporation membership status.

The DSL allows specifying part of the SEA methods that refers to assessing and reporting organisational performance. Modellers can define metrics (information to be input by the user) and indicators (calculations based on metrics, that are meaningful to judge the performance of the organisation). Optionally, the metrics and indicators can be grouped into categories of sustainability and business ethics topics. It is also possible to define a basic report by determining what indicators should be displayed and how (e.g., textually or using a chart). Finally, the modeller can specify the rules that determine which certification level is achieved; rules are conditions over the values of the indicators.

The experts have been positive about the metamodel and the tool features. Their interest in the model management operations is limited, but appreciated them as an added value.

B. Limitations of our work

This paper reports on preliminary results of a project that will undergo additional iterations. Concerning the problem investigation, we have not analysed all the SEA methods and tools that are available in the market and in academia. We are confident, nonetheless, that we have analysed a relevant sample, based on the results of the literature review and on the experience we have in this field. In any case, we will continue collecting and analysing methods and tools. This will increase our backlog of pending requirements for the DSL and the tool.

With respect to the survey, we applied convenience sampling, by approaching a group of representatives from social enterprises that were attending a training workshop we had access to. To some extent, it is also a homogeneous sampling, since the organisations are mostly pertaining to the social and solidarity movement in Spain. They all belong to the Network of Networks of Alternative and Solidarity Economy (REAS), which in turn is part of the Intercontinental Network for the Promotion of Social Solidarity Economy (RIPESS) [42]. This entails they live by strong values related to equity, worker ownership, environmental sustainability, weighing cooperation rather than competition, putting human capital before financial capital, and caring about the local territory and community [43]. The nature of this sampling and the low number of responses to the survey prevent us from generalising the results. However, the survey has provided

[5] The models can be found in the model repository of openSEA, here: https://open-sea.firebaseapp.com/dashboard/models/

insights into the motivations and context of the SEA practices of SMEs. Moreover, we have validated the results of the preliminary survey with a consultant that was helping the organisations perform their SEA practices. This allowed us to verify the responses, put them in context and provide meaning to the results.

The DSL provides a limited support for the specification of SEA methods. As a result, the technology is not yet applicable to many situations. The selection of the core activities and concepts that we have included in the DSL is dependent on the sample of SEA methods analysed. So far, we have analysed 13 methods and 10 tools, but many more exist. We plan to create the PDDs of additional SEA methods and analyse the results; then, other relevant activities and concepts might emerge. They will be included in the product backlog and they eventually will make it into one of the tool development sprints

Also, while the ultimate goal is to enable model management operations, the tool so far only provides limited support for this. The tool is capable of merging to models, but the matching operation (i.e. identifying the elements that are common in two methods so as to not duplicate them) relies on element identifiers. A more intelligent matching operation based on the intended meaning of the elements is desirable (e.g. identifying that two metrics named *Number of women executives* and *Amount of female executives* refer to the same piece of information). This requires additional research.

This will improve as we perform additional iterations of our research method, increasing the expressiveness of the DSL and adding new features to the tool. However, the proof of concept has already satisfied one organisation; namely, the Fair Trade Software Foundation.

Because Firebase is a Google project and the free tier gives the user no control over where and how the data is stored, it is likely that it will be later replaced with a custom solution.

VII. Conclusions and Future Work

This is a long-term research project. Our mission is to offer model-driven technologies that facilitate the application of social and environmental accounting (SEA) methods. During our problem investigation we have encountered many methods and tools, the variability of which pose challenges to the creation of a DSL that is sufficiently expressive to allow modelling a broad spectrum of methods. The problem seems relevant. We have anecdotal evidence of an organisation that used to belong to two networks of social enterprises and left one due to the lack of capacity to perform both of their SEA methods. This paper has presented the first results; namely, a domain-specific language (DSL) for SEA methods, and a web-based tool that interprets the models in runtime. While the experts that assessed the approach were positive about it, there are many open challenges ahead.

A full-fledged problem investigation is now taking place, with a larger survey to organisations from several countries and interviews with SEA practitioners. We are also analysing additional SEA methods and tools. As a result, we plan to add features that will require a substantial redesign of the language and the interpreter; for instance, stakeholder survey management. Similarly, some features of the tool will require extending the technology stack; for instance, generating infographics with the results of a social and environmental account, or allowing an independent auditor to inspect the results and attest the report by signing it digitally.

Another open challenge is to be able to automatically merge the models of two full-fledged methods that belong to two different networks. The tool should identify commonalities and avoid the definition of redundant metrics, thus saving effort and reducing the likelihood of inconsistencies.

Finally, other interesting pending challenges are supporting the modelling of arbitrary activities beyond the ones predefined so far (e.g. validation of the data by a technical staff) and defining user rights by assigning activities to organisational roles, defining conditions (e.g. “the data-entry period lasts 3 weeks”, or “once the data is validated, it cannot be edited anymore”). Such modelling will require adopting techniques from the situational method engineering discipline. In that case, instead of reinventing the wheel, we will likely opt for the *language exploitation* design pattern [14], which allows for reusing (parts of) existing languages.

So far, we have opted for a textual grammar for the sake of producing a minimum viable product that focuses on the interpreter, rather than on a modelling tool. However, when the DSL becomes more expressive and enables the specification of complex processes, then we plan to combine textual and visual notations.

The validation is still limited, since, so far, we have only proved that the vision of modelling SEA methods and having a tool interpret them in runtime is feasible and promising. Nonetheless, the implementation has already gathered the interest of the Fair Trade Software Foundation and we are negotiating a technology transfer, maintaining the free, open-source licence. In this setting, we will play the role of R&D and scientific advisors, contributing to the evolution of the DSL and the interpreter, and to the validation of new releases. This prospect keeps us motivated to continue in this line of work.

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APPENDIX A. LIST OF ANALYSED SOCIAL AND ENVIRONMENTAL ACCOUNTING METHODS

Method	**Organisation**	**URL**
B Impact Assessment	B Labs, of the B Corporation movement	https://bimpactassessment.net
XES Social Balance (Balanç Social de la XES)	Xarxa d'Economia Solidaria (XES) is the Catalonian network of the Network of Alternative and Solidarity Economy (REAS)	http://mercatsocial.xes.cat/ca/eines/balancsocial/
Common Good Balance Sheet	Economy for the Common Good	https://www.ecogood.org/en/common-good-balance-sheet/common-good-matrix
Fair Trade Software Foundation certification method	Fair Trade Software Foundation	https://dspace.library.uu.nl/handle/1874/368079
ISO 26000 Social responsibility	International Standards Organistion	https://www.iso.org/iso-26000-social-responsibility.html
ISO 14000 family - Environmental management	International Standards Organistion	https://www.iso.org/iso-14001-environmental-management.html
UN Global Compact	United Nations	https://www.unglobalcompact.org/library/231
GDRC	Global Development Research Centre	http://www.gdrc.org/index.html
Global Reporting Initiative	Global Reporting Initiative (GRI)	https://www.globalreporting.org/standards
Social Accounting and Audit	Social Audit Network (SAN)	https://www.nefconsulting.com/our-services/evaluation-impact-assessment/prove-and-improve-toolkits/social-accounting
Sustainable Development Goals Compass	GRI, United Nations Global Compact, & World Business Council for Sustainable Development	https://sdgcompass.org
University Sustainability Assessment Framework	rootAbility	http://rootability.com/green-offices/assessment
Measurabl	Measurabl	https://www.measurabl.com

APPENDIX B. LIST OF ANALYSED SOCIAL AND ENVIRONMENTAL ACCOUNTING TOOLS

Name	Organisation	URL	Extensibility[a]	Usability[b]
B Impact Assessment	B Labs	https://app.bimpactassessment.net	Single method, no extension	5
Common Good Balance Sheet	Economy for the Common Good	https://www.ecogood.org	Single method, manual extension of Excel	3
Green IT	Swiss Informatics Society, Green IT Special Interest Group	http://greenit.s-i.ch	Single method, no extension	4
LM3	Impact Measurement Ltd.	https://www.lm3online.com	Single method, no extension	4
Measurabl	Measurabl, Inc.	https://www.measurabl.com	Three methods (GRESB, CDP, GRI), no extension	4
Integrated Impact Analysis Tool (iIAT)	PLUREL (6 FP EU project)	http://www.plurel.org/IIAT-111.html	Single method, no extension	2
Rapport	Rapport	http://rapport.io	Single method, no extension	3
Tool for Sustainability Impact Assessment (ToSIA)	European Forest Institute	http://tosia.efi.int	Single method, manual extension of paper forms	No software
UniSAF	rootAbility	http://rootability.com/green-offices/assessment	Single method, manual extension of Excel	2
XES Social Balance (Balanç Social de la XES)	Xarxa d'Economia Solidaria (XES)	https://ensenyaelcor.org	Single method with several variants, no extension	5

[a] Extensibility determines whether the tool supports one or more methods, and whether a user can include additional indicators that their organisation is interested in accounting.

[b] Usability indicates, with a value ranging from 1 (less usable) to 5 (more usable), the extent to which we perceived the tool as easy to use, the metrics and indicators offer explanations, their layout seems logical and proper visual metaphors are used.

APPENDIX C. TEXTUAL EBNF GRAMMAR OF THE OPENSEA DSL

```
SEA model = method name, '/n', method version, '/n', [ category list, '/n' ], metric list, '/n', indicator list, '/n', report item list, '/n', [ certification list ];
method name = 'name:', text;
method version = 'version:', number;
category list = 'categories:', '/n', category, { category };
(* Groups of indicators related to the same sustainability or business ethics topic, ethical value or principle *)
category = tab, category identifier, ':', '/n', tab, tab, 'name:', text, '/n';
category identifier = identifier
metric list = 'metrics:', '/n', metric, { metric };
(* Fields requesting values, later used to calculate indicator values*)
metric = tab, metric identifier, ':', '/n', [ tab, tab, 'help:', text, '/n' ], tab, tab, 'name:', text, '/n', tab, tab, 'type:', metric data type, '/n';
metric identifier = identifier
metric data type = 'number' | 'text';
indicator list = 'indicators:', '/n', indicator, { indicator };
(* They offer a meaningful way to assess the performance of the organisation *)
indicator = tab, indicator identifier, ':', '/n', tab, tab, 'name:', text, tab, tab, 'description:', text, '/n', [ tab, tab, 'category:', category identifier, '/n' ], tab, tab, 'type:', indicator data type, '/n', tab, tab, 'value:', indicator formula, '/n';
indicator identifier = identifier;
indicator data type = 'number' | 'text' | 'percentage';
indicator formula = expression; (* Simple formulas based on metrics and other indicators *)
expression = term, { ( '+' | '-' ), term };
term = factor, { ( '*' | '/' ), factor };
factor = base, { '^', exponent };
exponent = '(', expression, ')' | metric identifier | indicator identifier | number;
report item list = 'reportItems:', '/n', report item, { report item };
(* Elements that present information in the organisational dashboard, typically the result of the SEA *)
report item = tab, '- name:', text, '/n', tab, 'value:', indicator identifier, '/n';
certification list = 'certifications:', '/n', certification level, { certification level };
(* Some methods only grant certifications under certain conditions, typically defined over the results of the indicators *)
certification level = tab, '- name:', text, '/n', tab, 'colour:', HEX color code, '/n', requirements list; (* Levels; e.g. gold, silver, bronze *)
HEX color code = '"#', 6 * hex digit, '"'; (* Three-byte hexadecimal code for an HTML colour; e.g. "#cd7f3d") *)
requirements list = tab, 'requirements:', '/n', requirement, { requirement };
(* Conditions for achieving a given certification level *)
requirement = tab, tab, '- indicator:', indicator identifier, '/n', tab, tab, 'operator:', logical operator, '/n', tab, tab, 'value:', number; (* So far, we only support numeric comparisons and thresholds *)
logical operator = '<' | '<=' | '==' | '>=' | '>';
tab = space; (* YAML uses whitespace indentation *)
space = ' ';
text = ( letter | digit ) { letter | digit | space }; (* Any text *)
identifier = letter, { letter | digit | '_' } ; (* Identifiers do not have spaces *)
number = digit, { digit }, [ '.', { digit } ] ; (* Natural or real numbers *)
letter = 'A' | 'B' | 'C' | 'D' | 'E' | 'F' | 'G' | 'H' | 'I' | 'J' | 'K' | 'L' | 'M' | 'N' | 'O' | 'P' | 'Q' | 'R' | 'S' | 'T' | 'U' | 'V' | 'W' | 'X' | 'Y' | 'Z' | 'a' | 'b' | 'c' | 'd' | 'e' | 'f' | 'g' | 'h' | 'i' | 'j' | 'k' | 'l' | 'm' | 'n' | 'o' | 'p' | 'q' | 'r' | 's' | 't' | 'u' | 'v' | 'w' | 'x' | 'y' | 'z';
digit = '0' | '1' | '2' | '3' | '4' | '5' | '6' | '7' | '8' | '9';
hex digit = 'a' | 'b' | 'c' | 'd' | 'e' | 'f' | 'A' | 'B' | 'C' | 'D' | 'E' | 'F' | digit;
```

APPENDIX D. UNISAF MODEL FRAGMENT

All metrics and indicators of the Education, Research and Community categories are omitted. Also many from Operations and Governance. A complete model can be found in the openSEA repository https://open-sea.firebaseapp.com/dashboard/models/

```
name: University Sustainability Assessment Framework
version: 5
categories:
  Education:
    name: Education
  Research:
    name: Research
  Community:
    name: Community
  Operations:
    name: Operations
  Governance:
    name: Governance
metrics:
  GHG_emissions:
    name: Greenhouse gas emissions
    help: Greenhouse gas emissions of the institution in
tons of CO2 equivalents.
    type: number
    category: Operations
  staff_academic_women:
    name: Women academic staff of the university
    help: Provide the total number of women academic
staff members working in the university, including those
who only teach, only research or do both, in full-time
employments (FTE).
    type: number
    category: Governance
  staff_academic_men:
    name: Men academic staff of the university
    help: Provide the total number of men academic staff
members working in the university, including those who
only teach, only research or do both, in full-time
employments (FTE).
    type: number
    category: Governance
  staff_non_academic_women:
    name: Women non-academic staff of the university
    help: Provide the total number of women non-academic
staff members working in the university, in full-time
employments (FTE).
    type: number
    category: Governance
  staff_non_academic_men:
    name: Men non-academic staff of the university
    help: Provide the total number of men non-academic
staff members working in the university, in full-time
employments (FTE).
    type: number
    category: Governance
  students_total:
    name: Students in the university
    help: Provide the total number of students that were
enrolled in programmes during the previous year.
    type: number
    category: Governance
indicators:
  O13a:
    name: Greenhouse gas emissions
    description: Greenhouse gas emissions of the
institution in tons of CO2 equivalents.
    category: Operations
    type: number
    value: GHG_emissions
  O13b:
    name: Greenhouse gas emissions per capita
    description: Greenhouse gas emissions of the
institution in tons of CO2 equivalents, per capita.
    category: Operations
    type: number
    value: GHG_emissions / (students_total +
staff_academic_women + staff_academic_men +
staff_non_academic_women + staff_non_academic_men)
  G6a:
    name: Number of staff members
    description: Total number of staff members in the
university.
    category: Governance
    type: number
    value: (staff_academic_women + staff_academic_men +
staff_non_academic_women + staff_non_academic_men)
  G6b:
    name: Number of academic staff members
    description: Total number of staff members in the
university.
    category: Governance
    type: number
    value: (staff_academic_women + staff_academic_men)
  G6c:
    name: Gender ratio
    description: Number of women staff members divided
per number of men staff members.
    category: Governance
    type: number
    value: (staff_academic_women +
staff_non_academic_women) / (staff_academic_women +
staff_non_academic_women + staff_academic_men +
staff_non_academic_men)
  G16:
    name: Number of students
    description: Total number of students that were
enrolled in programmes during the previous year.
    category: Governance
    type: number
    value: students_total
percentage_male:
    name: Percentage of male staff
    description: ""
    category: Governance
    type: percentage
    value: ((staff_academic_men +
staff_non_academic_men) / (staff_academic_women +
staff_academic_men + staff_non_academic_women +
staff_non_academic_men)) * 100
  percentage_female:
    name: Percentage of female staff
    description: ""
    category: Governance
    type: percentage
    value: ((staff_academic_women +
staff_non_academic_women) / (staff_academic_women +
staff_academic_men
reportItems:
  - name: Greenhouse gas emissions, in total
    value: O13a
  - name: Greenhouse gas emissions per capita
    value: O13b
  - name: Number of staff members, in full-time
employments
    value: G6a
  - name: Number of academic staff members, in full-time
employments
    value: G6b
  - name: Gender ratio
    chart:
      type: bar
      data:
        - percentage_male
        - percentage_female
  - name: Number of students
    value: G16
```

Supporting Journalistic News Angles with Models and Analogies

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***Abstract*—News angles are approaches to content presentation in journalism, where the journalist chooses which facts of an event to present. The News Angler project investigates how to computationally support the creation and selection of original news angles for a news event based on information from big data sources. At least two creative approaches are possible. One is to maintain a library of well-known news angles represented in a suitable modeling language, matching published reports on a current event to news angles in order to identify possible angles that have not yet been used. A second approach is not to represent news angles explicitly, instead matching the current event with previous events, and transferring angles from past to present reports by similarity and analogy. Both approaches are described and technologies needed to proceed in either direction are discussed.**

I. Introduction

In the journalist's daily work they need to find the most interesting way of presenting a newsworthy event for the readers. A *news angle* is *how a journalist or other news worker makes an event (or situation) interesting for an audience* [1]. It is a general way to turn an event into a report (or news story) that will interest an audience. It may be obvious what this angle should be, but in many circumstances only a creative, original angle would warrant a new report on the same event. Simultaneously, tight deadlines and high productivity expectations (in the form of numbers of reports) may suppress natural creativity in search for good and original angles.

In the News Angler project we therefore aim at developing methods and tools to support journalists in their work, by making them able to find new ways of looking into an event. This will require computerised means of knowledge representation, collection, organisation, and reasoning to support the identification of novel, useful, and readable angles on an event, leveraging a big data repository organised as a knowledge graph of facts represented as RDF triples [2]. News Angler is a collaboration between a university research group and Wolftech Broadcast Solutions [1], a developer of newsroom systems for the international market. Our collaboration aims to extend Wolftech's commercial tool for newsrooms with support for creative journalism.

Knowing how to select a suitable angle on a current event is part of the human journalistic skill set, along with the ability to compose new angles by combining simpler ones. In this short paper, we ask *How can a newsroom tool automatically suggest original news angles on current or otherwise interesting events to journalists?* We attempt to answer this research question by exploring two alternative approaches: news-angle modelling and analogical reasoning (which can possibly also be used in combination).

News-angle modelling: The first approach is to maintain a library of news angles, which externalises the knowledge that is normally included in reports using each particular angle. If we are able to recognize which angles have been used already for a news event, a journalist can then be suggested to use one of the other alternatives, in particular if we are able to match the available knowledge about the event to another angle.

Analogical reasoning: A second approach is to forgo the news angle library, instead identifying original angles by identifying similarities or, even more challenging, analogies between a current and previous events. Furthermore, similarities can be identified among individual reports from two similar events, suggesting a similarity-based match. The unmatched reports of a similar event may then suggest a new news angle for the current event.

For a computer to support these approaches, it needs access to knowledge about news events: e.g., the people and other entities (animals, organisations) involved, their relations, and their attributes, as well as important sub-events they undergo and how they are temporally and causally related. The representation of such events is a central research topic for News Angler [1].

In section II, we will explain the news angle concept and describe a typical use case. In sections III and IV we describe the two approaches and how they can be realised. In the discussion section V we summarize the approaches, and compare the modeling and computational issues to be handled by the two approaches.

[1] http://www.wolftech.no/

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II. News Angles

In previous work [1], we have discussed the idea of news angles in the journalism literature and online sources. Examples are very general angles like the event itself (just report the facts of the newsworthy event), the influence of an event (the effect of an event on something else), proximity (a connection from the event to something near you), milestone (the event made something special be achieved), and many others. This is how an *event* becomes the nucleus of a *news report*: unless the event is so significant that it is newsworthy in itself, it must be made newsworthy by the match with a good and hopefully original angle.

A. Use Case

In collaboration with Wolftech, we have already developed a first prototype, News Hunter, [3] that is able to harvest news-relevant information from the web, represent the information items semantically as facts in a knowledge graph, and make the information available to journalists that work on related news events. We are now re-implementing our prototype using proper big-data technologies to make it more scalable and augmenting it with support for news angles. Drawing on the prototype experiences, we have detailed the potential functionality of News Hunter through eleven use cases with extensions and variants. A particular important one is *What's my angle?*, which comprises the following steps:

1) A journalist types a working news report into the front end.
2) News Hunter lifts the working report and returns IRIs for named entities, concepts/topics/categories, relations, and sentiments in the report.
3) News Hunter retrieves angles that fit the working report.
4) News Hunter recommends the most suitable angles.
5) The front end makes recommendations to the journalist.

It can be extended by the *Fill in my angle* use case as follows:

6) The journalist selects a recommended angle.
7) The front end retrieves from the knowledge graph a subgraph of related named entities, concepts/topics/categories, dates and locations, relevant to the report and that fit the selected angle.
8) The front end presents the facts to the journalist.

This paper outlines two alternative solutions to these steps.

B. An example

As an example, consider an imagined news report, where a journalist in the local newspaper covering the Valderdal rural area, writes the following (in a more lively language): Football player Hans Hansen owns a cabin in Valderdal. Hans Hansen visits his cabin regularly. Hans Hansen plays on Vålerborg football team, which is coached by John Johnsen, and they will play the cup final the next weekend. An additional point is that Hans Hansen's mother Anna Hansen, who happens to live in Valderdal, recently married the coach John Johnsen, so that Hans Hansen now plays for his stepfather's team.

This report might instantiate two different news angles. The first is *Local Person in Sports Event*. Important entities in this news angle are the local person and, if a team sport is involved, the team of the local person. Furthermore, the relation of the player to the local area is important: in this case derived through the location of the cabin combined with the ownership of the cabin. Additional facts about the sports event itself, with temporal and location attributes and relations, e.g., when and where the cup final is going to happen, are also in this news angle.

The second news angle is the *Possible Nepotism* angle, in which one powerful person (coach Johnsen) controls something of value (a place on the team), which a gaining person (player Hansen) attains access to. Furthermore, there must be a familiar or other private relation (stepson/stepfather) between the powerful and the gaining person.

C. Representing events

The News Hunter platform will maintain a dynamic knowledge graph that is continuously updated with published news articles/reports, social media messages and other potentially news-relevant information items, and enriched from relevant sources of background knowledge (for example from DBPedia[2] and Wikidata[3]). The knowledge graph will contain potentially newsworthy information as *event (sub-)graphs*, each comprising facts about entities, relations, and attributes related to the event.

An important research problem in News Angler is how to constrain event graphs to remain computationally feasible, without excluding context information that might suggest highly interesting and surprising news angles.

D. Representing news angles

As mentioned, we consider a news angle to be a general view that could match a particular event. The requirements for a match are that certain types of entities (for example agents such as people, organisations, teams...) are present and that there are certain kinds of relations between them, e.g., that particular types of events have happened or are happening.

For example, the nepotism angle can be described more precisely as follows:

```
Person(powerfulPerson)
Value(value)
controlsValue(powerfulPerson, value)
Person(gainingPerson)
privateRelation(powerfulPerson, gainingPerson)
accessesValue(gainingPerson, value)
```

E. Representing fabulas

To be able to work with news angles computationally we need to develop a firmer conceptualisation of how they match events in the knowledge graph. For this purpose, we borrow concepts from literature theory, as Gervás does in his discussion of computational storytelling [4]. In literature theory, a story consists of the *fabula*, which comprises facts about the event

[2]https://wiki.dbpedia.org/
[3]http://wikidata.org

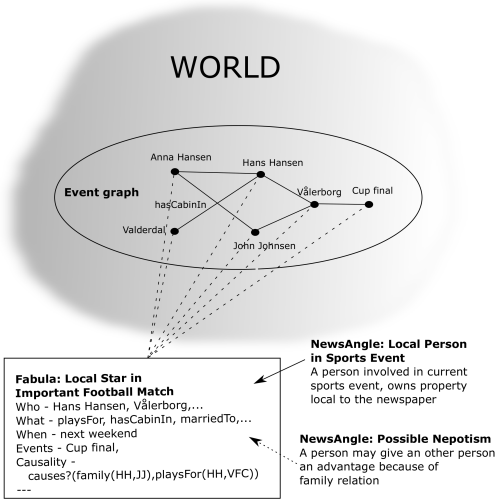


Fig. 1. A conceptualisation of news angles with the world, an event graph, a fabula, and two news angles.

that the story (in our case: report) is about, and the *discourse*, which is how the facts in the fabula are presented (or reported). Because the knowledge graph may contain many more facts about entities, relations, and attributes than the journalist wants to present in a report, we use the term *fabula (sub-)graph* about that restricted part of an event (sub-)graph that forms the basis of a report, perhaps after having been extended by the journalist.

In Figure 1 we show the instantiated fabula "Local star Hans Hansen in the cup final". The fabula consists of six entities — three human agents, an organisation, a location, and an event — as well as relations between them, all coming from the event graph. The construction of the fabula draws on a combination of requirements from the nepotism and local person news angles, and includes a subset of entities and relations in the event graph (like "has cabin in" or "plays for"). Notice, that already here we have identified general relations that are relevant for many events (like "family of").

III. A Model-Based Approach

To represent the news-relevant world, its many events, and news angles precisely, we use OWL — the Web Ontology Language — to define useful terms and RDF — the Resource Description Framework — to represent the facts in our knowledge graph [2].

A. Harvesting and lifting news items

Following the earlier prototype [3], the News Hunter platform will continually harvest RSS messages, tweets and other kinds of news-relevant information items from the web. Each item is then *lifted* into a small knowledge graph, an *item (sub-) graph*, using standard NLP techniques such as named entity, concept/topic/category, relation, and sentiment extraction [5], [6], [7]. Because they link the same named entities, concepts, and so on, the many item graphs will overlap to form a big connected knowledge graph. An ontology based on our earlier prototype, shown in Figure 2, provides a basis for this work.

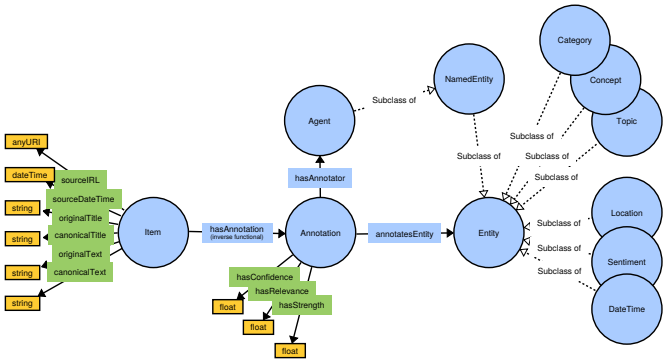


Fig. 2. Ontology for representing news items and other texts.

Items represent the news-relevant texts themselves, which can for example be a: published article/report, tweet, Facebook message or report in preparation. An item has a title and a text, both in the original language and possibly translated into a canonical platform language (such as English). The results of semantic analysis are associated with the *Item* through *Annotations*, each having a confidence, relevance, and strength. Each annotation is in turn related to an *Entity* in the knowledge graph, which can be either a *NamedEntity*, *Concept*/*Topic*/*Category*, *Location*, *DateTime* or *Sentiment*. Because every *Entity* has an IRI, they can be enriched semantically with further facts (or RDF triples) taken from the Linked Open Data (LOD) cloud. Not shown in Figure 2 are *RelationAnnotations* that describe a semantic relationship between two annotation entities of the same item.

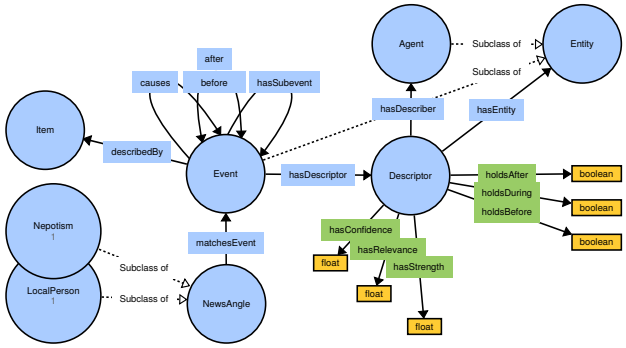


Fig. 3. Ontology for representing events, their event graphs, and their matching news angles.

B. Detecting events

The individual item (sub-)graphs according to Figure 2, must be aggregated to form events, which are also described by knowledge graphs, called *event (sub-)graphs*. Because they are described using the same *NamedEntities*, *Concepts*, *Locations*, *DateTimes* so on, the many event graphs will also overlap and be part of the big connected knowledge graph. Aggregation serves to increase both the trustworthiness, completeness, and precision of the event graphs, which can be further enriched

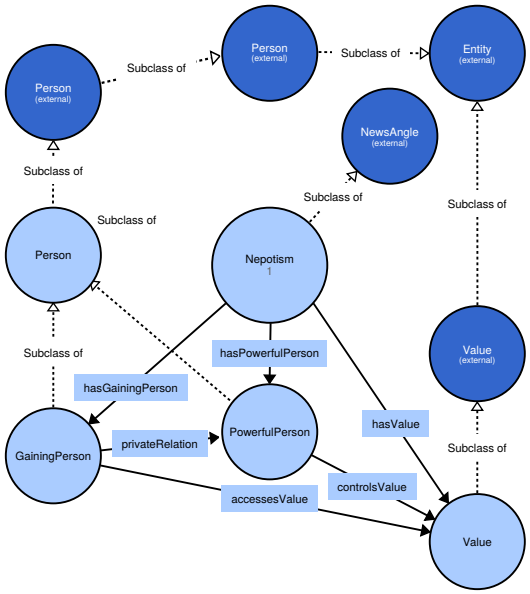


Fig. 4. An OWL representation of the nepotism angle.

with data from linked-open data sources such as DBPedia[4] and Wikidata[5]).

Figure 3 illustrates some of the most important concepts that we need in order to support events and match them with news angles. An *Event* is related to all the *Items* that describe it, and from which its event graph has been aggregated. The *Event* also has *Descriptors* that are similar to *Item Annotations*. Each descriptor relates the event to an *Entity* in the knowledge graph, which can be a named entity, concept/topic/category, location, date-time or sentiment as before. Descriptors can represent facts that hold either *before*, *during* or *after* the event. Not shown in Figure 3 are *RelationDescriptors*, similar to *RelationAnnotations*, that describe semantic relationships between pairs of entities in the same event graph. The particular analysis tool used to derive a descriptor is again represented as an *Agent*. Finally, an *Event* may partially match *NewsAngles*. In the figure we see two subclasses of *NewsAngle*, *Nepotism* and *LocalPerson*.

C. Detecting news angles

Detecting a *NewsAngle* on an *Event* now boils down to finding an angle whose restrictions on entities and relations match the entities and relations in the event graph, thus producing a fabula graph. For example, the *Local star Hans Hansen in cup final* fabula, would be an instance of both the Nepotism and the LocalPerson angles and inherit constraints from both.

The Nepotism angle with its constraints is illustrated in Figure 4, and involves a *PowerfulPerson*, a *Gainingperson*, and some entity of *Value*. They must stand in specific *familyRelations*, *controlsValue*, and *accessesValue* relations to one another, as explained in Section II-D. The *NewsAngle* thus describes some constraints on its instances, which could be the presence of particular types of and relations between entities.

[4]https://wiki.dbpedia.org/

[5]http://wikidata.org

We plan to start by crafting news-angle ontologies by hand before exploring ways to automatically derive news angles from news knowledge graphs. In previous work [1], we have already collected news angle types from the journalism literature, generalising the angles that are available to the journalist.

Assuming we have such a library of news-angle ontologies describing the required entities and relations, the steps of suggesting original news angles can be summarized as: (1) For the whole collection of reports on an event, extract entities and relations existing in the collection, as well as extracting other relevant knowledge. This can be seen as constructing a representation of the event as an event graph. (2) For each report, identify the entities and relations presented in that particular report, i.e, identify the report's fabula graph. (3) Identify all known news angles that match some report's fabula graph. (4) Match *unused* news angles to the knowledge in the event graph. (5) Suggest instantiations of entities (including events) and relations in the unused news angles, i.e., a fabula, to the journalist.

IV. An Analogy Approach

The model-based approach can be productive, but it also has some computational challenges which need to be solved: It relies on a library of ready-defined news angles (which also may be constraining), and also on semantic lifting of content from items into item graphs and aggregated event graphs.

Analogical reports about other newsworthy events may provide an alternative way of identifying new angles. The reports themselves can be seen as examples of angles that could be pursued by the journalist, and more or less advanced similarity measures for documents and document collections can be used to identify candidates for analogies, not by naming the news angles, but by presenting an example that could to some extent be transferred to the new report. This can be handled by different similarity measures, ranging from classic document similarity to structural similarity as found in several analogical reasoning techniques. The latter is an approach we also find in work by Maiden et al. [8].

Hence, the analogical approach is not constrained by a library of angles. And, while it can be implemented on top of knowledge graphs, it can also use similarity measures and analogy-reasoning techniques that work directly on item texts, thus removing the need for precise semantic lifting.

A. Assumptions

First, reiterate that any fabula may be considered to be a small knowledge graph. The graph contains entities e_i that are part of the event and also (binary) relations r_j between pairs of entities. These entities and relations are not necessarily known to the News Angler analogy machine but are *externalised* in news items m_k. See Figure 5.

Since the relations r_j may not be explicit and hard to identify from existing technologies, an alternative approach to detecting analogies may be to base a search on the idea that analogical or similar stories have similar externalisations.

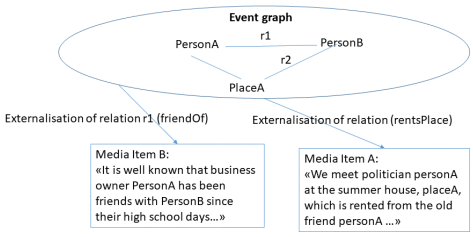


Fig. 5. Externalisation of entities and relations

B. Finding unmatched news items

Let us assume that we have a target (current) event t that we want to find a new angle for, as well as an *identified and analogical* base (previous) event b that already has n_b base news items $m_i \in B, i = 1, \ldots, n_b$. We also may assume that t has n_t news items $m_j \in T, j = 1, \ldots, n_t$. We must also assume that we have a similarity measure $sim(m_i, m_j) \in [0, 1]$ for each pair of items from the base and target events ($m_i \in B$ and $m_j \in T$). In terms of news items this similarity can be based on item type, text similarity, similarity among identified entities etc. As discussed later in the paper, the similarity measure is an abstraction that can be realised in many different ways, from traditional cosine similarity to analogical similarity.

Now, let A be a binary matrix with entries $a_{ij} = 1$ if there is a *match* between $m_i \in B$ and $m_j \in T$, otherwise 0. This matrix represents the total matching between items in the base and target events. There are several soft constraints that should be fulfilled for a matching to have high quality. These are first of all that we should have maximum similarity among matched items, secondly, items with low similarity should not be matched, even if they are the only candidates left for matching, and thirdly, items should normally not match more than one item. To handle the problem with low similarity we may subtract a constant c_l from all similarity values to ensure that all matched items have a similarity above the limit c_l. To ensure almost one-to-one matching we count the number of 1's in each row (cr_i) and each column (cc_j) of A. The penalty for having more than one 1 in a row or column is c_p. A lower c_p would allow for more freedom in matches, higher c_p would lead to one-to-one matches.

A matching of presumed high quality is then found by maximizing the objective function

$$\begin{aligned} f(A) = & \sum_{i,j} a_{ij}(sim(m_i, m_j) - c_l) \\ & - \sum_i max(0, cr_i - 1) \cdot c_p \\ & - \sum_j max(0, cc_j - 1) \cdot c_p \end{aligned}$$

When we have found the solution A, there will be items in the base event which are unmatched, i.e., there are rows where all entries in A are 0. These items may represent a new angle. The most original candidate could be the item that has the lowest similarity to any existing item in the target, i.e., has the highest $o(m_i) = 1.0 - \max_j sim(m_i, m_j)$.

C. Ranking among many base events

Having established an algorithm for finding the candidates for a news angle in a known analogical base event b, and ranking them using an *originality*-function $o(m_i)$, it is possible to use a general ranking approach to finding the best candidate reports from all possible base events b_k. This requires that we are able to compute an analogical similarity among events based on their total collection of items and identified entities.

For now, let us assume that we are able to compute the similarity $sim(b_k, t)$ for all base events b_k and the target event t. Further, assume that we for each b_k is able to compute an optimal item matching A^k with t. All unmatched items in the various base events will now be candidates for being suggested as an angle. To rank all these candidate items, we may use the similarity of the event they belong to, as well as the originality-measure $o(m_i)$ suggested above. A function used for ranking could be $score(m_i^k) = sim(b_k, t) \cdot o(m_i^k)$. Notice that it is possible to swap the originality measure o for any measure indicating some requirements for the new report item, for example by using click counts for previous reports, or other established knowledge about the journalist and the media users.

D. Similarity measures

The discussion on matching above is based on undefined similarity measures for documents. In her classical work on analogy, Gentner [9] claimed that analogies can only be detected based on the structural similarity of object relations in two models, and together with Falkenhainer et al., she proposed an analogical matching approach based on structural similarity, the structure mapping engine [10]. An alternative constraint-satisfaction approach to analogical matching is based on structure, semantics, and pragmatics [11].

Analogical similarity is useful as soon as we have fabulas for every report, but initially we will have to use other approaches. Classical document similarity measures could be a good starting point to establish a baseline for later research in the project. Traditional information retrieval techniques like cosine similarity, combined with tf-idf are obvious candidates [12].

The use of word embeddings is a recent technology that enables document similarity at a level closer to graph similarities, and thus also may be more of the analogical type than standard cosine similarity. Pre-computed and possibly multilingual word embeddings generated from neural networks such as word2vec [13], [14] and GloVe [15] combine precise semantics with efficient similarity calculation as scalar products of dense word vectors. doc2vec [16] captures the semantics of longer texts as similarly comparable vectors, but can only be used for existing collections of aggregated or important texts because new vectors must be learned per document.

Taking it a step further, in the ConceptNet project[6], Speer et al. [17] describe how word embeddings generated by neural networks can be improved by aligning them with embeddings generated for the same words from knowledge graphs. Algorithms have also been proposed that generate embeddings for nodes and subgraphs of graphs. Such graph-embedding approaches are potentially useful for News Angler, but only, as for analogical reasoning strategies, when we are able to represent news items and events as graphs. Only a few of the proposals around graph embeddings address RDF specifically [18], [19], and none of them support incremental node and subgraph embeddings.

Calculating similarities between pairs of items is the inner loop of this algorithm. They should therefore be stored for reuse by this and other future similarity-based analyses. It is also likely that similarities should be pre-calculated when news items are lifted into the knowledge graph, as part of categorisation and clustering.

V. Discussion

We have presented two different approaches to suggesting news angles to the journalist, a news-angle modelling approach, and an analogical reasoning approach. In addition, we suggest several similarity models that may be used for analogical reasoning: traditional document similarity and tf-idf; word embeddings representations of item texts; knowledge-graph embeddings representations of items; and pure analogical reasoning based on the structure-mapping engine.

Evaluating the different approaches will have to take two different directions. One will be to see if analogical approaches to news angles or a model-based approach will be more successful with practitioners. This type of evaluations can be conducted as empirical investigations in collaboration with our industrial partner Wolftech, and will inform the modeling of news angles as well as the support functionality itself.

As for evaluating the similarity approaches, we need to choose a rich corpus of news articles/reports, grouping them into stories, and selecting additional items (tweets, Wikipedia) of relevance for each. We aim to build such a corpus by selecting content from, for example, the NOW corpus[7].

Many of the ideas we present here are based on an ability to lift item content into knowledge graphs. How to extract entities like persons and other entities from such content is a problem where well established methods exist [5], [6]. However, News Angler is very much based on being able to extract relations among entities in texts [7]. This is a research topic of relevance in many domains. For example, it is an issue in automated literature-based discovery as applied in medicine [20]. Anyhow, relation extraction is still an immature field of research, where we need to contribute in order to enable news angle suggestions.

[6]http://www.conceptnet.io/

[7]https://corpus.byu.edu/now/

VI. Conclusion

This paper has presented ongoing work in the News Angler project. Focus has been on supporting creative journalism with use of two different approaches to identifying alternative news angles, one model-based and another analogy-based. A conceptual understanding of the domain is developed, the fundamentals of the two approaches for selecting news angles are presented and future research topics are identified. In particular there is a need for developing algorithms for mining relations in documents, a library of news angles, and strategies for evaluating the approaches selected.

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Correlation between textual similarity and quality of LDA topic model results

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***Abstract*—The LDA topic model describes a corpus on the basis of its vocabulary. Our experiment aims at determining whether LDA outputs' quality can be estimated through text similarity metrics, and if so determining the most relevant one. To do so, we use a categorized corpus on which we apply these metrics on every pair of categories. We present correlation scores between several metrics and the quality of the topic model. The experiments also include a comparison between simple and complex term extraction within our framework. We observed very high correlations with the Hellinger distance with or without complex terms, while the Soergel distance is most efficient when including complex terms. These experiments are a case study on a categorised corpus of 20,000 article abstracts.**

I. Introduction

Given a corpus, Latent Dirichlet Allocation (LDA) [1] is a topic model which discovers a set of k topics which models the whole corpus and thus each document is represented by a weighted vector of topics, the number k of topics is given beforehand. LDA also represents topics with distributions over the vocabulary. In this paper, we will refer (i) to *categories* as categorized document groups coming from a manually labelled corpus, (ii) to *classes* as clusters derived from LDA outputs and (iii) to *category pairs* as pairs of categories from the corpus.

In previous experiments with LDA [2], we observed variations of quality results depending on the input, even with only category pairs. Moreover as we used a non deterministic algorithm, we observed in some cases very large quality variations between the executions on the same dataset. And these variations were more and more large as the number of categories increased.

We hypothesize that LDA performs differently according to the vocabulary distributions of the classes to discover. We present here an extensive and exhaustive comparison experiment to test a possible correlation between the LDA results quality and similarities between category pairs.

This experiment follows a previous research which we conducted on exploitation of n-grams and other complex syntagms in LDA [2]. Thus we will compare LDA results between a classic representation of documents and a version based on NLP processing.

Our contribution is as follow. First we collected and implemented a large number of similarity metrics. Then we considered every possible category pairs in our categorized corpus and ran several executions of the LDA algorithm on each pair. The LDA result was interpreted as a clustering, and it was evaluated with $F\text{-}measure$ according to the two categories (the gold reference). These $F\text{-}measures$ were then correlated to the similarities.

In the following, we provide a review of similar works and related topics of interests, and then a presentation of our experiment. We conclude with result analysis and perspectives.

II. Related works

Our focus is to study different similarity metrics in correlation with LDA's results. The comparison between statistical distributions is a widely studied field of research, long before the apparition of computer science. The different metrics rely on a scope of hypothesis, from information theory to geometric interpretation. We focus here on text similarity metrics. Several research papers synthesize part of these metrics [3]–[5] while others focus on existing measure modification, on enhanced data representation or on different scale of text segments [4], [6]–[9]. Measure modification implies a variation of the metric, enhanced data representation a modification of the data on which the metrics are applied and the scale of the text segments often involves external knowledge to alleviate the lack of information in short texts. These external resources can be in the form of manually built thesauri like WORDNET [10] or GEONAMES[1], or be automatically built on external documents through corpus frequencies, word embeddings [6] and other machine learning applications [4], [9]. Using these resources allows finer semantic analysis of texts. In our case, we prefer to work with a standard representation of documents and a full NLP pipeline pre-processing, but without external resources. Including more complex syntagms in statistical models has already proven successful, either through thesauri [11] or through n-grams extraction and alignment [12], [13].

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[1]http://www.geonames.org/

In this experiment we go beyond thesauri and n-grams through syntactic analysis which allows the extraction of relevant semantic syntagms.

Beyond syntagm extraction and available metrics for statistical similarity, our experiment also involves LDA's quality estimation. Researchers have already studied metrics to evaluate LDA's result, especially in terms of topic coherence [14]–[18]. Contrary to these researches which rely on metrics applied on LDA's topics, we propose to directly apply the metrics on the representation of categories as bag of words. Lots of statistical similarity metrics are available to compare two bags of words, and we will present them in Sect. III-F.

III. Experiment

A. Motivations and observations

In a previous experiment [2], we observed variations between executions according to the categories the LDA algorithm had to identify; $F\text{-}measure$ variations ranged from 75% to 99% for $k = 2$. We hypothesize that a low $F\text{-}measure$ – *i.e.* a poor clustering quality – is linked to a high similarity between the two category vocabulary distributions.

B. Text representation

In our experiment we use the usual representation of documents as bags of words, though the definition of *word* varies between "standard LDA " and "LDA with NLP". In the standard LDA, parsing relies on few regular expressions to split a document into simple words and does not perform any stemming nor lemmatization tasks. LDA with NLP relies on a full NLP pipeline to extract relevant syntagms and conflate grammatical variations [19]. The pipeline is based on: Part of Speech tagging, Dependency Tree building, followed by an extraction restricted to nominal, adjectival and verbal groups.

Example: The sentence "*Neural networks are useful tools*" would provide the syntagms *neural_network*, *useful_tool* and *be_useful_tool* as the two former are nominal syntagms and the latter is a verbal syntagm.

The same representation is used both as input to LDA and to compute the category similarities.

C. Corpus material

We decided to work on an extract of the iSearch corpus [20], which is a corpus of technical and scientific documents and research papers. We chose this corpus because of i) the language quality which is syntactically correct contrary to collections extracted from social interactions such as 20 NEWSGROUPS[2], ii) the use of technical terms which are not simple words. Here are the four categories we picked from iSearch and their respective subcategories (total of 19):

- **Mathematics:** Probability, Analysis of PDEs, Quantum Algebra.
- **Physics:** General Physics, Optics, Atomic Physics, Chemical Physics, Fluid Dynamics.
- **High Energy Physics:** Experiment, Lattice, Phenomenology, Theory.
- **Condensed Matter:** Statistical Mechanics, Strongly Correlated Electrons, Materials Science, Superconductivity, Mesoscale and Nanoscale Physics.

We extracted research paper abstracts for each subcategories and removed multitopic / improper documents. As we also wanted balanced subcategories, they contain between 750 and 1,000 documents. Considering the size of our corpus, we are able to gather results on every pair of subcategories listed above, that is 171 pairs for 19 subcategories.

D. Framework

Considering the observations above, the purpose of this experiment is to estimate LDA's capacity to distinguish two given categories beforehand. This would allow one to either get an *a priori* quality estimation in a supervised case or an *a posteriori* quality measure in an unsupervised case. To do so, we measure here correlation scores between several statistical distribution distance measures and the $F\text{-}measures$.

In order to evaluate the LDA outputs with the straightforward $F\text{-}measure$ we turned it into a hard clustering by picking the most prominent topic for each document as its single class [21]. Furthermore, this transformation allows us to omit special tuning of LDA's hyperparameters, as stated in III-E.

To conduct our experiment on our categorized corpus, on one hand we execute LDA on each category pair to compute an averaged $F\text{-}measure$ and on another hand we compute the similarity measures on this pair. Then for each similarity metric and for the $F\text{-}measure$ we have a vector of 171 values, one for each category pair. Finally, we compute both Pearson (R) and Spearman (ρ) correlation coefficients between these vectors.

E. LDA *algorithm executions*

1) Tuning: As previously stated, LDA is a topic model which represents documents with distributions over topics and topics with distributions over vocabulary. LDA relies on two hyperparameters α and β [1] which will respectively influence the tendency of the model to share vocabulary between topics and to share topics between documents. As we are not working with the direct LDA outputs but we transform them into hard clustering, we did not need a special tuning of α and β. Indeed, no matter the value of α, the most prominent topic remains the same one. Likewise, β does not influence our experiment as we compute the metrics on the corpus – not on LDA vocabulary distributions. So the hyperparameter values set in the model were not changed from their default values in our implementation[3]: $\alpha = 0.1$ and $\beta = 0.01$.

2) Evaluation: In order to alleviate our LDA's implementation non determinism (*i.e.* its results depend on a random generation), we average the results of ten executions with the same settings and on the same data. As mentioned in Section I, the variations between executions increase with the number of

[2]https://kdd.ics.uci.edu/databases/20newsgroups/20newsgroups.html

[3]https://github.com/chen0040/java-lda

categories to identify. Only working with category pairs allows us to get a relatively representative averaged result with ten executions, whereas working with more than two categories and thus giving to LDA a number k of topics to discover with $k > 2$ would require more executions due to the variation increase.

Obtaining $F\text{-}measures$ from LDA output is straightforward with the transformation toward hard clustering. For a given collection of documents $\mathcal{D}$ for which we know its k categories and a k clustering, we can consider two partitions over $\mathcal{D}$: (i) existing categories: $C_1, C_2, \dots C_k$ and (ii) calculated clusters: $G_1, G_2, \dots G_k$ with an alignment $C_i \leftrightarrow G_i, i = 1, k$. We should ideally obtain a perfect match between G_i and C_i, but most of the time G_i and C_i are different. In order to measure the distance between these two sets, we use accuracy, recall and $F\text{-}measure$. Let C be a reference set and G a calculated set supposed to perfectly match C, let us define:

$$accuracy(G, C) = \frac{card(G \cap C)}{card(G)}$$

$$recall(G, C) = \frac{card(G \cap C)}{card(C)}$$

$$F_1(G, C) = \frac{2 \times accuracy \times recall}{accuracy + recall}$$

In the perfect case $G = C$, all $accuracy$, $recall$, and F_1 measures worth 1.

Thus we gather ten $F\text{-}measures$ per category pair and simply average them to get a unique score for each pair.

F. Distance metrics

Considering the small size of our corpus, we are able to compute results with a large number of metrics.

A category $\mathcal{P}$ composed of documents from the corpus is considered as a set of terms with their frequencies – *i.e.* a bag of words – and we note P_i the absolute frequency of term number i. Each category is thus represented by the vector of its relative frequencies p_i, where $p_i = \frac{P_i}{\sum P_j}$, $i = 1, n$ where n is the number of distinct terms.

When we compare two categories $\mathcal{P}$ and $\mathcal{Q}$, we use their relative frequency vector, respectively p and q. In some cases we take into account the set operations – $\cap$, $\cup$ or $\setminus$ – between the set of unique terms appearing in the documents of $\mathcal{P}$ ($Term(\mathcal{P})$) and those of $\mathcal{Q}$ ($Term(\mathcal{Q})$).

For non symmetric correlations and divergences we respectively apply the following transformations:

$$distance_x(\mathcal{P}, \mathcal{Q}) = |1 - corr_x(\mathcal{P}, \mathcal{Q})|$$

$$distance_x(\mathcal{P}, \mathcal{Q}) = \frac{div_x(\mathcal{P}, \mathcal{Q}) + div_x(\mathcal{Q}, \mathcal{P})}{2}$$

Table I presents the metrics we chose according to their typology. In this Table, we clustered together some measures considering either their underlying hypothesis or their mathematical formulas. To be thorough, we picked metrics from different groups and with different behaviours in our context. Thus we can group Minkowski's metrics like Manhattan (also known as *Taxi cab*) and euclidean distances. We can also cluster geometry based metrics like chord and cosine distances. Several metrics can be grouped due to their weightings like WED, Canberra and χ^2 distances. Some measures only rely on set operations like intersection and alt-intersection distances. Finally, some metrics are derived from correlation metrics like Pearson or Kendall τ. The remainder of the metrics we picked can not be coherently clustered, like Soergel, Hellinger and others.

IV. Results and discussions

We present here the results we gathered for the metrics we formerly introduced. Table II below synthesizes all the results we computed in terms of $F\text{-}measures$ and distance metric values with minima, maxima, averages and standard deviations. Table II also contains the correlation values given by the Pearson coefficient (R) and the Spearman coefficient (ρ) between distance metrics and $F\text{-}measures$. Finally the table presents results on LDA version with NLP. Pearson and Spearman values **boxed and bolded** denote a high correlation, high values with an **asterisk*** denote better correlation for LDA and underlined values denote very low correlation scores. Correlation values are considered high if within the ranges $[-1, -0.7]$ or $[0.7, 1]$, low if within the range $[-0.5, 0.5]$. Results not included within these ranges are considered non relevant.

From this table we learn that LDA with NLP outperforms standard LDA in terms of $F\text{-}measures$, which confirms the relevance of NLP in topic modeling and in similarity calculi. We also learn that Canberra, Kešelj and wave hedges distances do not seem correlated to LDA's $F\text{-}measures$ in either version of LDA. With very low Pearson and Spearman coefficients, we can discard these metrics as answers to our problematic. These low correlation scores can be explained by a large number of hapax in the frequency vector which has a negative effect on these three metrics. This is confirmed by the increase in number of hapax from standard LDA to LDA + NLP. Indeed, including complex terms highly increase the proportion of hapax within a bag of words vector.

Most of the metrics we picked demonstrate high correlation values with $F\text{-}measures$. In order to evaluate them, we have to rely on comparison between their respective Spearman and Pearson coefficients. Computing Spearman correlation scores for close significant Pearson values allows better distinction between metrics in terms of correlation with the $F\text{-}measures$. For instance Pearson values for cross-entropy and Kullback-Leibler distances have very close absolute values (-0.706 and 0.714 respectively) but their Spearman rank coefficients are not: -0.922 for cross-entropy and 0.785 for Kullback-Leibler. With the highest Pearson R and Spearman ρ, Hellinger distance appears to be the metric that is most correlated to $F\text{-}measures$ for standard LDA.

While Hellinger distance still gets good correlation scores for LDA with NLP, several metrics surged from NLP preprocessing. Soergel and Hellinger distances both appear as

TABLE I
METRICS GROUPED BY TYPOLOGY

Divergence based metrics	
Jensen-Shanon	$div_{JS}(\mathcal{P},\mathcal{Q}) = \frac{div_{KL}(p,m) + div_{KL}(q,m)}{2}$ with $m = \frac{p+q}{2}$
Weighted Euclidean (WED)	$div_{WED}(\mathcal{P},\mathcal{Q}) = \sqrt{\sum_{p_i \neq 0} p_i(p_i - q_i)^2 + \sum_{p_i=0} q_i^2}$
Geometry based metrics	
Chord	$dis_{chord}(\mathcal{P},\mathcal{Q}) = \sqrt{2 - 2\cos(p,q)}$
Cosine	$dis_{cos}(\mathcal{P},\mathcal{Q}) = 1 - \cos(p,q)$
Minkowski based metrics	
Minkowski	$dis_{Minkowski}(\mathcal{P},\mathcal{Q}) = \left(\sum |p_i - q_i|^{\alpha}\right)^{\frac{1}{\alpha}}$
Euclidean	$\alpha = 2$
Manhattan [22]	$\alpha = 1$
Weighting based metrics	
Canberra [3]	$dis_{Canberra}(\mathcal{P},\mathcal{Q}) = \sum \frac{\lvert p_i - q_i\rvert}{p_i + q_i}$
χ^2 [3]	$dis_{\chi^2}(\mathcal{P},\mathcal{Q}) = \sum \frac{(p_i - q_i)^2}{p_i + q_i}$
Set operations based metrics	
Alt-intersection	$dis_{altIntersection}(\mathcal{P},\mathcal{Q}) = \frac{1}{card(Term(\mathcal{P}) \cap Term(\mathcal{Q})) + 1}$
Jaccard [23]	$dis_{Jaccard}(\mathcal{P},\mathcal{Q}) = 1 - \frac{card(Term(\mathcal{P}) \cap Term(\mathcal{Q}))}{card(Term(\mathcal{P}) \cup Term(\mathcal{Q}))}$
Correlation based metrics	
Kendall τ	$corr_{\tau}(\mathcal{P},\mathcal{Q}) = \frac{card(concordant\ pairs) - card(discordant\ pairs)}{n(n-1)/2}$
Kendall τ B	$corr_{\tau B}(\mathcal{P},\mathcal{Q}) = \frac{card(concordant\ pairs) - card(discordant\ pairs)}{\sqrt{((n(n-1)/2) - n_1)((n(n-1)/2) - n_2)}}$ where n_1 is the cumulated number of possible tied pairs of values from $\mathcal{P}$ to $\mathcal{Q}$, and reciprocally for n_2
Pearson	$corr_R(\mathcal{P},\mathcal{Q}) = \frac{covariance(p,q)}{standard.dev(p) \times standard.dev(q)}$
Other metrics	
Soergel	$dis_{Soergel}(\mathcal{P},\mathcal{Q}) = \frac{\sum \lvert p_i - q_i\rvert}{\sum \max(p_i, q_i)}$
Wave hedges	$dis_{waveHedges}(\mathcal{P},\mathcal{Q}) = 1 - \sum \frac{\min(p_i, q_i)}{\max(p_i, q_i)}$
Bhattacharyya	$dis_{Bhattacharyya}(\mathcal{P},\mathcal{Q}) = \left\lvert \ln\left(\sum \sqrt{\lvert p_i - q_i\rvert}\right)\right\rvert$
Kešelj weighted	$dis_{Keselj}(\mathcal{P},\mathcal{Q}) = \sum_{p_i \times q_i \neq 0} \frac{(p_i - q_i)^2}{(p_i + q_i)^2} + card(Term(\mathcal{P}) \setminus Term(\mathcal{Q})) + card(Term(\mathcal{Q}) \setminus Term(\mathcal{P}))$
Hellinger	$dis_{Hellinger}(\mathcal{P},\mathcal{Q}) = \frac{1}{\sqrt{2}}\sqrt{\sum(\sqrt{p_i} - \sqrt{q_i})^2}$

relevant with very high and close correlation values for both correlation metrics: 0.827 and 0.809 for their respective Pearson score, 0.944 and 0.958 for their Spearman score. Furthermore, metrics with high correlation scores in standard LDA improve through NLP preprocessing. We can observe Pearson and Spearman scores increase for most metrics from standard LDA to LDA + NLP. Beside Hellinger and Soergel which perform best in LDA, chord and Jaccard distances also demonstrate high correlation scores with $F\text{-}measures$. Beyond the three common non relevant metrics – Canberra, Kešelj and wave hedges – several metrics also demonstrate significative decreases with LDA: alt-intersection, Kendall τ, Kendall τ B and Bhattacharyya distances. Like the three non relevant metrics, alt-intersection and Bhattacharyya distances are impacted by the number of hapax in document frequency representations; the raise in number of hapax decreases already medium values.

V. CONCLUSIONS AND PERSPECTIVES

We measured Pearson and Spearman scores between LDA's result quality and several similarity metrics in order to correlate document cluster similarity and clustering quality. We also compared a standard version of LDA to a version including complex terms. We showed that three metrics – Canberra, Kešelj and wave hedges distances – can be dismissed no matter the length or form of the bag of words – *i.e.* with or without complex terms. Two metric demonstrated high correlation with LDA's result with or without complex terms: Hellinger and Soergel distances. While Hellinger showed more correlated to LDA's results, Soergel distance seems promising as well in terms of complex terms extraction. Jaccard and cosine distances also demonstrate high correlations. Furthermore, we can notice significant improvements with complex terms for

TABLE II
RESULT TABLE PRESENTING PEARSON AND SPEARMAN CORRELATION SCORES BETWEEN DISTANCE MEASURES AND LDA'S QUALITY, THE LATTER EXPRESSED THROUGH $F\text{-}measures$.

STANDARD LDA						
	Minimum	Maximum	Average	Standard Deviation	Pearson correlation (R)	Spearman correlation (ρ)
$F\text{-}measure$	71.980	99.800	94.957	4.025	1.000	1.000
Jensen-Shanon	0.066	0.275	0.151	0.036	**0.752**	**0.917**
WED	0.002	0.016	0.007	0.003	0.692	**0.901**
Chord	0.113	0.426	0.234	0.047	0.629	**0.794**
Cosine	0.006	0.091	0.029	0.012	0.544	**0.793**
Euclidean	2.167	2.455	2.357	0.050	−0.699	**−0.922**
Manhattan	0.390	1.053	0.684	0.110	**0.752**	**0.886**
Canberra	2,583	5,110	3,984	406	0.438	0.474
Chi-Square	0.215	0.841	0.474	0.108	**0.754**	**0.909**
Alt-Intersection	3.131	7.496	4.738	0.674	0.629	**0.781**
Jaccard	0.456	0.729	0.597	0.052	**0.753**	**0.878**
Kendall	0.376	1.297	0.742	0.155	**0.736**	**0.912**
Kendall Tau B	0.525	0.872	0.685	0.056	**0.762**	**0.870**
Pearson	0.006	0.092	0.030	0.012	0.544	**0.793**
Soergel	0.327	0.690	0.506	0.061	**0.782**	**0.886**
Wave hedge	2,822	5,354	4,246	403	0.385	0.396
Bhattacharyya	3.531	4.045	3.835	0.083	0.668	**0.735**
Kešelj	2,266	4,809	3,623	412	0.497	0.555
Hellinger	0.285	0.599	0.432	0.055	**0.794**	**0.922**
LDA+NLP						
	Minimum	Maximum	Average	Standard Deviation	Pearson correlation (R)	Spearman correlation (ρ)
$F\text{-}measure$	73.955	99.891	95.866	3.453	1.000	1.000
Jensen-Shanon	0.115	0.474	0.267	0.069	**0.766***	**0.953***
WED	0.004	0.048	0.013	0.006	0.589	**0.930***
Chord	0.527	1.339	0.930	0.143	**0.801***	**0.928***
Cosine	0.139	0.897	0.449	0.135	**0.737***	**0.928***
Euclidean	0.032	3.154	0.553	0.816	0.491	0.874
Manhattan	0.623	1.596	1.071	0.184	**0.790***	**0.944***
Canberra	1,546	6,989	5,573	579	0.168	0.009
Chi-Square	0.376	1.418	0.822	0.198	**0.772***	**0.952***
Alt-Intersection	0.001	8.913	5.568	1.447	0.451	0.699
Jaccard	0.467	0.820	0.725	0.044	**0.814***	**0.903***
Kendall	0.392	1.575	0.928	0.173	0.659	**0.756**
Kendall Tau B	0.428	0.876	0.690	0.073	0.214	0.413
Pearson	0.153	0.928	0.480	0.140	**0.753***	**0.930***
Soergel	0.475	0.888	0.691	0.078	**0.827***	**0.944***
Wave hedge	1,700	7,227	5,801	603	0.116	−0.062
Bhattacharyya	3.421	4.319	4.152	0.070	0.522	0.428
Kešelj	1,339	6,677	5,258	552	0.236	0.104
Hellinger	0.372	0.780	0.576	0.075	**0.809***	**0.958***

either metrics on both Kendall and Pearson measures. We successfully showed that the quality of LDA is strongly correlated to document clusters similarity computation, especially with Hellinger and Soergel distances.

Finding out a highly correlated measure would allow one to estimate LDA results quality in either unsupervised and supervised experiments. As output evaluation is a recurrent problem in unsupervised experiments, such a measure would permit an *a posteriori* estimation of the quality of the results by measuring the distance between LDA's document clusters. Thus this measure would be gold standard independent. For instance, if after an execution the similarity between the vocabulary distributions of the two document clusters is very high, the quality of the topic models is expected to be low. In supervised experiments, such a measure would allow to a priori estimate LDA results quality, in this case the measure is gold standard dependant. It could also be used as a convergence limit for LDA's iterations rather than limiting it beforehand, which would be similar to the unsupervised evaluation mentioned above.

Our method is generalizable to any collection of documents. Even if we obtained better correlation coefficients with NLP which can only be used with syntactically correct texts, the LDA outputs' quality is highly correlated to the similarity metrics applied on simple word text representations.

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Identifying sound descriptions in written documents

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***Abstract*—Automatically identifying sound descriptions can be useful to extract soundscapes from written documents. In this respect, we present a preliminary work on the identification of sound descriptions which first expands a list of sound terms taken from a machine-readable lexical resource. Then, to find out the producer of each sound mentioned in a text collection, two methods have been tested out: one which relies on dependency parsing and the other which uses a pre-trained word embedding model. Both methods have been evaluated on a set of sentences extracted from three 19th century French novels; the obtained results suggest that dependency parsing performs better on this specific task. It should be noted that the first step of the proposed system is domain-independent and can generate a domain-specific lexicon for any topic.**

***Index Terms*—information extraction, sounds, lexical expansion, word embeddings, dependency parsing, automatic lexicon building**

I. Introduction

Since sensorial manifestations are an integral part of how we experience the world around us, a lot of texts contain details about sound experiences. Such information could be useful, for example, to study the sound characteristics of a particular place as well as their evolution throughout time or even to find out which types of sounds affect us the most. In particular, an automatic method for identifying sound descriptions will greatly simplify data gathering for digital humanities projects such as Bretez[1] and SoundCITYve[2], which seek to reconstruct the soundscapes of cities in previous centuries based on large collection of historical documents.

Like other papers dealing with the identification of sounds in written texts [1], [2], we started by collecting a list of sound-related terms. However, we did not narrow down the sound producers to a closed list of terms but rather attempt to develop a method which could be used regardless of the document's type or topic. For this purpose, we present a two-step system which first, expands the sound lexicon retrieved from existing lexical databases and then uses that lexicon to identify the corresponding sound producers. In this respect, it should be pointed out that the methodology proposed in the first step, for automatically extending the lexicon, is not specific to sound-related terms: it can be applied to any other topic by modifying the initial list used to initialize the system. In this work, since we are particularly interested in mining sound-related information in historical documents, we tested the pertinence of the resulting lexicon and our method for identifying sound producers on a corpus of 19th century novels.

The remainder of this paper is organised as follows: in section II, we describe the whole system with an emphasis on the two methods we propose for identifying sound producers in texts, which rely respectively on dependency parsing and word embeddings. In section III, we present our test data, a set of manually annotated sentences, and report our preliminary results.

[1]https://sites.google.com/site/louisbretez/home

[2]http://imu.universite-lyon.fr/appels-en-cours-et-bilans/2017-en-cours/soundcityve-archaeology-of-the-sound-landscape-a-sensitive-restoring-of-the-sounds-of-the-past-in-the-city-of-lyon-2017/

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II. Description of the proposed system

A. Architecture

Starting from a document collection and a first sound lexicon, our final goal is to identify in each document what or who is producing any sound. More concretely, given a text containing the sentence "When the bell rang, the children shrieked with delight" and provided the verbs "ring" and "shriek" belong to the used sound lexicon, we want to be able to identify "bells" and "children" as the producer of each respective sound. From a scientific point of view, to achieve this goal, two main questions must be answered:

- how to build an expanded list of sound-related terms from the initial sound lexicon?
- how can the resulting sound lexicon be exploited to detect all the sound producers mentioned in the text?

Two solutions could be proposed to answer the first question: hire humans (experts, crowdsourcing...) or use machine-readable lexical resources. We chose the latter since human expertise is often costly and time-consuming and the need for reliable tools to analyse the tremendous number of raw texts available online has encouraged the creation of lexical resources which describe words semantically and make it possible to group together synonyms. Good examples of such resources would be FrameNet [3] and VerbNet [4] in which words are described according to their prototypical syntactic and semantic properties. For instance, in FrameNet, "hiss",

"bang" and "trumpet" fall under the label "Sounds". However, the lists provided by this type of resources are far from being perfect as they may be not comprehensive enough or contain words that are too broadly related to the main concept. In this respect, to build our sound lexicon, we first created an initial lexicon by querying a lexical resource. Subsequently, this lexicon is manually filtered and afterwards, automatically expanded using a dictionary of synonyms. Therefore, as aforementioned, this lexicon expansion method is flexible enough to be applied to an initial list of words related to any domain.

As far as the second issue is concerned, based on the hypothesis that a sound producer generally occurs in the same sentence as the sound term to which it is related, the first stage consists in extracting all the sentences that contain at least a term listed in the sound lexicon. For this purpose, the document collection needs to be tokenised, lemmatised as well as tagged with part-of-speech information and the boundaries of each sentence are established. Then, the sound lexicon is used to find in the text all the sentences that contain a sound description *i.e.* a word from the sound lexicon. Finally, either the dependency parsing method or the word embedding based method is applied to generate the list of sound producers found in each document. Fig. 1 summarises the whole architecture of our system.

B. Sound lexicon expansion

This stage relies on a dictionary of synonyms to retrieve the synonyms of each word in the list of sound terms compiled from one or more lexical resources. It is particularly useful for languages such as French which lacks a lexical database which clearly indicates a synonymy relationship between words

Since some words have more than one meaning and there exist various degrees of synonymy depending on the context of usage, we had to find a way to single out the most pertinent synonyms among those proposed by the system. For instance, if the topic of interest is related to wildlife, for the word *crane* only the synonyms corresponding to its meaning *bird* such as *heron* should be retained and not the words close to its meaning *machine for raising*. In this respect, we distinguish between two different types of synonyms:

- **potential synonyms:** all the synonyms found in the dictionary for a meaning of a word related to the topic of interest;
- **candidate synonyms:** potential synonyms which share a certain amount of synonyms with the word we are working on

Based on these assumptions, we first generate the potential synonyms $LP(m, L)$ of each word m belonging to the lexicon L and then the potential synonyms $LP'(w, LP(m, L))$ of these potential synonyms. Finally, the candidate synonyms $LC(m)$ are obtained from the intersection of both lists.

More formally, given a word $m \in L$, our manually filtered lexicon, and $\mathcal{S}yn(m, i)$, the list of its synonyms for its meaning i, the list $LP(m, L)$ of potential synonyms of m is generated this way: $LP(m, L) = \{w; \exists i(w \in \mathcal{S}yn(m, i)) \wedge (\mathcal{S}yn(m, i) \cap L \backslash \{m\} \neq \varnothing)\}$ It is the union of all the $\mathcal{S}yn(m, i)$ that actually intersect $L\backslash\{m\}$.

Similarly, given w, a word in $LP(m)$ which is not in L, the list of its potential synonyms $LP'(w, LP(m, L))$ is defined by: $LP'(w, LP(m, L)) = \{w'; \exists j(w' \in \mathcal{S}yn(w, j)) \wedge (\mathcal{S}yn(w, j) \cap LP(m, L) \backslash \{w\} \neq \varnothing)\}$

Then using a modified Jaccard index [5] for filtering the list of potential synonyms LP, the list of candidate synonyms $LC(m)$ of m is obtained. This list is defined by: $LC(m) = \{w \in LP(m, L); \frac{|LP(m,L) \cap LP'(w, LP(m,L))|}{|LP(w, LP(m,L))|} \geq \beta\}$ where β is a parameter whose value determines the level of relevance required.

These main phases can be summarised as shown in Algorithm 1.

Data:
L: initial lexicon
$\mathcal{S}yn$: dictionary of synonyms
β: Jaccard threshold
$LC = \varnothing$;
repeat
  for $m \in L$ **do**
    $LP_m = \varnothing$;
    // LP_m is used to build $LP(m, L)$
    for *each meaning* i *of* m **do**
      if $\mathcal{S}yn(m, i) \cap L \backslash \{m\} \neq \varnothing$ **then**
        $LP_m = LP_m \cup \mathcal{S}yn(m, i)$;
      end
    end
    for *each* w *of* $LP_m \backslash L$ **do**
      $LP_w = \varnothing$;
      // LP_w is used to build $LP'(w, LP(m, L))$
      for *each meaning* j *of* w **do**
        if $\mathcal{S}yn(w, j) \cap LP_m \backslash \{w\} \neq \varnothing$ **then**
          $LP_w = LP_w \cup \mathcal{S}yn(w, j)$;
        end
      end
      if $|LP_m \cap LP_w| / |LP_w| \geq \beta$ **then**
        $LC = LC \cup \{w\}$;
      end
    end
  end
  $L = L \cup LC$;
until $end_{condition}$;

Algorithm 1: Algorithmic representation of the proposed method for lexicon expansion.

C. Strategies for the identification of sound producers

When thinking about sound producers, relying on syntactic clues immediately comes to mind as a sound producer is often linked to a sound-related term through a syntactic relationship. In this respect, our first method relies on dependency parsing. However, since such a method requires to list all plausible

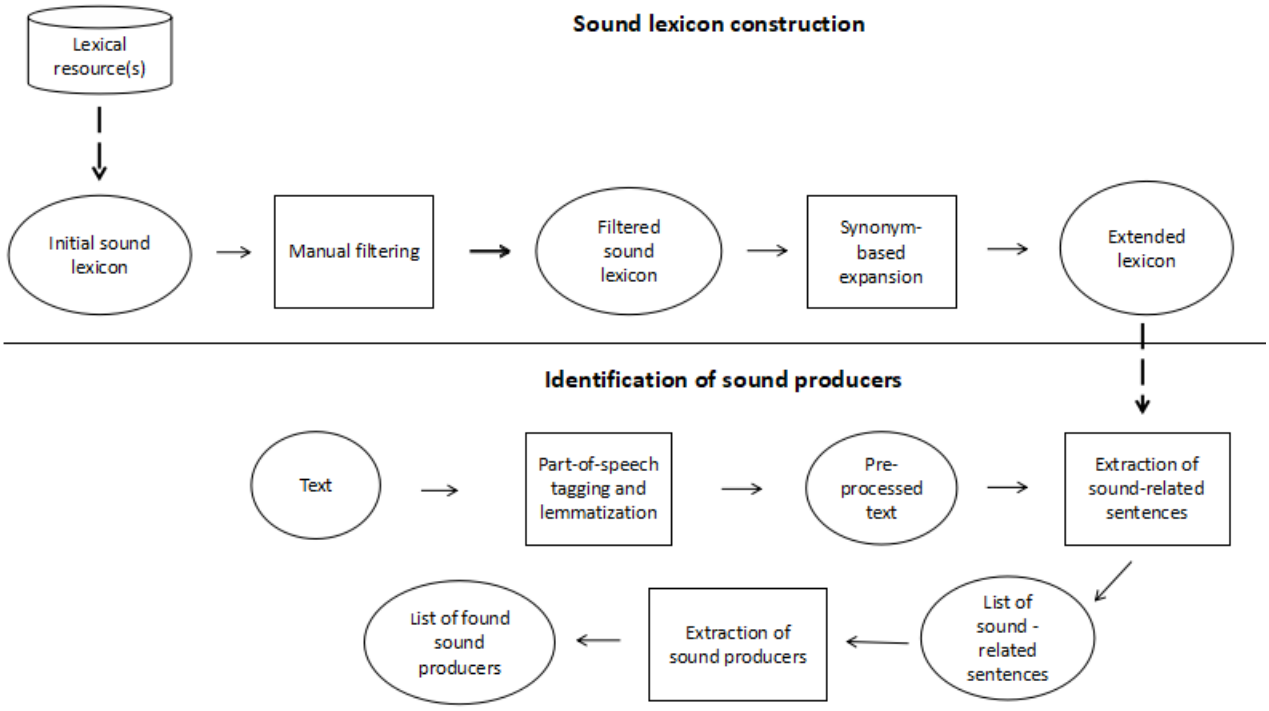


Fig. 1. Architecture of the sound producer identification system.

syntactic scenarios and needs additional rules to tackle coordination, we devised a second strategy which uses word embeddings. Both strategies are discussed in the sequel and first, extract all the sentences that contain at least one term listed in the sound lexicon. They are respectively summarised in Fig. 2 and Fig. 3.

a) Dependency parsing: Dependency parsing automatically provides the syntactic structure of a sentence based on the idea that words in any sentence are connected by binary asymmetrical relations called dependencies [6]. In other words, dependency parsing represents the hierarchies that govern a sentence by describing a word in terms of its link to another word to which it is syntactically subordinated. The root of such a representation is generally a verb.

Since sounds are generally expressed with verbs, nouns, and adjectives, the following dependency relations which involve a word from the extended sound lexicon were extracted:

- **verb**-*noun subject*
  e.g. That *dog* **barks** every night.
- **verb**-*noun direct object*
  e.g. The gesture made the *keys* **jingle** in his pocket.
- **noun**-*noun complement*
  e.g. The **shouts** of their *voices* could be heard through the **humming** of the *bell*.
- **noun**-*noun verb subject*
  e.g. [...] the wooden *soles* [...] quickly struck with a sharp **sound** against the leather of her boots [...]
- **attributive adjective**-*noun*
  e.g. She stopped to admonish the **crying** *child*.
- **predicative adjective**-*noun subject*
  e.g. The *concert* was very crowded and **noisy**.

The list of the sound producers produced by this method corresponds to all common nouns found through all these syntactic relations. The whole process is illustrated in Fig. 2.

b) Word embedding based method: The idea behind this method is to intersect an inventory of all sound producers in a language with the list of common nouns that occur in the same sentence as any word of the extended sound lexicon. In this respect, a word embedding model is used to derive all possible sound producers of the language from the extended sound lexicon, while the part-of-speech tags obtained during the pre-processing tasks are taken into account to reduce each sound-related sentence to a set of common nouns.

We chose to use a word embedding model since it allows words from a large corpus to be encoded as vectors in a high-dimensional space. These vectors take into account the context in which the words appear in the corpus so that two words that has the same neighbourhood should be close in the vector space. Thus, the cosine similarity between two word vectors can be used to compute their semantic similarity: a high value indicates that they have a similar context and are therefore semantically related. Consequently, to construct the list of all plausible sound producers for each word in the extended sound lexicon, we are going to extract all its neighbouring vectors which have a cosine similarity above a predefined threshold and which correspond to nouns.

This method could be transcribed as displayed in Algorithm 2 and Fig. 3.

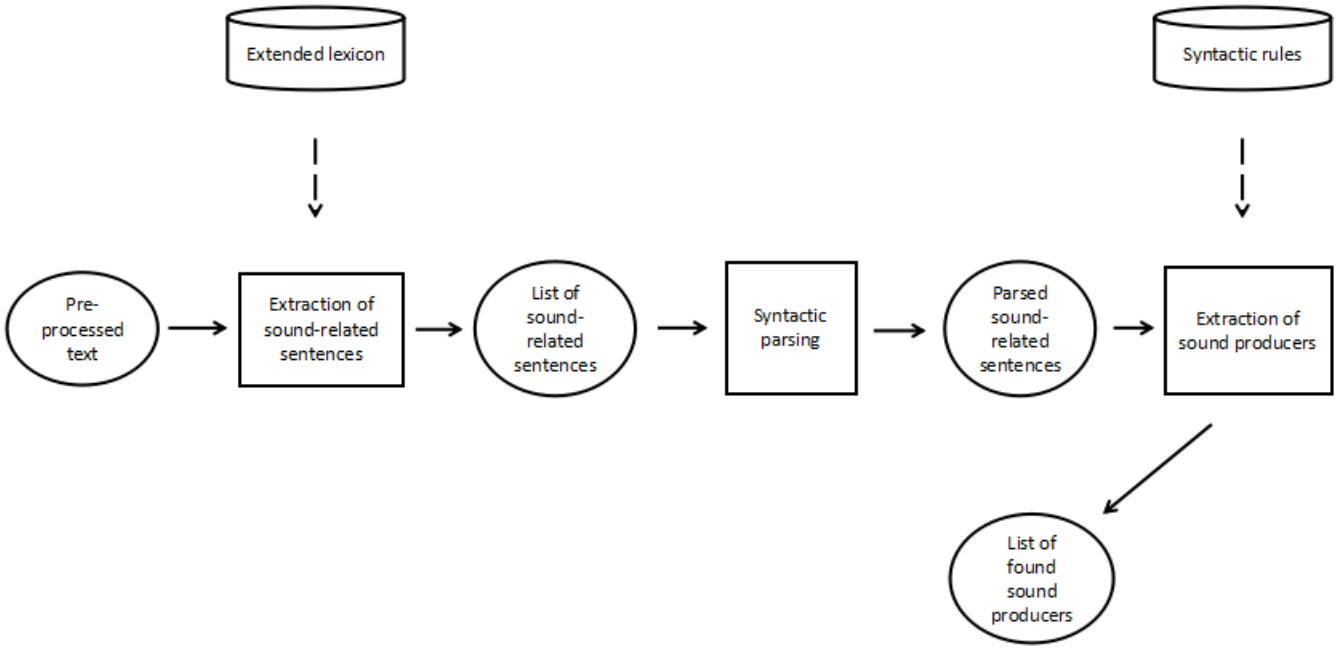


Fig. 2. Step of the method based on dependency parsing

Data:
L: sound lexicon
E: word embedding model
NC: set of all common nouns
T: all common nouns that occur in the same sentence as words of L
α: radius
$C_E = \varnothing$;
$PP = \varnothing$;
$Pc = \varnothing$;
for $m \in L$ **do**
  $E_m = \{w; \cos(E(m), E(w)) > \alpha\}$;
  $C_E = C_E \cup E(m)$;
end
$PP = C_E \cap NC$;
$Pc = PP \cap T$;

Algorithm 2: Algorithmic representation of the method for discovering sound producers with the word embedding method.

III. Experiments

In this section, we are going to describe the experiment that was performed on a French corpus to test out each method.

A. Data

a) Presentation of the test corpus: Since sound descriptions play an important role in creating the setting of a fictional text, we selected three 19th century novels: Honoré de Balzac's *Le Père Goriot* (1835), Gustave Flaubert's *Madame Bovary* (1857) and Emile Zola's *Germinal* (1885). The choice of these novels was motivated, on the one hand, by their date of publication, and on the other hand, by the fact that they were the subject of a manual study on sounds in novels. In addition, they are set in three distinct areas: whereas *Le Père Goriot* takes place in a big city, namely Paris, *Madame Bovary* is set in the countryside and *Germinal* in a mining town. In terms of length, *Germinal* has almost twice more sentences than the two other novels. The number of sentences of each novel as well as the number of sound-related sentences per grammatical category represented in the extended sound lexicon are given in Table I.

TABLE I
Sentence and sound distribution in the novels

Novel	Total number of sentences	Sound terms	Sentences containing a sound-related adjective	Sentences containing a sound-related noun	Sentences containing a sound-related verb
Le Père Goriot	5 473	60	4	152	199
Madame Bovary	5 943	109	8	338	340
Germinal	9 698	105	15	798	859

b) Ground Truth: To extract relevant sound-related sentences from the texts and to compile a list of sound terms associated with their corresponding sound producer(s), we based ourselves on Marie Jacquet's *Le Bruit du Roman: Le Père Goriot, Madame Bovary, Germinal*. We therefore manually identified, in that book, each occurrence of a sound

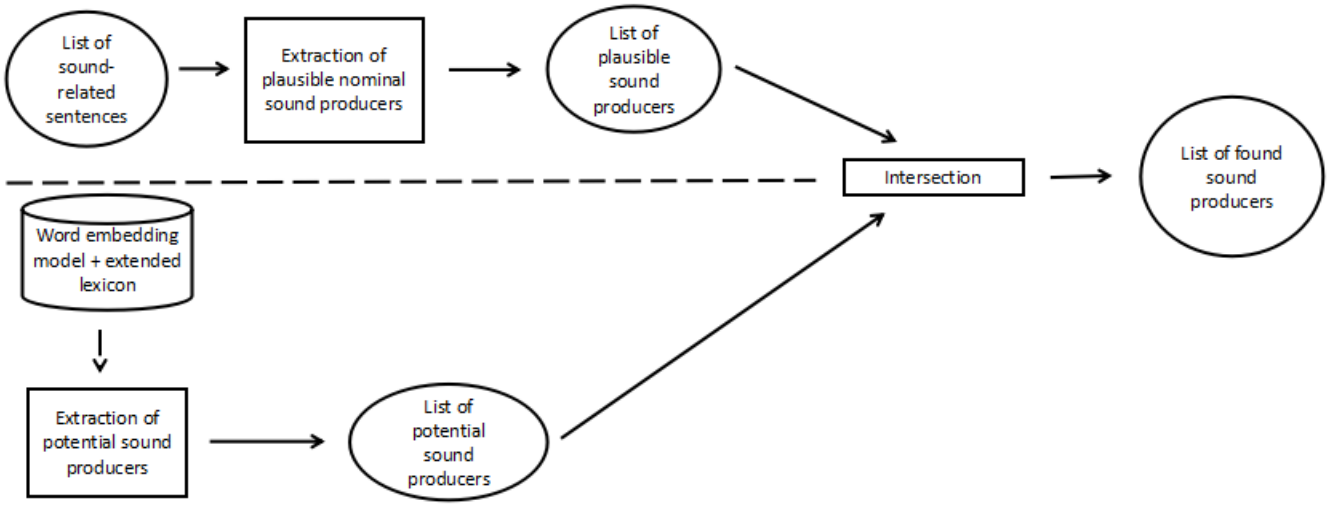


Fig. 3. Details of the method based on word embeddings

term mentioned alongside a sound producer. For all novels, we counted 553 pairs sound term + sound producer. It is worth noting that the term pair, here, is loosely used as a sound term can be associated with more than one sound producer, for example, in "the **sounds** of *forks, knives and spoons*". Table II provides some statistics about the ground truth. The number of novel-specific producers is particularly interesting and illustrate the complexity of this task as well as the importance of the setting since in *Madame Bovary* and *Germinal*, more than 70% of the sound producers are unique.

TABLE II
STATISTICS ON SOUND TERMS AND SOUND PRODUCERS LISTED IN *Le Bruit du Roman*: GROUND TRUTH

Novel	Number of pairs	Sound terms	Sound terms not in the lexicon	Producers	Novel-specific producers
Le Père Goriot	64	32	11	52	24
Madame Bovary	225	91	20	168	122
Germinal	264	94	22	173	125

B. Evaluation measures

We defined three measures to rate the performance of each method :

$$Precision = \frac{Ground\ Truth\ Pairs \cap Found\ Pairs}{Found\ Pairs}$$

$$Recall = \frac{Ground\ Truth\ Pairs \cap Found\ Pairs}{Ground\ Truth\ Pairs}$$

$$F\text{-}measure = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

Since the ground truth does not give a complete list of all sound descriptions, the recall, here, is purely indicative of the silence induced by each method.

C. Results

a) Construction of a sound lexicon: To build a French sound lexicon, we first retrieved sound-related words from two machine-readable lexical resources, *Les Verbes Français* [7][3] and *Le Dictionnaire électronique des mots* [8][4]. From *Les Verbes Français*, we extracted a total of 246 verbs belonging to 5 distinct classes whose descriptions are related to sound production. These classes, examples of those verbs and translation of the verb description into English are presented in Table III.

Then, we used our second resource, *Le Dictionnaire électronique des mots*, to add nouns that are semantically associated with those verbs as well as adjectives that describe sounds. We obtained a list of 519 words that was manually corrected by an expert to remove 201 words that were too specific or less directly connected to sounds such as "ultrason" (ultrasound) or "jargon", resulting in a filtered sound lexicon with 318 words. Finally, we performed two synonym query cycles using the *Dictionnaire des Synonymes*[5], an online French dictionary of synonyms, to expand the resulting list and ended up with a final sound lexicon containing 447 terms. Table IV gives more details about the successive lexicons' size and part-of-speech distribution.

[3]rali.iro.umontreal.ca/LVF+1/classe/index.html
[4]rali.iro.umontreal.ca/rali/?q=fr/dem
[5]http://crisco.unicaen.fr/des/

TABLE III
CLASSES OF VERBS SELECTED IN *Les Verbes Français*

Classes	**French description**	**English description**	**Examples**
C1a	émettre un cri + *sujet animal*	Verbs of sounds made by animals	aboyer, coasser, rugir…
C1b	émettre un chant + *sujet humain*	Verbs denoting a human singing activity	chanter, siffler…
C1c	émettre un son, un bruit significatif + *sujet humain*	Verbs denoting a sound made by a human using an object	carillonner, tambouriner…
H2g	avoir telle activité bruyante + *sujet animal/humain*	Verbs corresponding to a noise made by an animal or a human	bourdonner, grésiller…
H3d	produire un bruit, un son + *sujet non-animé*	Verbs for sounds made by an inanimate object	vrombir, tinter, chuinter…

TABLE IV
WORD DISTRIBUTION IN THE LEXICONS

	Verbs	Nouns	Adjectives	Total	Examples
Initial lexicon	246	229	44	519	*bourdonner, ronfler, gronder, bruit, cri, raffut, vacarme, cacaphonique, bruyant, assourdissant*
Filtered lexicon	149	152	17	318	**Some deleted words**: *donner, fausser, rendre, raper, traînement, trépidant, infrasonore, ultrasonique*
Extended lexicon	205	217	25	447	**Added words**: *maugréer, tempêter, murmure, sifflet, explosion, vociférant, hurleur, rugissant*

b) Identification of sound producers: For this experiment, we used as dependency parser, the French version of the Berkeley Parser [9] and as pre-trained word embedding model, the freely available word embedding model with part-of-speech tags built with the French TenTen corpus [10]. This model was built with fastText [11] using the SkipGram model with dimension 100; for the extraction of neighbouring vectors, the vocabulary size was limited to 500 000 words while the cosine similarity threshold was set to 0.5.

As can be seen from Table V, the method based on dependency gives better results and, as far as *Madame Bovary* and *Germinal* are concerned, enables to retrieve more than half of the sound producers. The low precision of both methods, however, suggests that they generate too many false positives and that some further adjustments should be made, for example, to consider only one syntactic dependency or to limit the relevant common nouns to those that are closer to the sound term.

	Dependency parsing			Word embeddings		
	Prec.	*Rec.*	*F1*	*Prec.*	*Rec.*	*F1*
Le Père Goriot	20.7	43.7	28.1	10.7	9.3	10.0
Madame Bovary	28.6	59.3	38.5	9.8	23.6	13.8
Germinal	14.6	53.9	22.9	6.2	17.3	9.1

TABLE V
RESULTS FOR BOTH METHODS

IV. CONCLUSION

In this paper, we presented a system aimed at expanding a sound lexicon extracted from an existing lexical resource and at using it to find sound descriptions in texts. While the first step relies mainly on a dictionary of synonyms, two methods have been tested for the second one: dependency parsing and word embeddings. So far, dependency parsing appears to be more promising, especially in terms of recall. It should be noticed that the method applied here to extend the sound lexicon which is ultimately used to discover the sound producers is not domain-specific.

ACKNOWLEDGMENT

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Posters

An Approach for Selecting the Most Suitable Business Process Modelling Method/Notation

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***Abstract*—Currently, several notations can be used for modelling business processes, and various researchers tried to compare them focusing on their specific properties or constructs. We propose an approach that, instead of resulting in selecting a notation, drives to pair specific business process modelling cases with suitable modelling methods, by matching the features required by the former with the ones supported by the latter.**

***Index Terms*—Business process modelling, UML, BPMN.**

I. Introduction

Let us consider how to face a *specific task* of modelling some *specific aspects* of a *specific business process* BP for *specific aims*, i.e. a specific *modelling case*. Currently, various modelling notations are available (e.g. BPMN, UML and EPC), and many researchers have analysed and compared such notations from different viewpoints (see [1]–[4] and the other works cited in [5]) but except Aguilar [6] that considers the aim of the model to produce, the comparisons have been made in general without considering the specific modelling case at hand.

For this reason, currently, modellers select the most suitable modelling notation for business processes without considering the specific modelling cases that they have to face, and then they are left to develop the models.

II. Proposal

Our work aims at providing a more effective answer to the modellers by helping to select *modelling method*s instead of just notations, since: (a) it is not true that there exists a unique way to use a given notation to model a business process, and (b) a method will reduce the effort of the modellers and will guarantee a better model quality. A *modelling method* has the following characteristics: (1) is based on one modelling notation; (2) provides precise indications of what are the modelled items (e.g. data-aware business processes); (3) defines the subset of the models of the chosen notation used by the method, the eligible models (e.g. the BPMN models consisting of just one collaboration diagram); (4) expresses the relationship between the modelled items and the eligible models (the modelling essence); (5) gives guidelines to drive the modeller activity; and (6) explicitly details the intended use of the produced models.

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Matching modelling cases and modelling methods based on features characterising both. Let F be a set of features characterising modelling methods and modelling cases. We have a collection of modelling methods M each one characterised by its set of features, say M_1 – F_1, …, M_n – F_n. Given a modelling case MC we determine the set F_{MC} of features characterising it. If F_{MC} is contained in F_i, then M_i is a suitable answer (we may have more than one answer). Otherwise, if it is possible to work out a new method based on one of the existing modelling notations covering all the features in F_{MC}, it will be the answer. Otherwise, select M_j such that F_{MC} intersected with F_j is maximal (again we can have more than one answer).

Reusing the effort. Following our approach, the method catalogue will increase, and so it will be easier to find a suitable method. Many modelling cases are strongly similar, thus it is possible to build up also a catalogue of typologies of modelling cases, hence if the modelling case at hand matches one of a typology already in the catalogue, then the method selection will be immediate.

How to define a sensible set of features? The current definition of the set F is based on our long experience backed up by the current literature (that is features characterising the business processes and the business process modelling notations proposed in the literature are included in F). F contains:

– Structural features, that are features related to managing some constituent elements of business processes, e.g. the data managed by the process;
– Model views, i.e. views of business processes (e.g. the interaction view, that is a representation of a process in term of messages exchanges);
– Dimensions of business process, such as the number of tasks or participants;
– Characteristics of the models; here we consider only "objective" characteristics, that are properties of the models that can be verified without the human intervention; for example readability is not objective (indeed it can only be verified by means of empirical assessments with human participants). In this initial version, we consider only the *level of precision of the model* determined by the formality of the used notation: *formal* (notation has a formal semantics, e.g. Petri net), *hard* (notation has a semantics, e.g. Java), *soft* (notation has at least a well defined syntax), *loose* otherwise.

TABLE I
SUITABILITY OF BPMN AND UML FOR FIVE MODELLING CASES

	Modelling cases														
	Data-aware process machine processable			**Data-aware process for human readers**			**Executable process**			**User-manual**			**Enterprise's processes**		
Features	***Case***	**UM1**	**BM1**	***Case***	**UM2**	**BM1**	***Case***	**UM3**	**BM2**	***Case***	**UM4**	**BM3**	***Case***	**UM5**	**BPMN?**
Participants (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Active participants (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Workers & Systems (E)							✓	Yes	P				✓	Yes	
Active Participant Structure & Behaviour (V)													✓	Yes	
Business Objects (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Business Object Structure & Behaviour (V)	✓	Yes					✓	Yes					✓	Yes	
Data (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Data Definition (V)	✓	Yes					✓	Yes					✓	Yes	
Organization Units (E)													✓	Yes	
Tasks (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Task Participants (E)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Task Behaviour (V)	✓	Yes					✓	Yes					✓	Yes	
Abstract tasks (E)	✓	Yes	P	✓	Yes	P									
Executable tasks (E)							✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Workfow View (V)	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	Yes	✓	Yes	
Interaction View (V)							✓	Yes	Yes	✓	Yes	Yes			
Messages (E)							✓	Yes	Yes	✓	Yes	Yes			
Goals (E)													✓	Yes	
Multiple Processes (E)													✓	Yes	
Process Overview (V)													✓	Yes	
Entity View (V)													✓	Yes	
Enterprise Architecture (E)													✓	Yes	
Long Processes (D)				✓	Yes	P									
Large Processes (D)				✓	Yes	P									
Formal (C)															
Hard (C)	✓	Yes					✓	Yes					✓	Yes	
Soft (C)															

✓ required empty: NOT required **P** partially supported **Yes** supported cannot be covered by any extension of the method
Features kind: **E** (for Element) **D** (for Dimension) **V** (for View) **C** (for Characteristic)

The first column of Table I lists all the features considered in this work, they are marked with either E (for Element), D (for Dimension), V (for View), or C (for Characteristic) to denote their kind. For example, the feature Workers & Systems expresses that (i) the modelling case requires that the active participants of the process must be distinguished in workers and systems, (ii) the method allows to distinguish between workers and systems.

Table I lists also the methods considered in this work, distinguished between those based on UML and those on BPMN with the indication of which features they support. A detailed presentation of the approach and of the considered modelling methods based on the BPMN and the UML (together with their application to several case studies) can be found in [5].

Table I introduces also the five modelling cases considered here, each one with the required features: (1) Data-aware processes machine processable; (2) Data-aware processes for human readers; (3) Executable processes; (4) User-manual; and (5) Processes of an enterprise. *Data-aware* means that the data managed by the process should be explicitly modelled. *Machine processable* means that the models should be processable by software applications, e.g. for transforming them into inputs for simulators, differently the *human reader* states that people should easily understand the models. *Executable* means that the modelled process will be enacted by a software system, whereas *user-manual* states that the model should replace a user-manual for documenting some procedures. When there is the need to model several processes of an enterprise we have the last case (*Enterprise's Processes*). Near each modelling case, we have presented the most suitable methods based on UML and on BPMN, together with the indication that some features cannot be provided by any method based on that notation.

The proposed approach, based on features, not only allows to select a suitable modelling notation together a method for specific modelling cases, but also provides a context-dependent way to compare modelling notations, UML and BPMN in this case. The result that UML covers more modelling cases than BPMN is in our opinion essentially motivated by the fact UML is a general-purpose notation with diagrams and constructs able to cover many different aspects and it is easily extendible using the profile mechanism. Indeed, all the proposed UML based methods use specific UML profiles, whereas BPMN is in some sense incomplete, since some fundamental parts of the models (e.g. the InputOutputSpecifications of the tasks) may be only provided using some tools dedicated to produce and execute the BPMN models and using non-standard languages. Thus, comparing UML with a BPMN (non-standard) variant supported by a tool we may obtain different results.

III. VALIDATION

Our initial approach will be further validated by repeatedly applying it to realistic case studies. Then, it will be possible to understand if the considered set of features F is complete (such features are enough to characterise any modelling case motivated by the practice and any method based on UML and BPMN that can be designed), or that new features have to be added (e.g. tool support) or also that some features may be irrelevant (they are not useful for discriminating between any case/method).

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DEMOS : a DEsign Method for demOcratic information System

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***Abstract*—The issue of democracy in society is at the heart of our current concerns. Organizations and their information systems are also concerned by this issue. Democracy in organization requires a debate about norms, values and language encapsulated in the information system. Participatory design approaches address this issue by proposing a democratic empowerment for users during design phase of projects. To go further, we propose a structured method to integrate democracy into information system. This method named DEMOS for DEsign Method for demOcratic information System is described and then illustrated by a real experiment provided by a "lifelong training" service at the University.**

Keywords—Democracy, Method engineering, Information system design, Requirement engineering, Viewpoint, End-users, Participatory design, Agility, User centered design

I. INTRODUCTION

An Information System (IS) is not neutral. In his book Brey speaks about "embedded values" in the IS [1]. Mingers says that IT systems embed particular values which have a "moral impact" [2]. In many cases, IT systems managers implement these standards without even realizing it. In 2010, Floridi proposed to elicit those embedded values and to take them into account during the IS development [4]. In 2008, Salles and Colletis described a "three-level grid" highlighting the link between representations, models and norms [4]. They explain how vocabulary, codifications used in the organization's IS are a direct consequence of higher-level models and representations. The need for democracy comes from these observations. On the one hand, those norms and values need to be debated, deliberated and recognized, in a democratic way. On the other hand, if we agree with Salles to say that « democracy is considered above all else to guarantee access to a plurality of worldviews" [5], a democratic IS is a system that respects viewpoints. For that, end-users representing different viewpoints have to be considered in the system design. To go further, viewpoints must be implemented in the IS, to conform to the first issue. The IS should not conform only to a dominant viewpoint.

In the continuity of Van Den Hoven [6], we propose a "proactive integration" of democracy with a Design Method for demOcratic information System, named DEMOS. Our method proposes to integrate democracy in two ways:

- A democratic design method, which lets users debate about IS values and norms, and to bring out viewpoints.
- A democratic IS, which respects viewpoints expressed in the design phase and implements them.

In this article, we first present a state of art of user involvement in design approaches. Then, we identify specific issues for a democratic IS and present how DEMOS can address them. We illustrate this part with a feedback from a real experimentation conducted with "lifelong training" service at the university.

II. STATE OF ART

The lack of user input during design has been identified as being a major factor in the failure of IS to be adopted by users. Users' participation is a way to increase functional qualities of the system and to be as close as possible to their needs. It is also a way of democratic empowerment for users, by a direct participation in decision making [7]. In the IT literature, we find several levels of users' involvement in projects: from considering the user as a "subject of study" in User Centered Design (UCD), to users playing a more collaborative role in co-operative design. With Participatory Design (PD), the user drives the design process himself. [8]. With UCD and co-operative approach, users have an informative or consultative role. As Ferrario says: software developers still "lead the process", whereas users participate by refining their ideas [9]. The quality of the developed system is increased, but the users are not empowered with this method. PD is the most involving approach and can provide a democratic empowerment if users participate in "defining project objectives and initial plans" [10]. According to Kensing and Blomberg, participatory design is an approach in which the participation of people in the co-design of the information system they are supposed to use themselves is a "central tenet" [11]. User is the "co-designer" of the system [12]. Some authors like Sanders defines PD as a "democratic approach" [9].

Agile methods are sometimes considered as participative approaches. In fact, agility and PD share some goals, like improve usability [13]. However, even if users can provide feedback, they don't participate in any design activities [7]. With agile method, the customer is the central partner of the collaboration with developers and design team [14]. In some methods like SCRUM, a Product Owner can play this role of partner, as a user representative [15]. Some authors show that a method as XP can integrate user participation [16]. RAD is definitely the most participatory agile method [18]. But even if users are involved in design, RAD is not always a participatory approach during development.

III. DEMOS : A DESIGN METHOD FOR DEMOCRATIC INFORMATION SYSTEM

DEMOS is a design method for democratic IS. We have identified 4 issues to develop a method which respects a democratic process and produces a democratic IS.

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Firstly:involve end-users in a participatory and democratic process. Secondly: allow a democratic debate to let viewpoints emerge. Thirdly: design a democratic IS which takes into account these viewpoints. Fourthly: provide traceability of viewpoints for system maintenance. DEMOS is presented in the form of a MAP : a "navigational structure" [19] developed by Rolland. It allows presenting the method as a selection of intentions (circles) and appropriate strategies (arrows) to achieve it (Fig. 1). Each intention in the MAP is a response to previous issues.

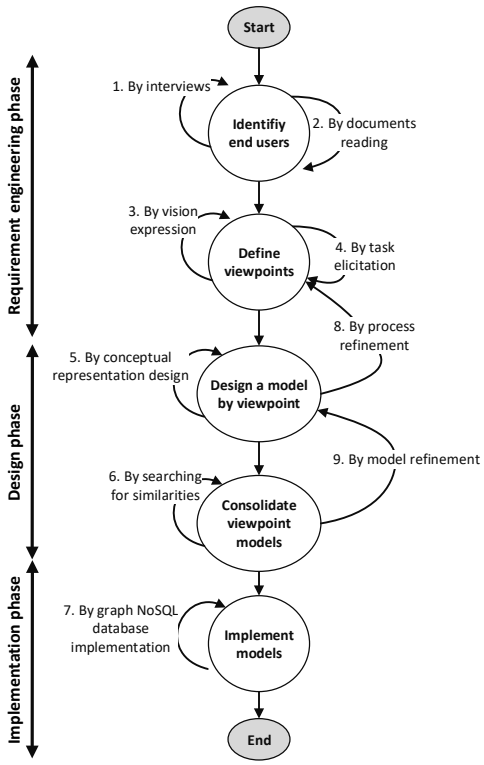


Fig. 1. General view of DEMOS

From January to June 2018, DEMOS has been used for a real project. The project focused on the implementation of an attendance management tool for the Toulouse 1 Capitole university's "lifelong training" service. This experiment was conducted with 8 end-users: 3 teachers, 4 schooling managers and the "lifelong training" service manager. The aim of the project was to develop a prototype to be tested by users. The designed software is currently being implemented.

IV. Discussion

We have shown with DEMOS that a structured design method can contribute to integrate democracy in IS, and we have illustrated our proposition with a concrete case. Following the experiment, we have evaluated DEMOS with semi-structured interviews with end-users. Evaluations revealed that end-users understand intentions of the method. They understand both aspects: a **democratic process** for a **democratic IS** which respects their viewpoints. Viewpoint notion that was not obvious to them at first became clearer during the workshops. Moreover, for users, sequencing of steps was coherent according to the intentions. Overall, they were assisted by techniques and tools used during the process. At the end, they are satisfied with the method results, which are consistent with what they have expressed. The final software is under development and was not considered for evaluation.

During the experiment, and according to the evaluation, each intention has been respected. However, the implementation of viewpoints is guaranteed by the implementation of a database structure that formalizes the IS through the vocabulary of the end-users' viewpoints. As future work, we want to add other intentions to implement activity model and interface model. Thus, we will propose a total implementation of viewpoints. We also want to explore further the possible link between DEMOS and agile development. A method as XP could, if it respects some criteria, extend our design method to the development phase. Thus, the integration of democracy would be effective in the final product

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Interacting with Overlaid Information in Augmented Reality Systems for Maintenance: A Preliminary Review

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***Abstract*— In this paper, we present a preliminary study over how augmented reality systems for industrial maintenance present and let users interact with virtual information. Ten papers are analyzed through three comparison tables presenting the type of information displayed, how the information is displayed with respect to the real world and the interaction techniques available to users.**

One of the many promising application domains of augmented reality lies with tools to help with the maintenance of industrial-grade complex devices, where a technician tasked with maintaining them will frequently have to keep at hand the equivalent of several hundred of pages of various documentation. Augmented reality (AR) systems provide the technician access to the digital version of this documentation, even in a hands-free manner when AR goggles are used. As we discuss further in this paper, the type of information displayed in such systems can range from annotations, to static pages presented in front of the user, to 3D models overlaid on the device. In this poster paper, we present a preliminary review of a range of AR systems for maintenance from the point of view of the type of displayed information. We then discuss preliminary observations from our study.

TABLE I: Type of information displayed

Article	Text	2D shape	3D model	
			Basic	Complex
[1]	X	X		X
[2]	X			X
[3]	X	X		X
[4]	X	X		X
[5]	X			X
[6]	X	X		
[7]	X	X		X
[8]	X	X		X
[9]	X		X	
[10]	X	X		X

I. THE STUDY

The goal of this study is to give a preliminary picture on how augmented reality systems for maintenance in the literature tackle the challenge of displaying information to a trained technician. We have selected a preliminary set of articles according to the following filters:

- We only take articles published after 2000.
- We select articles that have been quoted at least one time by another author.

TABLE II: Information displayed w.r.t. to reality

		Panel	Object
Environment	Floating	[3] [5] [8] [10]	[1] [2] [3] [5] [7] [8]
	Superposition	[6] [7]	[7] [9] [10]
Glasses		[1] [2] [3] [4] [5] [9] [10]	[3] [4]

- We search for articles with the following keywords on google scholar : Augmented Reality, maintenance, industry.

Please note that the articles we discuss in this poster paper are a subset of the whole literature, selected to be a representative set within paper size constraints.

In general, we observed two generic types of scenarios. The first one is to go through a step-by-step predefined process aimed at resolving a general problematic. This implies that such systems are partially hard-coded with specific information in a specific format for a set of predefined cases. The second type of scenario revolves around the visualization of complex sub-assemblies and their characteristics.

II. COMPARISON TABLES

We divide the comparison in three aspects: (a) the type of information displayed that can range from simple text to complex 3D models (see Table I), (b) how elements are displayed w.r.t. the user and the environment (see Table II) and (c) the interaction techniques used to interact with information items (see Table III).

Table I describes four different categories of data we encountered in our selection of papers. Any system displaying text belongs to the first column, also when text is written on a 2D floating square. The second column encloses systems with 2D shapes with possibly a texture. This includes diagrams, pictures, schemas, etc. Finally, the last two columns are differentiated by the complexity of a 3D mesh. Systems making use of primitive shapes such as cubes or spheres are displayed in the third column, while other cases are in the fourth column. When systems used both basic and complex shapes, we considered them only in the complex shape column to better distinguish them.

We can remark that almost all studied articles are based on a combination of text and shapes (see Table I), with textual information complementing shapes of some sort. In the great

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TABLE III: Interaction techniques used

Article	Device(s)	Vocal	Touch screen	Hands Gestures	Head tracking	Environment		Tangible Interactor
						interaction	recognition	
[1]	Glasses	X						X
[2]	Touch phone		X					
[3]	Glasses							X
[4]	Glasses					X		
[5]	Glasses						X	X
[6]	Touch tablet		X					
[7]	Glasses							X
[8]	Glasses	X						
[9]	Touch phone		X					
[10]	Touch tablet		X	X			X	

majority of cases, complex 3D meshes are used rather than basic 3D shapes. Typically, these are modelled as simplified versions of a real object, as for example in [9].

An analysis of how information is positioned in the view is presented in Table II. One may note that systems in the literature have been exploring multiple possibilities for interfacing virtual information with real environment, be it information floating in a fixed position in the environment (typically markers), superposed over a real object, or attached to the user's viewpoint, typically depending on the semantics of the information considered. Only specific cases display information elements only on a surface. Virtual objects can range from copies of a real objects, to visual guides, to entirely virtual objects overlaid on top of an otherwise empty real environment. Studies in [6] and [7] for example improve the capabilities of a real element in respectively displaying a digital menu next to a button and completing with pictures a blank sheet of paper.

Finally, we consider how the user can interact with digital information in the different reviewed systems (see Table III). We first describe the type of device used in the system as it usually plays a strong influence on the available interaction techniques. It is also important to notice that under the term "glasses", we consider all systems carried on the head and displaying information in front of the users' eyes. Touch screen interaction demands a touch surface (smart phone or tablet). Head tracking typically uses some sort of reticle in the center of the user's view as interactor. Some systems exploited the environment as interactors, e.g. protruding screws and nuts used as virtual buttons in [4], or detect changes in the environment. An analysis of the third table shows that there is room for improvement in terms of interaction techniques. In particular, there is still a strong division between the AR system and the environment, with few systems bridging the gap. Vocal interaction is also seldom used, but this can be explained by the usage context of maintenance work as good vocal interaction demands a quiet real environment.

III. PRELIMINARY OBSERVATIONS

Our review shows that a lot of work has been done on visual elements themselves: which kind, how to present them and how to map them to the environment. Another important observation is the almost systematic use of a fixed process guiding the user through a number of fixed steps, either to improve efficiency or for training purposes. Each step has specific information and is linked to a particular process. Few systems, if any, adapt dynamically the displayed information and the interaction based on e.g. the user's tasks, or environmental information. We can also remark that the position of elements are strictly defined as the user has no influence over the position of the elements and interaction with them. Finally, as described in the introduction, this paper presents a first review, that we intend to extend as a future work.

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Generating Value with Open Government Data: Beyond the Programmer

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***Abstract*—Open government data (OGD) promises to yield many benefits for society, such as the development of innovative products and services. Investments have been made to increase the publishing of OGD and its usage by the general public. However, the use of OGD remains low in practice, as potential OGD users can lack awareness, skills and resources to exploit this data. Current attempts to remedy this issue (e.g. hackathons) attract only a small subgroup of the citizenry, that is, digital literates with knowledge in programming, and therefore outputs digital solutions. In this paper, we present a tentative methodology aiming at involving a larger part of the citizenry in ideation with OGD to find applications relevant to citizens' everyday lives.**

***Index Terms*—Open government data; OGD; Ideation; Methodology; Citizen participation**

I. Motivation

Open government data (OGD) is interoperable data published on the Internet by public organizations to be freely used and redistributed by anyone [1]. Use can lead to several benefits, such as citizens engaged in policy-making, democratic accountability, self-empowerment of citizens, development of innovative products and services and collective problem solving [6]. However, the use of OGD remains low in practice [7]. Consequently, the opportunities promised by OGD do not reach their full potential [8] and the investments made by publishers risk not reaching fruition.

As a result, publishers have made efforts aiming to increase the use of OGD by citizens (e.g. organizing hackathons [4] or training programs [5]). However, these attempts only attract a digital literate part of the citizenry. Still, these skilled users face impediments when working with OGD. A recent study we conducted highlighted that citizens can play a role in alleviating part of these struggles. Some participants of the study experienced impediments in the ideation phase of their project, which is essential for producing a creative output [3]. They explained this issue by their lack of knowledge on citizens' needs and public issues, and noted that discussing ideas with citizens would have been helpful to increase the value of their product.

We argue that citizens have an essential role to play in solving public challenges, that OGD can inform the creative process, and that digital solutions are not the only valuable output of OGD use. In this paper, we propose a tentative workshop methodology aiming at involving citizens in the generation of value with and for OGD, going beyond the development of digital applications. The research question at hand is to study how OGD can help citizens to generate ideas on public challenges, based on their needs and experiences, to be met by problem-solvers.

II. Ideation Methodology Proposal

The methodology proposed here is a collaborative problem solving approach, aiming at overcoming the gap between OGD users (product or service creators - e.g. developers), citizen end-users (users of the said product or service), OGD publishers and relevant stakeholders, to address a predefined issue of public interest. Its purpose is not to output digital applications based on OGD, but rather to enable the creation of new forms of value from OGD for the citizens based on their needs. It aims to increase the social impact of OGD and innovative use cases to enhance its use.

For this methodology, the **input** is composed of an initial problem statement, citizens' needs and perceptions about it, a set of data representations accessible to non-expert users to inform on the problem on hand, and artifacts to foster creativity and the design of solutions (e.g. a 3D model of a city serving as common workspace). The expected **results** are idea (re)presentations (e.g., mock-ups, cases with personas, sketches, user journeys or prototypes) and insights on OGD useful for the publisher (e.g. identification of missing datasets by the expert users and issues experienced with datasets). Below, we give an overview of the methodology steps:

1) Start with formulating a challenge or a theme of interest for citizens to drive their ideation process, in collaboration with relevant stakeholders.
2) Send invitations to stakeholders (e.g. for mobility, invite the public servants in charge of mobility and urban planning, a public transportation company) and a group of citizens (users). The population of citizens concerned by the question or theme on hand should be identified to ensure that invited citizens form the most representative sample possible. Invitees should be provided preparatory documents (information, context of the theme, and objectives of the event).

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3) The workshop starts with a presentation of the question or theme on hand by domain experts. This first phase aims at setting a common understanding of the issue and at leaving room to the citizens to reformulate the challenge based on their experience and views. Further information about OGD is provided and the artifacts that will be used to foster creativity throughout the workshop are introduced.
4) Then, in the ideation activity, the participants (citizens and users in mixed teams) work to generate prospective solutions and design of solutions. This activity is iterative and can be supported by a city model to help participants visualizing the solutions in action and their impact.
5) The workshop ends with a presentation of the idea (re)presentations and voting by citizens for the the best solution. The winners are awarded.
6) The ideas are subsequently published for others to implement, e.g., on an OGD portal or the municipality website.

We conducted two unstructured interviews with two students who are OGD users and participate frequently to hackathons in order to have a preliminary validation of the interest of the methodology. Its main strength compared to similar attempts of OGD use is that citizens participate in the ideation stage to give ideas based on their needs and have the lead on the proposed solution, working in team with OGD users. Furthermore, as the output of the methodology can consist of non digital solutions, citizens can also take part in the early prototyping of the ideas. One interviewee mentioned a recent hackathon event that sought citizens' demands beforehand to provide a starting point to the users. However, he noted that no dialogue occurs between users and citizens, missing opportunities of early feedback to refine solutions. The other interviewee noted that such a methodology would be efficient to foster discussion among citizens, but that a mediation mechanism is necessary to keep the debate constructive.

Depending on the objectives pursued, the methodology could be part of a bigger project aiming to increase OGD use. The project would rely on the methodology to generate ideas and prototypes, and then invite the citizens back afterwards for testing and validation of implementations created by others, similarly to the framework proposed in [2]. Also, several workshops following the methodology could be iteratively organized to achieve better results. Then, the output of one workshop would be part of the input artifacts of the next one.

The methodology can improve the OGD use in several aspects. First, involving citizens in OGD use allows capturing their needs and thus delivering solutions that answer real-life needs. Second, since digital non-literates are involved, the scope of OGD outputs, usually consisting in digital solutions in practice, is broadened. Third, it increases awareness of the OGD existence and value among citizens and leads to further interest and use.

The methodology creates value for OGD publishers as well. In the OGD use process, the datasets that are the most essential to answer public challenges are identified. Then, issues such as the absence of a necessary dataset or poor data quality can be identified and transferred to the OGD publisher, who can take appropriate actions.

Future Work

Although our proposal is grounded in the results of a previous study and underwent preliminary validation of its potential, it is at its early stage. It needs to be further refined with insights from literature and additional interviews and workshops. We still need to collect feedback from citizens who have no experience with hackathons nor OGD use and OGD publishers to improve our methodology. Then, we plan to conduct in-the-wild experiments to evaluate the methodology and refine it accordingly.

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Visualization of MBT testing coverage

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***Abstract*— Context: The testing phase is an important but very expensive part of development process. Model-Based Testing (MBT) allows the automation of the generation of test cases to decrease part of this high cost by using software conceptual models. Indeed, JMermaid is a tool that allows the automatic generation of software applications from the conceptual models.**

Objective: The main objective of this investigation is to develop a module to visualize the coverage of test cases of the applications generated by the JMermaid tool.

Method: Model-based testing technique was used to generate test cases from the JMermaid conceptual models, and a tool called TesCaV was implemented for the automatic generation of test cases.

Results: TesCaV was integrated with JMermaid allowing the visualization of the coverage of test cases on the generated Java applications.

Conclusions: The visualization of test cases improves the understanding of the testing phase in the development process.

Keywords*— *Model Based Testing, Visualizing, Coverage

I. Introduction

Software development cycle considers the realization of a set of activities by the different roles that participate on the development team, in which there is a high possibility of the appearance of an error caused by human nature. These errors can occur starting on the first moment of the software modelling, in which the raised solution can be defectively specified, or it can be specified in an inconsistent way respect to the business goals or the requirements. Because of this, software development must be accompanied by activities that guarantee its quality. Software testing is considered a way to guarantee the quality of the developed software products.

According to [1], testing is an important but very expensive part of the development process, and it can represent between the 30% and 50% of the cost of software development. Many times, the lack of experience of development teams leads to the testing process to not be successful since they don't make a high coverage of the software. In literature, diverse techniques of software testing that search for reducing the high cost of testing process can be found, such as for increasing its coverage, within which can be found MBT [2], [3].

MBT is a testing approach that uses conceptual models to represent the desired behavior of a System Under Test (SUT). According to [4], a system can be described from different perspectives using different models, which contain the main elements of the business, for example, using the Unified Modeling Language (UML) [5]. Given that the information of the model can be specified in a standard notation, this model can be used as the basis to generate test cases or test scripts in an automatic way. This is just one of the biggest advantages of MBT, which allows a highest test coverage in an automatic form [6].

Despite the advantages of Model Based Testing, such as the strategies presented in [7]–[9], users are not able to know the test coverage achieved by them. In this work, we propose the use of visualization to make known the coverage of the tests achieved so far. Therefore, the user can know in real time which test cases he has executed and which ones he still must execute, this allows a better understanding of the test phase.

II. Development

Model Based Testing (MBT) [10] techniques generate executable test cases that include oracle information, it means that it is not necessary to manually indicate which exit values are the expected, since the test case contains this information and automatically knows if the test case has failed or not. For this research we are using the conceptual models created with the JMermaid tool [11], which allows to generate applications in Java through state transitions and class diagrams using a Code Generator module.

For the visualization of test cases coverage, the TesCaV tool was implemented, which generates in automatic way the test cases by using the XML representation of the conceptual models defined in JMermaid. This tool is a prototype since it is still in the development phase. The TesCaV tool is integrated with the Code Generator module of JMermaid, allowing the visualization of test coverage of each generated application (see Fig 1.).

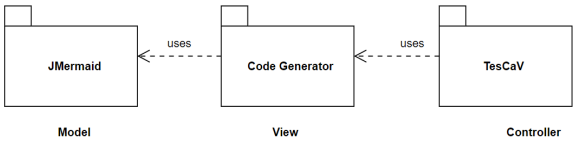


Fig. 1. Package Diagrams.

TesCaV has implemented 9 testing criteria to generate test cases, for instance: class attribute, all-states, all-transitions, among others. Class attribute criterion is related to the possibility to create an instance with a set of attributes of a class. All-states criterion is related to the execution of several services in order to visit all the states defined for a class. All-transitions

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criterion is related to execute all the services related to each transition defined for each class.

Once the application has been generated, it counts with the option to generate the test cases, showing the coverage of the test cases already executed by the user, as is shown in Fig. 2.

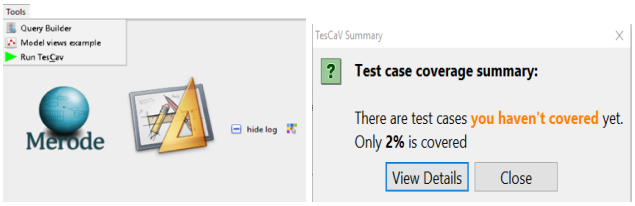
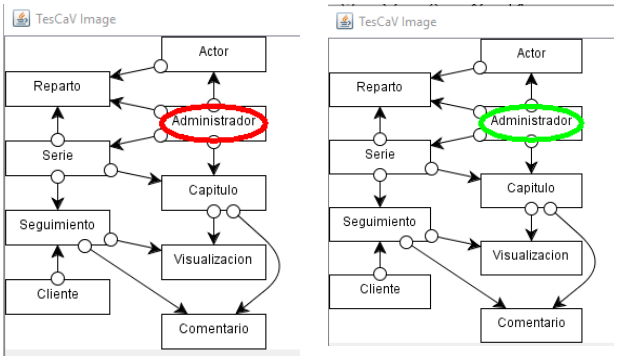


Fig. 2 Generation and Coverage of the application test cases.

In the details of the coverage, TesCaV allows the visualization of test coverage of each class defined on the model. Thus, once the user selects a class, TesCaV shows the coverage of the test cases performed by the user taking into account each MBT criterion implemented.

Therefore, the user can use the JMermaid generated application by creating objects, executing services, and so on. Later, the user can use TesCaV in order to know if the application has been tested or there are some parts to test, i.e. the coverage of testing. When the user see the coverage, it is possible to visualize the states, entities or involved transitions in each criterion to graphically see the test coverage. The model coverage metric is used to evaluate user performance. This metric is based on calculating how much the user spends on the set of tests cases that can be generated by TesCaV.

In Fig. 3 it was selected the *Class Attribute* (CA) coverage criterion. As it can be observed, the not covered entity is highlighted in red and the covered entity is highlighted in green. This allows the user a better comprehension of the tests cases that have been executed.

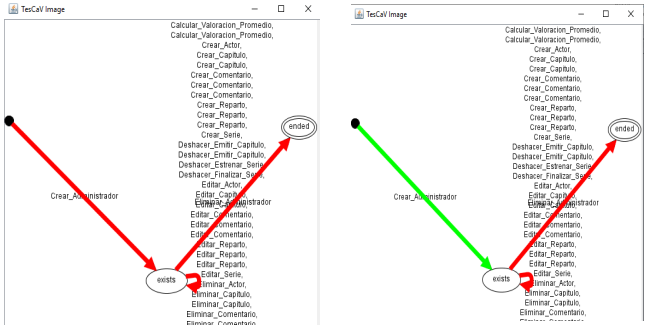


a) b)

Fig. 3. Selected CA criterion: a) not covered entity, b) covered entity.

Fig. 4 shows the coverage of the transitions when the *All-transitions* (AT) coverage criterion has been selected. TesCaV module highlights in green color the transitions that have been covered until the moment by the user.

We have use the TesCaV prototype with students in order to evaluate the perceptions about using TesCaV. Subjects argue that the visualization of coverage improve the testing process, but we need to perform more empirical studies to evaluate the benefits of TesCaV.



a) b)

Fig. 4. Selected AT criterion: a) not covered transition, b) covered transition

III. Conclusions

This paper presents the TesCaV tool, which is an MBT tool embedded with JMermaid. TesCaV allows the generation of test cases automatically by using the model generated in JMermaid. TesCaV facilitates the visualization of the coverage of test cases, since it shows graphically the model with the test cases covered in green, and in red the part that has not been covered yet. Future work is related to the experimentation with students and practitioners in order to understand the benefits of using TesCaV. These benefits are based on software testing analysis, allowing the detection of errors on early stages of the software development.

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Doctoral Consortium

Investigating how Business Process Ambidexterity facilitates business-IT alignment in public sector organizations.

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***Abstract*—In today's world of digital transformation and global hyper-competition the need for organizations to manage and innovate their Business Processes in both incremental and disruptive ways is greater than ever, both for private and public organizations. The nascent concept of Business Process Ambidexterity (balancing process exploitation and exploration) has been receiving a growing interest in the academia, and my research aims to address three research gaps: (1) the conceptualization of Business Process Ambidexterity and guidance on its implementation; (2) its impact on business-IT alignment, and (3) the specific contingency factors of Business Process Ambidexterity in the public sector. I will address these gaps through a research plan, covering a large-scale survey, extreme case research, Delphi study and design science research. At this stage I have completed a Systematic Literature Review of Business Process Ambidexterity, and I am preparing the next steps of my research.**

Keywords—Business Process Ambidexterity, IT Governance, Business-IT alignment, BPM, Organisational Ambidexterity

I. Introduction

A. *Business Process Management (BPM) and Process Orientation (PO)*

Business Process Management (BPM) is defined as all efforts to analyse and continually improve fundamental activities of organisation's operations (adapted from [1]). BPM was proven to positively impact organisations' performance and competitiveness [2], in particular for processes spanning different domains and departments [3]. Additionally, the academic community has recently issued calls to focus more research on BPM implementation, which is arguably lagging behind [4], and also to reach out beyond IT-driven process modelling towards a holistic view of the managerial aspects of process management [5].

Several attempts exist to categorize the main elements of BPM. For instance, researchers have proposed two key elements of process management: process control and incremental process improvement [6]. Six core elements, or success factors of BPM have been identified [7]: strategic alignment, governance, methods, information technology, people and culture. On the other hand, [8] proposed a framework capturing six main BPM capability areas and 17 sub-areas, based on organizational theories and a comprehensive sample of 69 business process maturity models. The capability areas are as follows:

- Process modelling: this initial stage in the business process lifecycle dedicated to design and analysis of business processes;
- Process deployment: comprises implementation, enactment, measurement and control;
- Process optimization: improvement of the business process;
- Process management: covers daily management, as well as aligning with business strategy and stakeholder relationships;
- Process-oriented culture: process-oriented values, attitudes and behaviors;
- Process-oriented structure: process-oriented organization chart and governance bodies.

B. *Business Process Ambidexterity (challenge 1)*

Today, we are facing the fourth industrial revolution driven by social, mobile, cloud and smart technologies [4]. In order to reap benefits from "new IT" (e.g. Artificial Intelligence, Internet of Things [IoT], blockchain) and their (often disruptive) opportunities for digital process innovation, [9] argues that organisations need to simultaneously pursue exploitative and explorative process capabilities in order to deliver both *incremental* and *disruptive* process innovation. This so-called Business Process Ambidexterity provides a fascinating challenge for the BPM discipline since it requires to move beyond its founding paradigm of process control and optimisation, towards identifying opportunities for process disruption and "*the creation of process designs that truly excite customers*" [10] (p. 636).

The concept of organizational ambidexterity was introduced by [11], who proposed setting up separate organizational structures to manage contradictory forces in an organization. The organizational tension between exploration and exploitation can be traced back to the seminal work of [12], who described the inherently contradictory dichotomy between exploration and exploitation in organizational learning. Exploration can be defined as searching and experimenting, while exploitation drives profit from the results when optimizing the operation [13]. Ambidexterity has eventually been defined as the dynamic capability of balancing these two opposing activities [14]. More recently, the need to balance contradictory activities has been replaced with the concept of paradox thinking, where the tensions are actually beneficial and enlightening [15]. Ample empirical evidence proves that ambidexterity is beneficial for both

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organisations' productivity and innovativeness, in particular in uncertain market conditions [16]. Moreover, organisations with greater technological capability are proven to benefit to an even greater extent from ambidexterity [17].

From an IT perspective, the concept of 'bimodal IT' (IT structures pursuing both explorative and exploitative objectives) has received the attention of researchers and practitioners pursuing ambidexterity [18]. However, it is still unsure whether this approach truly delivers sustainable ambidexterity [19].

One of the key limitations of analyzing Business Process Ambidexterity is the lack of a clear definition or a widely recognized conceptual framework for this term. We have identified two definitions of process ambidexterity in the literature: (1) the first one focusing on firms' capabilities in a structural ambidexterity setting: *firm's capability for utilizing both process alignment and process adaptability* [20]; and (2) the second one concentrating on the "dynamic equilibrium" in the setting of contextual ambidexterity: *the dynamic equilibrium state of business process efficiency and business process flexibility"* [21].

Guidance for practitioners in this field still remains fairly limited. Looking at the BP lifecycle, BP ambidexterity plays the most critical role in BP modelling, and optimization capabilities. Following this, a few researchers attempted to conceptualize new frameworks for the modelling phase of ambidextrous processes [15, 16] and the optimization phase [24]. The fundamental question of how Business Process Ambidexterity should be implemented remains nevertheless unanswered. Should organizations focus on structural Business Process Ambidexterity, and as such concentrate primarily on explorative processes? Or, alternatively should they design their processes to be both exploitative and explorative? How should they pursue both paths?

C. *Business Process Ambidexterity and Business-IT alignment (challenge 2)*

Business-IT alignment plays a critical role in management of information systems, being the corner stone of digital transformation and digitalisation [25]. As such, business-IT alignment, which is aimed at ensuring that key IT resources are aligned with an organisational strategy in order to improve the organisation's performance [26], has been one of the main concerns of IT practitioners and IS researchers for the past 30 years [27]. Studies have recently moved beyond the paradigm of aligning IT with strategies, towards the concept of IT actually *being* the strategy, which can be conceptualised as the Digital Strategy [28]. [29] demonstrated the surprising lack of convergence between IT alignment and BPM studies, and proposes to analyse IT alignment from the perspective of BPM. [30] argued that business value was created from IT using BPM, positioning BPM as a critical enabler of Business-IT alignment. [31] paraphrased Nicholas Carr by stating *"IT does not matter, business processes do*" [32]. Moreover, some researchers argued that digitalization can actually resolve the exploration/exploitation paradox, and they proposed three digitalization paths aimed at delivering ambidexterity. The paths were: assets digitalization, digitally based process integration, and disruptive analytics-led decision-making [33]. In this context the role of Enterprise Architecture is critical, as an enabler of business-IT alignment in an agile enterprise [34].

Is there then a relationship between Business Process Ambidexterity and business-IT alignment? Some researchers argued that business-IT alignment could lead to greater process innovation [35] and organizational ambidexterity [36]. [37] provided a framework for ambidexterity facilitating business-IT alignment and [38] proposed a method to evaluate processes, aiming to align business and IT. [39] speculated that emergent ambidextrous IT capabilities could indeed advance IT strategic alignment.

D. *Process management in the public sector (challenge 3)*

While BPM is applied in many organizations of different types, BPM studies mainly focus on large and private organizations. Nonetheless, public sector organizations also profit from improving their processes and from digital process innovation to better serve their customers/tax payers. As argued by [5] context awareness is one of the ten principles of good BPM, and [40] provide evidence that the maturity of processes is generally lower in the public sector, which does not face the competitive pressure of the private sector. Nevertheless, even in the public sector, there are pockets of digital innovation and organisational ambidexterity, as documented by [41] in the IoT smart city projects. Also, a few papers have explored organisational ambidexterity in the public sector - looking for specific enablers [42] or strategies [43].

Thus, this project proposal addresses the identified gaps by looking at digital process innovation and organisational ambidexterity in the public sector and the related IT alignment, especially in EU institutions and EU member state administrations. Being an employee at the European Commission in IT governance, the applicant benefits from first access to the targeted units of analysis.

II. AIM OF THE RESEARCH

The purpose of the research is to understand if and how public sector organisations implement Business Process Ambidexterity, and whether this facilitates IT alignment, which increases in importance in the digital era.

The research will provide valuable contribution to academia by addressing several gaps in the body of knowledge: the so far unexplored capabilities, environments and contingency factors of Business Process Ambidexterity; the relationship between Business Process Ambidexterity and IT alignment, in particular in the context of digital innovation; and finally, it will broaden the knowledge about BPM implementation in the public sector. The research will also respond to the call of [4] to focus on the implementational aspects of BPM.

One of the greatest challenges for practitioners in the digital era, in both the private and the public sector, is building appropriate BPM and IT structures enabling both incremental and disruptive innovation. The research will address this need by delivering a decision tool, supporting the practitioners in the creation of ambidextrous processes.

The research aims to answer the following questions:

RQ1. To which extent do public organizations develop capabilities for Business Process Ambidexterity, and how?

The output are patterns or evolution paths to evolve in Business Process Ambidexterity in a public sector context.

RQ2. How can Business Process Ambidexterity facilitate IT alignment in the digital era, considering different environments and contingency factors within the public sector (such as domains, organisational structures and cultures, size)?

The output is a research model with correlations between capabilities for Business Process Ambidexterity and IT alignment capabilities, including contextual variables that affect those correlations.

RQ3. How can public organizations develop ambidextrous processes, to achieve better IT alignment?

The output will be practical guidelines in the sense of decision criteria in a decision tool (i.e. as an alternative to a prescriptive maturity model).

III. METHODOLOGY

The PhD student's work and experience in the private sector and the EU public service, and in particular his current role as IT Portfolio Manager, and member of the European Commission's IT governance team, will strongly facilitate the execution of the research. This will be facilitated through first-hand access to a wide array of project documentation and analysis, as well as direct contact with stakeholders across the European Commission, other EU Institutions and Agencies, and EU Member State administrations. This provides synergies and complements the objectives of the research, enriching it with a practitioner's perspective. There are nevertheless also privacy and ethical concerns, which will need to be thoroughly analysed in the preparation of the research.

A. Methodology per research question

Below is the proposed methodology for each question:

RQ1. To which extent do public organizations develop capabilities for Business Process Ambidexterity, and how?

We conduct a large-scale survey research within the EU Institutions based in Brussels and Luxembourg (in particular the European Commission, the European Parliament, and the Council of the EU), EU Agencies (in particular those working on IT themes: eu-LISA and ENISA), and a selection of EU Member State national administrations (chosen based on identified contingency factors), in order to get insight into the AS-IS situation, starting from the validated framework of the supervisor [8] and literature on organizational ambidexterity [44, 45, 14, 16]. The survey data will be used for pattern-matching purposes, to find best practices, and to select cases for RQ2.

RQ2. How can Business Process Ambidexterity facilitate IT alignment in the digital era, considering different environments and contingency factors within the public sector (such as domains, organisational structures and cultures, size)?

We apply an extreme case research approach [46] to get deeper explanations about the TO-BE situation. Based on RQ1, we select those EU case organizations that have advanced most in terms of Business Process Ambidexterity (top 10%), and investigate their IT alignment strategies, hurdles and success stories. The findings are refined for context-awareness [5], by considering a variety of contextual variables that elicit from the data.

RQ3. How can public organizations build ambidextrous processes, to achieve better IT alignment?

We continue with the findings from RQ1 (AS-IS) and RQ2 (TO-BE) to formulate concrete guidelines in RQ3. A Delphi study [47, 48] is conducted for criteria ranking. Afterwards, we follow Design-Science Research [49] [50] to build and test a practical and methodologically sound decision tool, using two iterative build-test cycles.

B. Timeline

Below is the timeline of the activities. Each research question corresponds to a work package (WP) with different phases.

*1) **WP1 Survey (Year 1)** => Evolution paths via pattern-matching, and selection of best cases*

- Output: paper for an Information Systems (IS) conference (e.g. BPM, ECIS, ICIS, HICCS); first A1 paper with a statistical state-of-play on EU level and pattern-matching exercise

WP1.1	Systematic Literature Review of Business Process Ambidexterity	Q1-Q2 Year1
WP1.2	A priori specifying the theoretical constructs (with a pre-test with PhD students and EU servants for questions' clarity)	Q3 Year1
WP1.3	Large-scale data collection	Q3 Year1
WP1.4	Data analysis with pattern-matching	Q3-Q4 Year1
WP1.5	Case selection for RQ2	Q4 Year1
WP1.6	Consolidating the finding / Writing up	Q4 Year1

*2) **WP2 Extreme case research (Year 2)** => Contextual factors to be considered when aligning IT with PM ambidexterity*

- Output: paper for an IS conference (e.g. BPM, ECIS, ICIS, HICCS); second A1 paper with a theoretical contingency model to link Business Process Ambidexterity with business-IT alignment

WP2.1	Establishing a case study protocol	Q1 Year2
WP2.2	Primary data collection with data triangulation, and iterative coding	Q2-Q3 Year2
WP2.3	Within-case and cross-case analysis	Q3-Q4 Year2
WP2.4	Consolidating the finding / Writing up	Q4 Year2

*3) **WP3 Delphi study (Year 3)** => Decision criteria for aligning IT with PM ambidexterity*

- Output: paper for an IS conference (e.g. BPM, ECIS, ICIS, HICCS); third A1 paper reporting on the decision criteria elicitation and ranking

WP3.1	Delphi protocol	Q1 Year3
WP3.2	Phase 1: brainstorming	Q1 Year3
WP3.3	Phase 2: narrowing down by consensus-seeking decision-making	Q2 Year3
WP3.4	Phase 3: ranking and weighing criteria by multi-criteria decision-making	Q2 Year3

WP3.5	Consolidating the finding / Writing up	Q3 Year3

4) ***WP4 Design-Science Research*** *(Year 3-4) => Context-aware decision tool for aligning IT with Business Process Ambidexterity*

- Output: paper for an IS conference (e.g. BPM, ECIS, ICIS, HICCS); third A1 paper reporting on the build and evaluate phases of the decision tool

WP4.1	Build tool sub artefacts (constructs, model, tool method, instantiation)	Q4 Year3
WP4.2	Pilot test (= design evaluation for utility, quality, efficacy) by means of testers (5 EU servants working with process managers and IT managers)	Q1 Year4
WP4.3	Re-build phase considering early feedback	Q1 Year4
WP4.4	Test phase by means of case studies (5 EU administrations wishing to advance in PM ambidexterity)	Q2 Year4
WP4.5	Consolidating the finding / Writing up	Q3 Year4

IV. Current Status and Next Steps

In reference to the plan above, I am currently in WP1 (as of March 2019). I have just completed the Systematic Literature Review (WP1.1), and I am in the process of starting preparations of the large-scale survey (WP1.2).

A. Systematic Literature Review (SLR)

Our SLR was following an SLR Protocol [51], and the search strategy was based on three steps: (1) search in predefined databases using wildcard keywords, which generated 892 articles; (2) qualitative screening of articles based on exclusion criteria, which narrowed down our search to 47 articles; and finally (3) analysis of the complete text of the articles and answering to SLR research questions. The research questions aimed to position the articles in the context of established frameworks for BP capability areas [8], types of ambidexterity (structural and contextual [45]), IT governance elements [26] and finally their relationship with Business-IT alignment.

In our research, we have divided all articles into two main strands of research focusing on: (1) organizational capabilities enabling Business Process Ambidexterity, and (2) the actual dynamic balance between exploration and exploitation in BPM, which is enabled by the modelling and optimization stages of the business process lifecycle. As there was no widely accepted definition of Business Process Ambidexterity, we proposed one for future use, based on the concept of paradoxical thinking. We have not identified any evidence that Business Process Ambidexterity enables Business-IT alignment in an ambidextrous setting; however, we highlighted that several studies show a mutually reinforcing relationship between Business Process Ambidexterity and digitalization. The main research gap we highlighted was the lack of a conceptual model of. Business Process Ambidexterity, and the fragmented guidelines on Business Process Ambidexterity implementation. The full SLR is available in the proceedings of this conference.

B. Preparation of large -scale survey

We are currently reviewing the identified frameworks for Business Process Ambidexterity ([14], [22], [52], [53], [54]) to prepare the survey, and looking to expand the potential scope of the survey with frameworks from past research in Business Process Reengineering and New Public Management. Based on the analysis in the SLR none of the identified frameworks provide a holistic conceptualization of Business Process Ambidexterity.

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The impact of new IT adoption on Business Process Management.

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***Abstract*— Business Process Management is dynamically changing in the era of IT and Digital Innovations. This research focused on developing a standardized decision tool/matrix having ability to assist Best Fitting Technology Adoption decisions in ambidextrous BPM environment. This study mainly composed of three parts starting from systematic literature review, moving towards theory development and testing, and finally building a decision tool/matrix. Systematic Literature Review (SLR) protocols will be followed to explain an historical view of BPM and IT alignment, by using NVivo tool, by developing nodes and themes. Case studies and empirical analysis will be performed to develop Process-Technology Fit theory and testing it by using Structured Equation Modelling (SEM) techniques. Further, we build artefacts and validate them using Design Science Research (DSR). Outcomes of this research includes presentation of novel research agenda's in the field of Ambidextrous BPM, enhanced and validated form of Task-technology Fit theory as Process-Technology Fit theory in the context of Best Fitting Technology Adoption in ambidextrous BPM environment. Another, foremost output will be a decision tool or matrix that practically assist BPM practitioners and technology adoption decision makers to choose best fitting technology in accordance with specific BPM capabilities.**

Keywords*—*Business Process Management, Digital Innovation, Ambidextrous BPM, Technology Adoption, Design Science Research

I. INTRODUCTION

In this technological era, Business Process Management (BPM) is a dynamic field that is rising through digital innovations. Digital innovations are making our lives easier and support business units at the decision, design and process level in organizations. Attempts for business process efficiency were initiated from the concept of business process re-engineering (BPR), lean manufacturing, six sigma, and total quality management (TQM) with continuous improvement [1]. These management tools and techniques are frequently used in business process management. After the internet infusion, enterprise resource planning (ERP) and decision support systems (DSS) provided backing to BPM, leading to Business Process Management Systems (BPMS) [2]. Many studies have focused on the BPM lifecycle, BPM capability and maturity models, and BPMS. Business process modeling and design remain highlighted areas, developing new modelling languages, design tools and information technologies.

Nowadays, an ambidextrous BPM approach is trending in organizations to bring innovation in business processes, resulting in smart and intelligent BPM. It includes both exploitative and explorative BPM approaches [3].

Information Technology (IT) or Information Communication Technology (ICT) brings innovation and a mindset of change into BPM. New IT includes, for instance, cloud computing or green computing, big data analytics, artificial intelligence (AI), Internet of Things (IoT), industry 4.0, blockchains and agile platforms penetrating in business processes [4][5]. Such emerging technologies enable business processes to perform healthier by increasing the capabilities for an optimal utilization of time and resources within a specific process. These new technologies are being used in each step of the BPM lifecycle, namely from the discovery phase throughout monitoring and control [6]. The technologies also influence the BPM core elements, including strategic alignment, governance, people and culture. New IT is thus not limited to enhancing the IT capabilities of BPM, but also enhancing managerial competences [7].

This study's emphasis is on three main research areas. First, the BPM and IT co-evolution will be scrutinized through a detailed literature review to understand the current stage of BPM and IT. The review also intends to dig out novel research paradigms. Secondly, we will determine the possible

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paradigms that organizations may follow to select the best fitting technologies for BPM. By extending the scope of the Task Technology Fit (TTF) theory [8] towards a Process Technology Fit theory, new theoretical foundations will be established to present a solution how to choose the best fitting technology in different BPM application areas to enhance organizational performance.

Thirdly, we attempt to develop a decision mechanism that has the ability to select the best fitting technology/ies in specific scenarios and find an optimal fit in accordance with an organizational context.

In subsequent sections, we elaborate on the problem statement, research questions, research objectives, current research level, research methods and the study's timeline.

II. Problem Statement

Rahimi, Møller, & Hvam, [9] discussed the integration of IT and BPM among organizational planning levels, such as operational, managerial and strategic levels. While similar studies on the IT integration in the BPM discipline have been published [9], no systematic research is available that investigates the evolution of BPM along with IT alignment for the purpose of identifying IT trends and benefits of digital innovations in BPM in ambidextrous environment. Likewise, no decision tool or matrix is available or presented for real-time decision making regarding the best fitting technology use in business processes management. Information Technology/-ies have revolutionized BPM. A paradigm shift is witnessed from old and legacy BPM approaches, towards an explorative type of BPM [1]. For instance, organizations practicing TQM, Six Sigma, lean manufacturing and continues improvement techniques are actually applying exploitative BPM [10]. Presently, however, they are progressively shifting towards more efficient paths, processes, technologies and paradigms such as agile BPM, IoT, industry 4.0, ITIL v4 and blockchains [1]. In this situation, there is a dire need of understanding the BPM-IT success path as well as to specify the role of new IT/technologies with particular BPM core capabilities to achieve maximum advantages of digital technologies. For instance, "Blockchain technology might change governance towards a more externally oriented model of self-governance based on smart contracts" [11, p.11], hence governance capability of BPM could be changed with blockchain technology. Moreover, a comprehensive decision tool/matrix is also required to choose the best fitting technology in ambidextrous BPM environment of organization's business context.

III. Research Questions

Keeping in view the above circumstances, we will be answering the following research questions:

RQ1. What is the state of the research regarding the link between BPM and IT/technologies?

RQ2. How do organizations adopt the best fitting technologies for specific business processes, given the organization's business context?

RQ3. How can a decision tool be build and tested that selects the best fitting technology/-ies for specific business processes, given an organization's business context?

IV. Research Objectives

Our research objectives to perform this study are as follows.

RQ1. To benefit from the historical BPM-IT link by investigating the current state of research and to explore novel research avenues by means of a research agenda(s) that focus on new IT contributions in BPM explorative shift.

RQ2. To investigate the specific technology characteristics as well as business process capabilities to explain how organizations can adopt the best-fitting technology/-ies for specific business process to attain organizational performance in ambidextrous BPM environment.

RQ3. To develop and test a decision tool/matrix that can assist business process managers in choosing the most appropriate technology/-ies as taking into account the requirements or needs of a particular business process used in an organization.

V. Proposed Research Methods

To respond research questions, both qualitative and quantitative research methodologies will be used. Systematic Literature Review, interviews, case studies, a large-scale survey and design-science research, methodologies will be used mainly. We continue with proposing the research methods per RQ.

A. Methodology for RQ1 (In-Progress)

In RQ1, we will apply the systematic literature review technique of [12] to analyze the BPM-IT co-evolution in more detail, and to demonstrate emerging themes along with existing BPM frameworks including the BPM life cycle [13], BPM core elements [14] BPM context factors [15] and Research Agenda [16]. We will use various keywords such as "Business Process Management", "Information technology", "Agile BPM", "Artificial Intelligence", Ambidexterity", Social Media", "Digital Innovations", "Internet of Things", "Cloud Computing", "Industry 4.0", "ITIL v4", "Blockchains", "Explorative BPM" and other keywords that covers new IT and explorative BPM prospective. We will use NVivo tool recent version, to create codes, nodes and themes to perform this

meta-analysis. Results will be demonstrated in table(s), graph(s) and conceptual framework.

a) Output:

A better understanding of the BPM-IT link over time, and the corresponding research avenues. This output can be in the form of conceptual model based on existing studies.

B. Methodology for RQ2

In our second study, we will conduct case studies in organizations that already using exploitative and explorative BPM approaches, or organizations in the transformation phase of adopting explorative BPM techniques. Mainly ten to 15 different case studies will be targeted for a better understanding and to find patterns, depending upon when data saturation will be reached. After theory development, a large-scale survey will be conducted in organizations of Belgium and Pakistan, that fall under the above scope. A survey instrument will be developed and a statistical analysis (SEM) will be performed. Data will be collected from BPM and IT managers and practitioners by using purposive and quota sampling techniques. The population will be first segmented into mutually exclusive sub-groups, and then purposive sampling can be used.

a) Proposed theoretical framework

The best fit between technology adoption and BPM can be explained in the light of Task Technology Fit theory which says that technology is useless if it is not fulfilling expectations of user/practitioner. Technology has positive impact on individual performance, and technology characteristics should be aligned with tasks or processes performed by the user or system [17]. Efficient BPM should capable to trigger the desired changes in organization for continues improvement and competitive advantage. Technology is also being used to enhance the ambidextrous BPM capabilities both exploitative and explorative. To predict process behavior, technology plays a vital role in process improvement and innovation. This process initiated by technology automatically explores the character of improvement in business process management [1].

Companies abruptly using Social Media, Cloud Computing, Internet of Things, Artificial Intelligence in decision making, and Big Data Analytics in operations and processes. Facebook, Linkedin, Uber, WhatsApp, Bitcoin and Paypal are technological innovations that reshaped business processes according to the need of 21st century customers [1]. In a nutshell, we extend Task-Technology Fit Theory in shape of Process-Technology Fit Theory on the basis of literature as well as statistical evidence.

Organizational context and technological context are significant indicators of best fitting technology in BPM. Similarly, the environmental factors such as competitive pressure, trading partners and legal obligations are paramount factors for new technology adoption. Therefore, we will develop theory accordingly.

First, a tentative research model is developed as shown in figure 1, which reflects the possible output of this section in the form of theoretical framework (that will be developed further in more detail sub-factors). At this moment, it shows that Process Characteristics, Technology Characteristics and Ambidextrous BPM Characteristics have a role in the adoption of the Best Fitting Technology Adoption. The best fitting technology adoption will leads to boost organizational performance. Hence, Best fitting Technology Adoption is also act as a mediator between Process Characteristics, Technology Characteristics, Ambidextrous BPM characteristics and Organizational Performance. Environmental Factors behave as moderator between relationship of Process Characteristics, Technology Characteristics, Ambidextrous BPM Characteristics, with Best fitting Technology Adoption. It also moderate the relation of Best Fitting technology Adoption and Organizational Performance.

Therefore, the following tentative hypothesis are developed to test later by using case studies and large-scale survey analysis.

H1: Best Fitting Technology Adoption mediates the relationship between Process Characteristics and Organizational Performance.

H2: Best Fitting Technology Adoption mediates the relationship between Technology Characteristics and Organizational Performance.

H3: Best Fitting Technology Adoption mediates the relationship between Ambidextrous BPM Characteristics and Organizational Performance.

H4: Environmental Factors moderates the relationship between Process Characteristics and Best Fitting Technology Adoption.

H5: Environmental Factors moderates the relationship between Technology Characteristics and Best Fitting Technology Adoption.

H6: Environmental Factors moderates the relationship between Ambidextrous BPM Characteristics and Best Fitting Technology Adoption.

H7: Environmental Factors moderates the relationship between Best Fitting Technology Adoption and Organizational Performance.

H8: Process Characteristics and Technology characters influence each other.

These tentative hypotheses will be tested by both case studies and interviews with BPM practitioners as well as quantitatively with large-scale survey based on a survey instrument; the research model is developed illustrated in figure 1. Hence, the best technology and process fit could become attainable. Modifications in hypotheses and the details of process, technology and environmental sub-characteristics will be explored and presented during this research phase. Moreover, findings will highlight how an organization can adopt the best fitting technologies for specific business processes.

b) Output:

The intended output will be an extension of the Task-Technology Fit theory [8] towards a validated

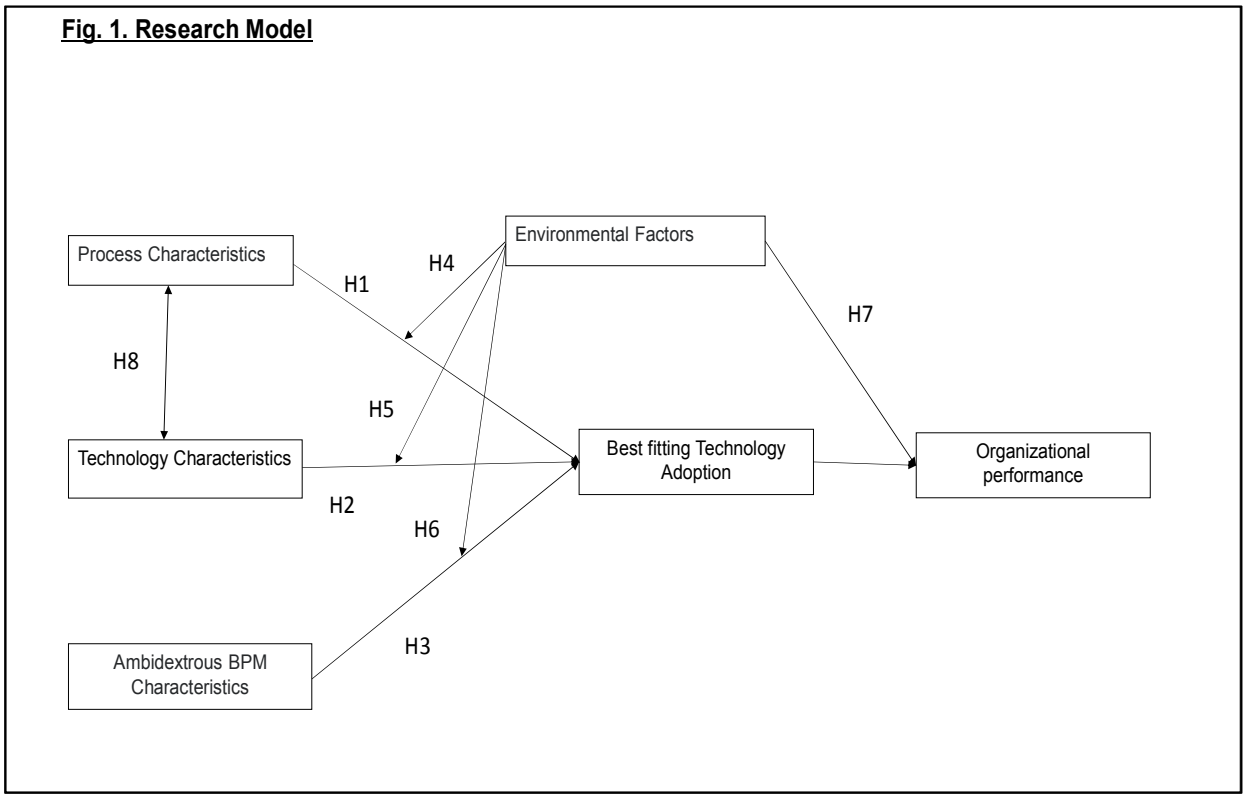


Fig. 1. Research Model

Process-Technology Fit Theory (e.g. by changing Task characteristics into Process characteristics, plus "Ambidextrous BPM characteristics", and by adding context factors such as organization size and sector), in order to ultimately uncover adoption patterns. This theory will not focus on particular technologies (which will change fast over time), but rather on technology characteristics.

C. Methodology for RQ3

Due to the pragmatic nature of RQ3, we will use the design-science research methodology [18] in our third study. This study focuses on developing artifacts (i.e. construct, model, method, instantiation) for finding the best fitting technology use in BPM and to develop a decision matrix/tool having ability to provide guidelines to practitioner and BPM users. This will be the two way process as we develop model based on previous studies, case studies, large-scale surveys and validate them with real-time scenarios in companies that will be in transformation phase of adopting explorative BPM approach, will be targeted for this purpose. Experience of practical solutions will be documented and designed iteratively by field studies and action research.

a) Output:

A validated decision tool/matrix or aid that can give advice to select the best matching technology for an organization's specific process characteristics and contextual factors. In other words, this third study intends to support the theory from RQ2 with a practical decision tool for organizations.

VI. TIMELINE

This PhD research is composed of three parts. Ideally, on average, one academic year will be allocated to each phase. The timeline of this study is given in Table I. So far, the PhD is sampling and reviewing the articles to be considered in the SLR study of RQ1.

TABLE I TIMELINE

Timeline		
Phase -I		
Task	***Start Date***	***End Date***
Initial Article Readings	24-09-18	28-02-19
Systematic Literature Review	01-11-18	29-04-19
Analyzing Results	13-04-19	05-06-19
Phase 1 Write-up	22-04-19	30-06-19
Phase -II		
Task	***Start Date***	***End Date***
Build initial theoretical model	01-07-19	20-08-19
Case studies	01-08-19	31-10-19
Large scale survey	01-10-19	27-02-20
Analyzing Results and build a revised theoretical model	01-02-20	22-03-20
Phase 2 Write-up	16-02-20	30-04-20
Phase -III		
Task	***Start Date***	***End Date***
Developing artefacts	01-05-20	31-07-20
Validation through various testing techniques	01-08-20	30-11-20
Modifications	01-12-20	30-01-21
Developing a Decision tool/Matrix/Aid path	01-02-21	31-03-21
Phase-III Write-up	01-03-21	15-04-21
Final Thesis Write-up	16-04-21	30-06-21
Final Defense	Fall 2021	

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A Green-by-Design Methodology to Increase Sustainability of Smart City Systems

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***Abstract*—Smart Cities are increasingly cited as a solution to decrease CO_2 emissions within cities. However, the technology that supports Smart City systems may in turn cause direct, indirect and rebound environmental impacts, including greenhouse gas emissions. Recent studies assessing the positive environmental impact of Information and Communication Technology (ICT) tend to focus on direct effects, thus giving little attention to indirect and especially rebound effects. The goal of our thesis is to propose an evaluation methodology to assist Smart City systems designers in assessing all possible environmental impacts of candidate Smart City systems designs. To design and validate the proposed methodology, the research scope will be narrowed on a subcategory of Smart City systems, chosen according to its relevance in terms of risk to produce rebound effects. The research process will follow the guidelines defined by Wieringa for conducting design science in ICT.**

***Index Terms*—Environmental impact assessment; Information and Communication Technology; Smart City; Rebound effects; Greenhouse Gas**

I. Introduction

Smart City systems are widely discussed in research and practice to find innovative solutions for our cities. The Internet of Things (IoT) is one of the technologies used to build the infrastructure necessary to develop Smart City systems. It includes a wireless network with embedded systems, gateways and end-devices such as smartphones. The emergence of these systems is one of the main reasons that explain the forecast in the quantity of connected devices: by 2021, the number of devices connected to IP networks is estimated to reach three times the global population [1]. These new technologies will change the way we interact with our environment. For example, city workers will be notified in real-time when a public bin is full or when a road needs to be repaired. Citizens will be able to change their routes according to traffic or air quality measurement in a city. The list of projects and concepts linked to smart systems is long and may concern many domains.

With Smart City systems comes an environmental impact. Indeed, the production of connected devices implies, for example, greenhouse gases (GHG) emissions, water consumption and pollution [2]. Furthermore, the extraction of the required rare metals is more and more difficult and energy consuming [3]. Finally, these impacts are amplified by the decreasing lifespan of end-devices, partially due to the *Obsolescence effect* [4].

However, Smart City systems can help us to reduce our environmental impact. Connected bicycles, car sharing platforms and public transportation based on open-data are examples of such systems. In that sense, ICT and Smart City systems are at the same time part of the problem and part of the solution.

Another important issue of Smart City systems is the user behaviour that might change when the system is put in place. New features brought by a system may change the day-to-day behaviour of its user and potentially void the benefits of a sustainable initiative. This issue is partially due to rebound effects [5].

The goal of our research is to propose a Green-by-design methodology to help Smart City system designers in the assessment of all environmental impacts of ICT.

In Section II, we give a brief description of the three main fields linked to the context of the doctoral research: the link between sustainable development and ICT solutions, IoT systems and their usages in the context of Smart Cities and the possible negative impact due to user behaviour changes, also called rebound effects. In Section II-D we present a short literature review on the different techniques and methods used for the assessment of environmental impacts of ICT. In Section III we define our research goal and in section IV we list our research questions. In Section V the research method used to conduct our research is explained and in Section VI we propose a work plan that breaks our research work in different steps.

II. Research context

A. Sustainable development and ICT

Sustainable development is often defined according to the Brundtland Report as *"a development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* [6]. ICT systems and devices produce *GHG* emissions during all of their life cycle phases from production to end of life. Rare metals are required to manufacture electronics components and the production and the recycling phases imply different natures of pollution. All these impacts go against the concept of sustainability. The research field that studies the positive and negative impact of

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ICT systems can be structured into three categories, as defined by Murugesan [2]:

- Green IT: *"The efficient and effective design, manufacture, use and disposal of computer hardware, software and communication systems with no or minimal impact on the environment"*.
- IT for Green: *"The use of IT and information systems to empower – that is, support, assist and leverage – other enterprise-wide environmental initiatives"*.
- Green awareness: *"The harnessing of IT to help create awareness among stakeholders and promote the green agenda and green initiatives."*

B. Smart Cities and the Internet Of Things

IoT has been defined by the International Telecommunication Union (ITU) as the *"global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies."* [7].

IoT includes embedded systems, sensors, actuators, a network infrastructure, communications protocols and end-devices. Major actors in the IT market, such as Microsoft and Cisco, already provide their own solutions and aim to respond to the demand in terms of smart systems. According to the context where the technology is used, we will talk, for example, about *Smart Cities*, *Smart Homes* or *Smart Rurality*. This list is not exhaustive and the keyword "Smart" is more and more used to refer to an ICT-driven system in order to improve the efficiency and the quality of life of users.

All devices used in smart systems need to be manufactured and consume energy. Furthermore, the user behaviour when facing this technology can also have a negative impact on the environment, as discussed in the next section.

C. Rebound effects

In their report, Berkhout and Hertin define three levels of environmental impacts linked to ICTs [8]:

- First order impacts: *"direct environmental effects of the production and use of ICTs."*
- Second order impacts: *"indirect environmental impacts related to the effect of ICTs on the structure of the economy, production processes, products and distribution systems."*
- Third order impacts: *"indirect effects on the environment, mainly through the stimulation of more consumption and higher economic growth by ICTs, and through impact on life styles and value systems."*

The third level of impacts may be caused by rebound effects induced by an ICT system. In the context of energy efficiency, the rebound effect can be defined as *"the social and behavioural response to the introduction of more energy efficiency technologies and processes by which there is a corresponding increase in energy service demands."* [5]. In other words, a more efficient system induces the user to consume more. For example, an organizational change like using video conferencing to work at home instead of using a car has a second order impact that may produce rebound effects leading to increased consumption: video conferencing allows an employee to stay at home few days a week, so he might decide to move further away from his workplace. At the end, the distance driven by the employee might be longer than before the introduction of the system. Hilty [4] uses the term *enabling impact* to define the actions that are enabled by the application of ICT. In our example, the enabling impact is the fact that an employee is able to work from home thanks to video conferencing. In his paper, Sorell [9] sorts rebound effects into three categories: direct, indirect and economy-wide effects. Gossart [10] reviews this concept and gives practical examples for each category in the energy domain:

- Direct rebound effects: *"lower energy cost induces price reductions that trigger an increase in the demand for the cheaper good [...] For example, if washing machines needs less power, consumers can afford to wash more frequently"*.
- Indirect rebound effects: *"when a resource is used more efficiently and its prices goes down, it induces the consumption of other commodities (consumers buy extra DVD players for the money they saved due to an energy-efficient product)"*
- Economy-wide rebound effects: *"appear when declining energy prices induce a reduction in the prices of intermediate and final goods throughout the economy and cause structural changes in production patterns and consumption habits. For example, cheaper gasoline enables people to live further away from their workplace by making it less expensive to drive longer distances to work"*.

Rebound effects are not limited to energy efficiency [10] and can have an impact on the environment. In the context of this thesis, they are especially relevant when the initial system providing an efficiency gain is driven by an ICT solution and claims to reduce negative environmental impacts. Therefore, it is crucial to include the analysis of rebound effects in a Green-by-design methodology.

D. Assessing indirect environmental impacts of ICT

Different methods and tools exist to make an assessment of ICT systems. For example, Life Cycle Assessment (LCA) is a well known method for the analysis of direct impacts of an ICT functional unit [11].

However, it's less clear what is the most suitable method to assess indirect effects. In his literature review, Bieser [12] classifies the different assessment methods of indirect environmental effects of ICT according to four criteria: application domain, number of use cases, the type of pattern (production or consumption) and the modeling approach. This review shows that LCA, ICTem and partial-footprint approaches are the most frequently used but face methodological challenges to include rebound effects. Bieser also explains that simulation models such as system dynamics (SD) or agent-based modeling (ABM) are less used, even if other research works have shown that such models are well suited for the assessment of rebound

effects. For example, Achachlouei and Hilty [13] use system thinking and system dynamics modeling to study rebound effects caused by an increase in speed efficiency for passenger transportation (time rebound effects). Xu [14] creates an agent-based model to explore the dynamic of an e-commerce market and the associated environmental impacts.

Taking into account indirect and especially rebound effects in the assessment of an ICT system is essential because the GHG emissions caused by the impacts of these effects can invalidate the result of a research work. For example, Bieser and Hilty [15] have shown that a study conducted by Accenture tends to overestimate the capacity of ICT to reduce GHG negative impacts.

Therefore, it is important to analyze different methods to determine which ones are better suited to understand indirect effects and then be used to lead decision makers toward more sustainable ICT solutions for cities.

III. Research goal

The goal of our thesis is to propose a methodology to assist Smart City systems designers in evaluating the environmental impacts of candidate smart systems designs. According to [16], a methodology can be defined as *"a set of recommended means for information systems development or part of it which is based on logics and specific philosophy. The recommended means often contain of definition of phases, procedures, activities, rules, techniques, documentations, tools and guidance [...]"* . Accordingly, our methodology would typically be composed of:

- A procedure to design a Smart City system and evaluate its environmental impacts taking into account the risk of rebound effects.
- Models establishing the relation between Smart City systems, rebound effects and possible corresponding mitigation techniques.
- Tools for the assessment of the environmental impact such as LCA.
- Advice, guidelines and good practices on how to reduce the risk of rebound effects by applying risk mitigation techniques.

IV. Research questions

This thesis will seek to answer to the following main research question (MRQ): **how to assist Smart City system designers in evaluating environmental impacts of candidate Smart City systems designs?** The main research question is itself composed of four research questions (Figure 1).

RQ1 What are the main enabling impacts categories used by Smart City systems that aim to reduce environmental impacts of an existing system?

RQ2 According to the literature, which enabling impacts categories present the highest qualitative risk to produce rebound effects and why?

RQ3 Which methods and tools have to be applied at the design phase of Smart City systems for the assessment of:

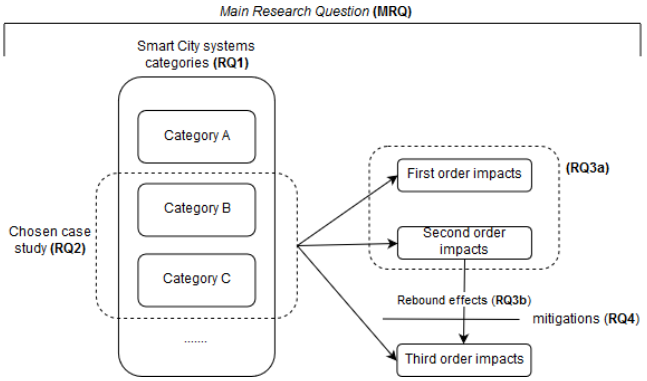


Fig. 1. Research questions

a First and second order impacts?

b Impacts caused by rebound effects?

RQ4 Which techniques or solutions can be used to mitigate the risks of rebound effects in Smart City systems and when are they appropriate?

V. Research method

To help us in the research process, we will follow the guidelines defined by Wieringa [17] for doing design science in ICT and software engineering research.

A. Design problem

A design problem is defined by Wieringa as *"a problem to (re)design an artifact so that it better contributes to the achievement of some goal"* [17]. Wieringa proposes a template to express a design problem:

- Improve *<a problem context>*
- by *<(re)designing an artifact>*
- that satisfies *<some requirements>*
- in order to *<help stakeholders achieve some goals>*

An artifact is a broad term that can be defined as *"something created by people for some practical purpose."* The interaction between an artifact and a problem context aims to solve a problem. Therefore, the problem context should be understood and the researcher needs to study this interaction in order to evaluate if it solves the initial design problem. The template applied to our research context gives the following representation:

- Improve *the design process of Smart City systems*
- by designing *a Green-by-design methodology*
- that *supports the evaluation of CO_2 emissions and includes a risk analysis of rebound effects*
- in order to *help decision makers and Smart City system designers to decrease CO_2 in total emissions.*

B. The Design Cycle

To conduct the research we will follow the different steps described in the design cycle process proposed by Wieringa (Figure 2). The design cycle is part of a larger problem-solving process, the engineering cycle. The design cycle aims to

iterate into problem investigation, treatment design, treatment validation and evaluation where the engineering cycle also includes a task for the transfer of an artifact to the real-world, called implementation.

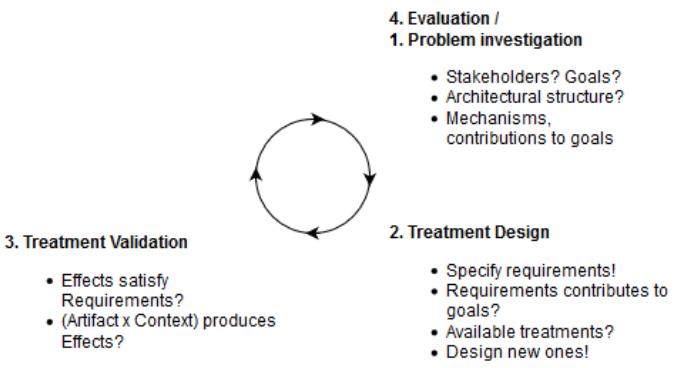


Fig. 2. The design cycle. Adapted from [17].

1) Problem investigation: A first step in investigation is to ask for knowledge about the world. More generally, we have to answer the question: what phenomena must be improved and why? This step requires to identify stakeholders and related goals. For example, in the context of the research, we have identified the following stakeholders (the list is not exhaustive):

- Normal operator (stakeholders who interact with the artifact): The Smart City system designer.
- Functional beneficiaries (stakeholders who benefit from the output produced): The decision maker who takes advantage of the environmental analysis. At the end, anyone who benefits from a system that produces less CO_2 emissions.
- Negative stakeholder (stakeholders for whom the situation would be worse when the artifact is introduced): Producers, sellers and implementers of the technology that supports a Smart City system may be financially affected by the result produced by the methodology.

Another important step during this phase is to represent the studied system as an architectural structure. The objective here is to decompose a Smart City system into components, processes and events. Then, the research needs to be refined to study a category of systems rather than any systems included into the context of Smart Cities. Therefore, a clear classification of Smart City systems is required to identify relevant sub-categories in terms of risk to produce rebound effects.

2) Design: The next phase is the design of the treatment. A treatment in the context of design science methodology is the interaction between an artifact and the problem context. In this part of the cycle we list the requirements for the Green-by-design methodology and justify how and why the fulfilment of these requirements may contribute to stakeholder goals. From this list of requirements, we need to search for existing treatments. In other words, a review of the literature is necessary to identify existing solutions for the assessment of environmental impacts of ICT and Smart City Green-by-design methodologies. A gap in the literature may result in the specification and the design of a new treatment to answer to the requirements defined previously. This will produce our new Green-by-design methodology.

3) Validation: The validation of a treatment is the justification that it would contribute to meet stakeholders goals if implemented. Because the validation needs to be conducted before the implementation, the researcher must build a model of the artifact interacting with a model of the context to simulate an implementation. If the interaction of our models fulfils the requirements defined in the design phase, then we can generalize the results to the real world to justify an implementation of the real artifact. In the context of the research, the interaction of our models could be students using the Green-by-design methodology to make an assessment of an hypothetical Smart City system. The specification of such systems can be based on the literature that studied similar systems.

4) Evaluation: In this cycle, evaluation and investigation are situated at the same phase. This is because both bring new knowledge questions about the world and the answer to these questions may lead to a new iteration in the design cycle. However, evaluation and investigation seek different goals. The goal of the evaluation is to assess an implementation of a treatment while the problem investigation goal is to search for an improvement problem where no requirements for an artifact have been identified yet. Implementation here has different meanings depending on stakeholders. From the point of view of an external stakeholder, implementation means the transfer of the treatment to the real-world. But for the researcher, a validated design is implemented on a model of the original context. In the specific case of our research, the goal is to investigate environmental assessment methods of ICT and Smart City systems design methodologies. The researcher will investigate and design a Green-by-design methodology prototype, validate and implement it. Then, the prototype will be used for his goal and evaluated. The result of the evaluation may lead to new research questions.

VI. Work plan and research situation

This thesis is carried out in the context of a six-year Teaching and Research Assistant position at the Faculty of Computer Science of the University of Namur in Belgium. At the time of writing this paper, five months have passed since the beginning of the research.

To achieve the research objective, we have established a work plan describing the different steps. These steps will certainly be refined during the progress of the research work:

1) From a classification of Smart City systems, identify subcategories that are more prone to produce rebound effects:

- Review the literature about ICT systems that aim to reduce environmental impacts in the context of a city.
- Classify the result according to the enabling impacts of each system.
- Review the literature to identify the different rebound effects caused by ICT systems and link these effects to the classification established at the previous step.

2) Conduct a literature review for identifying existing methods for assessing indirect environmental effects of ICT.
3) Create a model of some Smart City systems identified at step 1 to simulate the real-world system.
4) Define a risk analysis method to detect and avoid rebound effects at design phase.
5) Define a Green-by-design methodology for Smart City systems that includes a rebound effect risk analysis.
6) Apply the methodology defined in step 5 within the model created at step 3 to validate its capacity to reduce CO_2 emissions. Refine the proposed methodology accordingly and perform further validation steps.

The next action to be taken by the researcher in the investigation phase is to review the literature about ICT systems that aim to reduce environmental impacts (step 1 in the work plan).

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Towards personalized feedback in a smart learning environment for teaching conceptual modelling

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***Abstract*— Conceptual modelling is one of the most challenging areas of learning in software or enterprise engineering education. Building this complex skill requires tremendous efforts and amounts of elaborative feedback from the teacher, especially in the case of novice modelers. However, the growing numbers of students wishing to pursue degrees requiring conceptual modelling as an integral skill make sufficient personalized feedback an unreachable goal for educators. The situation is aggravated by the lack of a universal, commonly accepted educational framework for conceptual modelling, which could serve as a basis for learning material and feedback development. In this paper, the steps towards the development of feedback architecture of a smart learning environment for conceptual modelling are presented, along with the intermediate results of the research project. The steps include the development of learning ontology for conceptual data modelling, implementation of CaMeLOT educational framework and the learning ontology for providing personalized feedback and finding the appropriate feedback timing.**

Keywords*— *conceptual modelling, personalized feedback, learning ontology, e-learning, software engineering education

I. Introduction

Conceptual modelling is one of the most challenging areas of learning in software or enterprise engineering education. Building this complex skill requires tremendous efforts and large amounts of elaborative feedback from the teacher, especially in case of novice modelers. However, the growing numbers of students wishing to pursue degrees requiring conceptual modelling as an integral skill make sufficient personalized feedback an unreachable goal for educators, which makes a negative impact on students' achievements, engagement and overall experience in higher education [1]. Teaching and feedback automation became an obvious solution to the problem of student "overpopulation", being applied in different ways and contexts – a.g. in MOOCs (Massive Open Online Courses), SPOCs (Small Private Online Courses) on campus or in a professional setting and smart learning environments/intelligent tutoring systems. However, when it comes to conceptual modelling, or conceptual data modelling, in particular, automation of the learning process faces several important challenges, in addition to the general complexity of teaching automation. First of all, the ill-structured nature of the modelling problems does not allow for a straightforward "right-or-wrong" approach to the student solution assessment and, thus, elaborative, meaningful personalized feedback is necessary to provide. Second, unlike the more "traditional" disciplines and areas, such as microbiology or English literature, which have been taught in higher education for more than a century, conceptual modelling is a rather young field, and there are no commonly accepted methods of education or course curricula related to conceptual modelling. Given the fact that clearly defined learning outcomes are key to the success of a learning process [2], the lack of a structured set of learning outcomes makes the work of conceptual modelling educators even more challenging – and puts certain obstacles in the way of development of systems providing automated feedback for conceptual modelling education.

II. Research challenges and questions

The number of learning environments for teaching conceptual modelling remains scarce. According to [3], there are only a few systems utilizing automated feedback for teaching conceptual data modelling (e.g. UML modelling). For example, [4] proposed a framework and a software plugin for teaching UML class diagrams and providing feedback based on student behavior, learning styles, and student knowledge model based on probabilities for each component to be understood by the student, using Curriculum Information Network (prerequisite/equivalence relationships between concepts, measure of difficulty) as a domain model. Another approach to structuring the learning environment and feedback generation was taken in [5], where students' affective states were recorded during UML class diagram exercises and used to predict the appraisal of feedback and finding the appropriate moments to give hints. In [6], feedback during model simulation is generated based on rules defining consistency between state charts and class diagrams. The simulated model is tested against those rules every time the student performs an action.

Even though every of the abovementioned studies reported somewhat positive effect of the automated feedback on the student achievements, there are several aspects that remain unaddressed. First of all, the very task of development of personalized feedback implies that the learning objectives that the students are to achieve should be clearly defined – thus, the feedback would be tailored not only to the personal traits of the student, but also to the intended learning goals, allowing the smart learning environment (SLE) communicate with the student in the most effective way. Second, due to the unavailability of an exhaustive theoretical learning framework or learning ontology for conceptual data modelling, the development of learning environments for modelling remains a cumbersome task for educators, as they have to come up with (probably similar) structures for the domain models and feedback generation models, that is, design the learning environment "from scratch", as the knowledge structure behind such environments remains unreported. To our knowledge, no learning ontology for

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conceptual modelling, or conceptual data modelling exists to this day – neither does a centralized substantial knowledge database of cases, exercises, learning goals that could be used by educators. Third, a question of the types and timing of feedback appropriate specifically in the modelling context remains unanswered in the empirical research. Even though some glimpses into the appropriate feedback types and moments were given in a number of empirical studies (e.g. [7]), in order to determine the effectiveness of such feedback in terms of academic achievement, professional development, motivation or overall student satisfaction, additional empirical studies are required.

Given the concerns presented above, the following research questions are planned to be addressed in the upcoming research:

RQ1: What would be the necessary components of a learning ontology for conceptual data modelling and how should such an ontology be structured?

RQ2: What types of feedback would be most beneficial for novice modelers?

RQ3: What are the most appropriate feedback moments (feedback timing) for novice modelers?

III. Intermediate results

The preliminary work performed in the two years since the start of the doctoral research project allowed to get preliminary insights on the following aspects of conceptual modelling education: the current state of literature and courses on conceptual modelling, the possible learning outcomes to pursue in the field, as well as the current literature on automated feedback technologies. In addition, exploratory studies were performed in a blended learning context to evaluate the students' perception and effectiveness of online learning for conceptual modelling education.

A. Educational framework for conceptual modelling

Since the development of a feedback engine relies on the expert knowledge and domain knowledge of the field, and thus requires a clearly defined domain model, in the first part of the study a general assessment of the existent pedagogical methods for domain modelling was conducted [8]. To get an overview on the field of modelling education, we identified and classified learning outcomes from several educational resources (books, university courses and MOOCs) on domain modelling according to the revised Bloom's taxonomy of educational objectives [9]. This way we could identify the gaps among the resources, such as a general lack of evaluation-related educational tasks, as well as insufficient training in modelling procedures which was possibly caused by the general lack of procedural knowledge in the field of conceptual modelling. We also identified the most popular educational tasks and could create a blueprint for a systematic educational framework for domain modelling, and provide guidelines for educators.

As the idea of the systematic educational framework for conceptual modelling based on the revised Bloom's taxonomy received a positive feedback from the scientific community at a number of tutorials (e.g. [10]) and the conference presentation of the abovementioned paper, the blueprint of the framework was developed further and resulted in CaMeLOT – a Conceptual Modelling Learning Outcomes Taxonomy [11]. CaMeLOT was developed following design science research methodology to provide a more structural basis for feedback generation in the learning environment, and to give educators an opportunity to enhance the conceptual modelling part of software engineering curricula with a systemized set of learning outcomes to be pursued, and open the path for creating more complete, useful and effective assessment packages.

B. Implementation of pedagogical approaches

At the same time with the development of a theoretical framework, practical pedagogical challenges were addressed. As one of the most promising directions of contemporary university education lies in the field of e-learning and blended learning, we decided to look into MOOC technologies for testing various pedagogical approaches related to automated feedback. First, we looked into the possibility of using formative exercises and formative automated feedback in a Small Private Online Course (SPOC), and investigated the aspects of student behavior, performance and perception of the course [12]. The results of the study became a step towards the development of a Massive Open Online Course, which will become a rich source of data on usage of automated feedback. Second, we assessed the effectiveness of error-based step-by-step automated exercises in the framework of a SPOC [13]. The results proved the effectiveness of such an approach in comparison with the traditional teaching.

IV. Steps planned

A. Development of learning ontology (RQ1)

The development plan for the learning ontology is presented in Figure 1. The development process will follow the design science research method [14], where the developed artefacts (set of ontologies) would be continuously evaluated in the design cycle (through instantiation and application in a case study of a concrete university course) and updated through the rigor cycle from the knowledge base.

The learning ontology will require the development of (at least) three ontologies: a domain ontology, an exercise ontology and an error ontology.

The domain ontology will be developed from domain knowledge (with domain modelling and its corresponding learning objectives implied as a domain), and, at the first level of development, the main source of knowledge will be the course material (book) [15] for the course Architecture and Modelling of Business Information systems. It is important to note that in case of this specific learning ontology, the domain ontology can be also viewed as a "learning outcome ontology" – for in the educational context, the domain can be viewed not only as a composition of various concepts and their interrelations, but also a composition of the learning outcomes related to those concepts. An exercise set will be developed with help of CaMeLOT, and further modified and categorized into an exercise ontology. The error ontology will be derived from the set of common errors identified in literature and in the existing student solutions.

The learning ontology will be first derived on the level of one course topic and the corresponding exercise session, with the learning outcome of "Creating a simple model". On this level, the ontology will be evaluated in the field, by implementing it for assessment of student skills. In addition, the exhaustiveness of the error ontology will be checked by applying it to the errors identified in student models at the given level of competence. If the topic level ontology proves

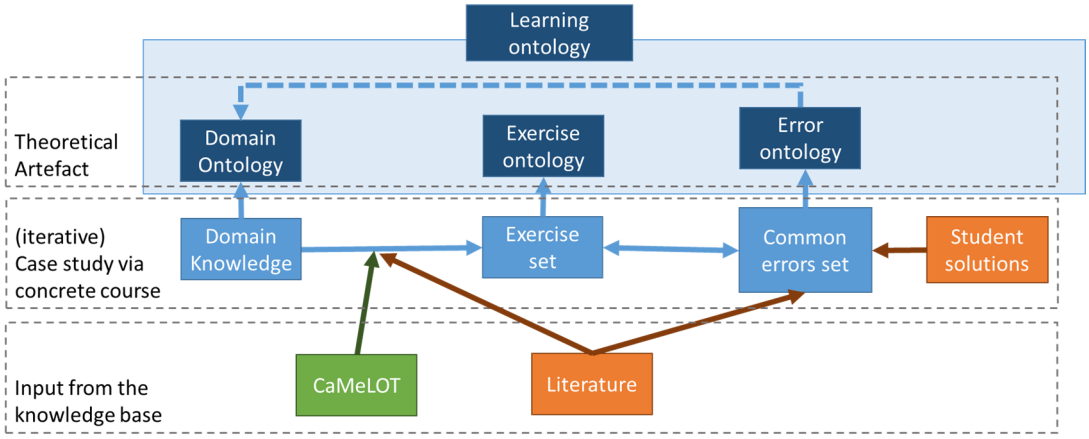


Figure 1. Learning ontology development plan

effective, the topic-level ontology will be expanded into module level (and so forth).

To evaluate the developed ontology and its possible uses, it will be applied in different educational contexts: in class, in a blended learning setting, in an online course, in standalone teaching material categorization, with an ultimate goal of application in a smart learning environment.

B. Implementation of CaMeLOT educational framework and the initial learning ontology for providing personalized feedback (RQ2)

A shift towards personalization will require a more student-centered approach to teaching, and, subsequently, the next pedagogical challenge will be to nurture self-awareness and metacognitive knowledge in students.

Traditionally, educational frameworks, such as Bloom's taxonomy, are used solely on the side of the teacher, without being applied by the students to evaluate their own knowledge. However, "non-traditional" uses of Bloom's taxonomy showed positive pedagogical results [16], allowing the learners to become part of the learning process and making teaching and assessment more transparent - "it helps our students gain increased awareness and control of their own cognitive development" ([16], p. 534).

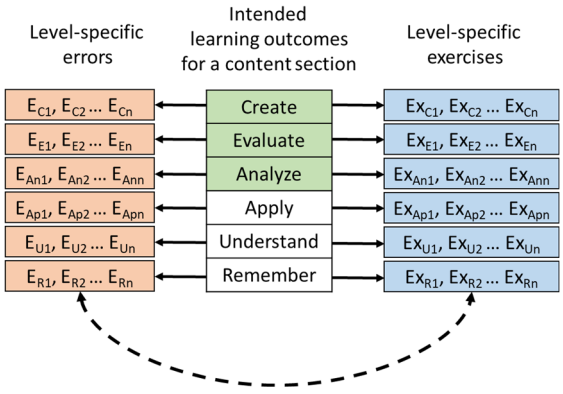


Figure 2. The possible interrelations between the learning outcomes, errors and exercises

In Figure 2, a proposed educational structure to serve as a basis for personalized feedback is provided. The central element of the figure are the intended learning outcomes, as presented in the CaMeLOT educational framework. It is assumed that on each cognitive level for a given learning outcome, a student can make a set of errors that are specific to this particular level. The presence of such errors mean that this particular outcome has not been completely achieved. Moreover, if a student does not make the errors typical for a higher cognitive level (e.g. "Evaluate"), but makes those typical for a lower level (e.g. "Understand"), the higher level learning outcome still cannot be considered as achieved.

Level- and outcome-specific exercises should be developed for achievement of the intended learning outcomes. Each exercise can be related to a set of errors possible in this specific exercise, and thus, based on the learning outcome, content area, level and corresponding errors, each exercise can be used for additional error-based practice.

According to [17], there are three major questions that should be answered by effective feedback: "Where am I going?" –the learning goals, "How am I going?" – where the student is in terms of their progress towards the learning goal(s) and "Where to next?" – what the student should do to make further progress.

The proposed structure allows for feedback that can help the student answer all these questions in the following way:

1. "Where am I going?" – the student should be provided with a transparent overview of the intended learning outcomes for each content section. This information can be derived from the CaMeLOT tables.
2. "How am I going?" – based on the errors the student makes and their correspondence to the cognitive and knowledge levels, as well as the content section, a thorough report can be provided to the student regarding their current performance.
3. "Where to next?" – based on the error type, content area and cognitive/knowledge levels, the student can be recommended to revise a certain section of theoretical content and/or to practice a set of exercises addressing the error the student made.

To illustrate the proposed approach, the following learning scenario can be given: according to the curriculum of a conceptual data modelling course, in a given content section the student should achieve a high-level learning outcome – e.g. LO1 "To be able to create a UML model of 3-4 classes based on a set of non-formalized textual requirements". The student is aware of what his goal is in this section and is trying

to solve an exercise where he is, indeed, required to analyze the requirements and draw a UML model. However, in this exercise he makes a mistake – he identifies a lot of superfluous classes from the requirements, as they were synonyms related to the same notion. This type of error is related to a much lower level learning "sub-outcome" ("Understand" level) – "To be able to correctly identify classes from the given textual requirements". Given the fact that the student made an error of a lower level, the student is proposed to solve another exercise on class identification that involves the same potential error, prior to be able to proceed to the higher level exercise. The student is also given a brief explanation on the type of error he made and the reason why an "easier" exercise is now given to him. In addition, he is provided with a link to a content section he needs to revise (as it is directly related with the given learning outcome set). This way it will be possible to fill in the knowledge gaps in a systematic and constructive way.

Prior to implementing this type of feedback and educational structure in an e-learning environment (which will be a combination of the existing learning platforms used in the course and a newly developed educational website dedicated to conceptual modelling), its effectiveness and student perception should be tested. Thus, a pre-test-post-test study, along with the student survey, will be conducted during the semester on the students of a master level course "Architecture

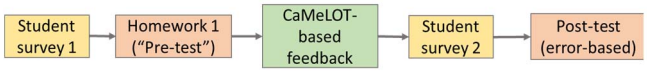


Figure 3. The feedback evaluation plan

and modelling of management information systems".

At the first exercise session (the third week of the course), the students will be given a survey (5-point Likert scale) to assess their current level of satisfaction from the course, their perception of own capability to finish the course and how they place themselves relative to others regarding the prospective performance in the course. Next, the students will be given their first homework, that will be aimed at an ultimate learning outcome: "The student should be able to create a class diagram from the given requirements". The ultimate learning outcome will be subdivided into smaller ones according to CaMeLOT framework, and the set of possible errors related to those sub-outcomes will be derived. After the submission, the homeworks will be checked, and based on the identified errors, the gaps in the achieved sub-outcomes will be identified. The personalized report will then be issued to the students, stating their current level of achievement in terms of cognitive/knowledge levels and the information on the necessary practice exercises and/or content that needs revision.

At the third exercise session, after the students have received the feedback, a second round of the student survey (with the same measurements) will be conducted. Afterwards, a post-test based on the most common homework errors will be distributed to check, whether the students made use of the feedback they were provided. There is also a possibility to conduct the error-analysis of the exam solutions at the end of the course.

An additional student survey will be conducted at the end of the course to determine the students' perception of all types of feedback used in the course to determine the most appreciated type.

C. *Finding the appropriate feedback timing (RQ3)*

The use of e-learning software of two types – a modelling tool (JMermaid [18] – which was developed to teach students information systems/enterprise modelling in a personalized way) and a Small Private Online Course platform (edX edge) provided us with a rich source of behavioral data from students. Thus, in addition to the rules identified from expert knowledge/literature, the interpretations of behavioral patterns will be conducted. The following data is already available for interpretation and has been partially explored:

1) Affective states: to be used for identification of needed/desired feedback moments

Within this section we should learn how the students indicate: "I need help"? In 2018, measurement of the reported frustration/need for additional information and engagement during the exercise sessions was conducted. The results will be suitable for identification of perfect feedback moments and typical confusion/frustration behavior in novice modelers. The possible feedback moments can be identified for task-specific and non-task-specific feedback.

2) Action-based feedback

The analyzed data is available for a particular type of feedback from the modelling software – simulation reminder feedback ([19] explored the effectiveness of various algorithms for mining this data, thus a set of process models is already available for interpretation) – the next stage of work would be to identify the behavior change after feedback appearance. Additional data on the reaction on simulation reminders will be gathered throughout the upcoming exercise session.

V. CONCLUSION

In this paper, the steps towards the development of feedback architecture of a smart learning environment for conceptual modelling are presented, along with the intermediate results of the research project. The steps include the development of a learning ontology for conceptual data modelling, the implementation of the CaMeLOT educational framework and the learning ontology for providing personalized feedback and finding the appropriate feedback timing. The feedback architecture will be tailored specifically to the needs of conceptual modelling education. While it builds on existing research results in the domain of conceptual modelling education, its encompassing nature and its structural and systematic combination of learning outcomes, assessment through exercises and common errors, will be a significant contribution to the field. The results of this research are expected not only to allow the educators and software developers to utilize a more structural approach to the development of e-learning environments for teaching conceptual modelling, but to also enable a constructive application of learning material in the traditional or blended learning class setting.

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Tutorials

Evaluating Artifacts using Experiments as part of the Design Science Framework

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***Abstract*—. Design science is of increasing importance in information systems (IS) with top journals and funding agencies recognizing it as an important component of IS research. One critical element of good design science is a solid evaluation of the artifacts, i.e., of individual algorithms and completed information systems. This tutorial focuses on the design and execution of experiments to evaluate such artifacts in an efficient manner. The artifact's life cycle is taken into account to ensure the evaluation is appropriate, effective and efficient through optimal use of resources. Evaluations can range from automated evaluations of algorithms using gold standards to user studies of an entire information system with representative users in situ. The tutorial will focus on the controlled experiment for artifacts, appropriate statistical analysis, and tips on common errors that can be avoided.**

Keywords—designs science, evaluation, experiment, user study

I. INTRODUCTION

In computer science (CS), information science (IS) and information systems and technology (IST), the outcome of research and development activities are theories, processes, models, algorithms and systems. This tutorial focuses on a subset of these: algorithms and information systems. They are referred to as artifacts from here on. To demonstrate and validate the usefulness of these artifacts, it is necessary to evaluate them. The evaluation can be comprised of simulations, stress tests, demonstrations, and a variety of other types of tests that demonstrates how input is transformed into the desired output and how well this process works. A controlled experiment is one such test.

Design science research in IS refers to research that bridges the business and IS environments. It includes stakeholders from and contributions to the application domain or business environment as well as the IS knowledge base [1]. To make interesting and valid contributions, it is essential that an evaluation is conducted that takes three principles into account. It is essential 1) to focus on the goal of the artifact, 2) to keep the stakeholders in mind, and 3) to optimize the evaluation for the timeline and development cycle of the artifact. These three principles ensure that the study measures what is important for this artifact, i.e., keep the end goal in mind. It also ensures that the study compares the outcomes with relevant comparison points. For example, new artifacts can be compared with existing ones, e.g., an improved app being compared to existing app, or they can be compared to an environment where no system exists, e.g., when a new technology is introduced where there was none. Furthermore, it is essential that the study is designed to be relevant to the stakeholders. These can be other researchers, potential buyers and funders or future users. This is important because they will have an important role in the future of the artifact. If stakeholders do not see the relevance of an evaluation they cannot judge the artifact's suitability for its environment. Finally, the evaluation should be designed to make optimal use of existing resources that are appropriate to the current state of the artifact. In early stages, evaluations can often be efficiently conducted with gold standards while information system in later phases may need human representative users for a useful evaluation.

II. VALUE OF THE TUTORIAL TO ATTENDIEES

Teaching design of experiments to evaluate an artifact, i.e., algorithm or system, is usually a small part of the educational curriculum presented to IS, CS, and IST students. Even so, it is essential to get an artifact properly evaluated to be able to draw valid conclusion about its working and impact. This is recognized by top journals and funding agencies. Poorly designed evaluations will contribute to failure to publish results, gain funding, and commercialize the product.

The tutorial will provide a focused overview of different types of experiments that are possible in different stages of the artifacts' life cycle. It will empower attendees to conduct evaluations that are a good fit for their artifact and so increase the value of their artifacts and ultimately their productivity as researchers and developers.

III. LEARNING OBJECTIVES

There are five learning objectives. The first learning objective is understanding the different types of studies and being able to choose an appropriate study at the appropriate time in the artifact life cycle. A controlled experiment is only one type of study but it can be part of most stages of the life cycle. Furthermore, it is the only type of study that allows for causal relationships to be discovered. The tutorial will help attendees envision experiments appropriate for their artifact.

The second learning objective is to develop the ability to choose independent and dependent variables that constitute the experiment design and do it in such a manner that they address the three principles discussed: appropriate for the study goal, of interest to the stakeholders and fittingly chosen for the time and life cycle.

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The third learning objective is to succeed in recognizing these variables in existing work, e.g., in all types of publications. This skill will be practiced during the tutorial with short exercises. It is a valuable skill since it helps evaluate and identify weaknesses in existing, prior work.

The fourth learning objective is to recognize and be able to avoid or control confounded and nuisance variables. This entails recognizing different types of bias and how they may affect the results of an experiment. These variables are important to be aware of, since not controlling them may result in false conclusions.

The fifth and final learning objective is to gain practical knowledge about how to implement experiments, where to find resources and dealing with administrative requirements such as review by the Institutional Review Boards (IRB).

IV. ACTIVITIES

The activities will consist of:

- a short lecture containing the overview that covers the five learning objectives,
- exercises in recognizing independent and dependent variables,
- exercises in drafting experiment designs,
- and discussions of ongoing work and advise on how to include experiments. This activity can be continued after the tutorial.

V. ATTENDEES

This tutorial is ideal for doctoral students and assistant professors who have the ability to adjust their research stream and optimize inclusion of experiments for better and more successful artifacts and the associated publications and grant proposals.

VI. MATERIALS AND TIMING

The lecture slides will be provided online via the presenter's website. The tutorial will commence with presenting information and will include short exercises. For example, a short explanation of different types of independent variables followed by short exercises in recognizing such variables in existing as it is published in different journals.

The tutorial will be conducted in 90 minutes with a short break in the middle.

VII. PRESENTER BIO

Gondy Leroy earned a combined BS and MS (1996) in cognitive, experimental psychology from the Catholic University of Leuven (Belgium) and a MS (1999) and PhD (2003) from the University of Arizona's Management Information Systems (MIS) department. She is a senior member of IEEE and Professor of MIS at the University of Arizona's MIS department. She serves on the editorial board of the Journal of Database Management, International Journal of Social and Organizational Dynamics in IT, Health Systems, Journal of Business Analytics, and co-chairs several sessions, tracks, workshops, and conferences focusing on design science and healthcare. She is the sole author of the book "Designing User Studies in Informatics" (Springer, 2011) and conducts tutorials on evaluating artifacts in a design science context. Her research has been published in ACM Computing Surveys, JAMIA, JASIST, JMIR, International Journal of Medical Informatics, and IEEE-TITB among others. Her work has been funded by several U.S. federal agencies, e.g., NSF, NIH, AHRQ, as well as industry, e.g., Microsoft Research, and foundations. She served as president for the AIS Special Interest Group on Health and as co-chair of the AIS Women's Network. She is active in promoting diversity and inclusion in computing through a variety of programs she created or supports.

VIII. HISTORY OF THE TUTORAL

The need for this type of tutorial became clear from observation of graduate program in IS. Many graduate students do not get practical experience with initiating and executing a controlled experiment. Students are often limited to one or two types of evaluations such as focus groups or simulations. This lack of knowledge and experience often continues throughout their early research career.

The material covered in the tutorial is based on detailed materials, complete with design equations, presented in the book "Designing User Studies in Informatics" [2]. While the book is mentioned in the tutorial for further reference, the tutorial is not intended as a sales pitch, since most libraries have acquired the book and provide electronic access for free.

Different versions of this tutorial have been conducted in a variety of places:

- Half-day Tutorials at the Hawaii International Conference on System Sciences (HICSS), January 2012-2014 and 2018-2019.
- Two-day Tutorial at the Aalto University, School of Business, Finland. Planned for March 18-19, 2013.
- Half-day Tutorial at the International Conference on Asia-Pacific Digital Libraries (ICADL 2011), Beijing, China, October 24-27, 2011
- Half-day Tutorial at the ACM-IEEE Joint Conference on Digital Libraries (JCDL), Ottawa, Canada, June 13-17, 2011.

While most of the tutorials were 3 hours long (half day tutorial: 3 hours + break), the materials can be summarized to the essential points and interactivity maintained by means of short exercises. Furthermore, individual feedback can be given to attendees after the tutorial.

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Towards Adaptive Enterprises using Digital Twins

Vinay Kulkarni
Tata Consultancy Services Research, India

Tony Clark
Aston University, UK

Abstract*— *Modern enterprises are large complex systems operating in highly dynamic environments thus requiring to respond quickly to a variety of change drivers. Moreover, they are systems of systems wherein understanding is available in localized contexts only and that too is typically partial and uncertain. With the overall system behaviour hard to know a-priori and conventional techniques for system-wide analysis either lacking in rigour or defeated by the scale of the problem, the current practice often exclusively relies on human expertise for monitoring and adaptation. We outline a knowledge-guided simulation-aided data-driven model-based evidence-backed approach to make enterprises adaptive. The approach hinges on the concept of Digital Twin - a set of relevant models that are amenable to analysis and simulation. We describe the core modeling and model processing infrastructure developed, and early stage explorations of its application to problems where the mechanistic world view holds. We argue similar benefits are possible for problem spaces involving human actors as well.

Keywords*— *Enterprise Modeling, Simulation, Decision Making, Actors, Enterprise Information Systems, Design & Control, Adaptation

Proposed length of the tutorial* – *3 hours

Level of the tutorial* – *Introductory

Target audience* – *Academic as well as industrial researchers, students, and industry practitioners having an exposure to information systems and modeling in general.

The presenters

Vinay Kulkarni is Chief Scientist at Tata Consultancy Services Research (TCSR). His research interests include model-driven software engineering, self-adaptive systems, and enterprise modeling. His work in model-driven software engineering has led to a toolset that has been used to deliver several large business-critical systems over the past 20 years. Much of this work has found a way into OMG standards. Vinay also serves as Visiting Professor at Middlesex University London.

Tony Clark is Professor of Software Engineering at Aston University in the UK. His academic research on meta-modelling led to the development of a tool called XModeler that has been used in a number of commercial applications including the development of tool support for a new Enterprise Architecture modeling language.

I. Motivation

Modern enterprises are complex systems of systems operating in highly dynamic environments that need to respond quickly to a variety of change drivers. Determining the right response often requires a deep understanding of aspects such as structural decomposition into subsystems, relationships between these subsystems, and emergent behaviour. The scale of organisations, their socio-technical characteristics, and fast business dynamics make this a challenging endeavour. Current industry practice relies principally on human expertise to arrive at suitable responses and has turned out to be inadequate[1]. Several enterprise modelling languages have been proposed to aid human-in-the-loop decision making, however, none fully addresses the problem. Languages capable of specifying all relevant aspects are not amenable to automated rigorous analysis, and the languages that provide sophisticated analysis capabilities address only a subset of the relevant aspects. Moreover, lack of interoperability makes it a challenge to use a set of relevant languages together. Furthermore, implementing the desired response through suitable modifications to enterprise IT systems, business processes and strategies is no less complex. Little help exists to identify what needs to modified where and how.

Having identified the desired set of modifications, technology exists to introduce these changes to an enterprise, albeit in a widely varying spectrum of efficacy. For instance, modern IT systems are relatively more amenable to such modifications than legacy systems. However, adapting enterprises suitably and effectively in increasingly dynamic environments remains a time-, effort- and intellectually-intensive endeavour.

To address the problem of enterprise adaptation, in this tutorial, we propose a novel approach that is based on domain knowledge, is driven by real-world data, and that uses simulation models to support evidence based adaptation. The approach hinges on the concept of Digital Twin – a set of relevant models amenable to rigorous analysis and simulation. We describe the core modeling and model processing infrastructure necessary to support the proposed approach. We describe early stage explorations of its application to problems where the mechanistic world view holds. We argue similar benefits are possible for problem spaces involving human actors as well.

II. Overview of the Tutorial

We illustrate the knowledge-guided data-driven model-based simulation-aided evidence-backed approach for design, control and adaptation of large enterprises. Though validated in problem spaces where the mechanistic world view holds, we argue, it is equally applicable for socio-techno spaces as well. Though not described here for want of space, the tutorial will outline a line of attack for this aspect as well.

A. Line of attack

[1] http://www.valueteam.biz/why-72-percent-of-all-business-transformation-projects-fail

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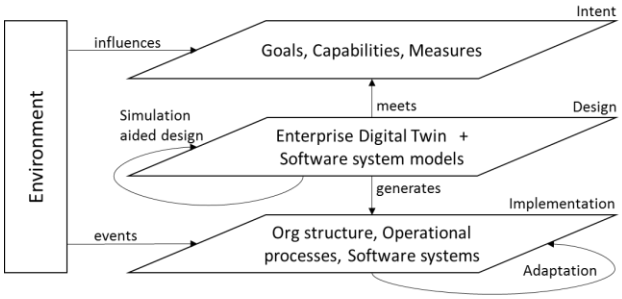


Fig 1. Adaptive Enterprise

We envisage a line of attack wherein an enterprise is viewed at three related planes namely: *Intent* defining goals, capabilities, and measures; *Design* defining organisational structure, processes, and information systems; *Implementation* realizing the design plane in terms of organisation and its software systems; and interactions of the three planes with an environment as shown in Fig 1. The design plane needs to provide suitable machinery to arrive at the specifications of the right organisational structure, processes and information systems so as to meet the specified intent. To this end, we propose simulation-guided data-driven machinery for design space exploration. The outcome of this human-in-loop process is an executable model of the enterprise and specifications of its software systems – *i.e.* an enterprise *digital twin*. We use model driven techniques to transform the design plane specifications into an efficient implementation of supporting software systems that are capable of dynamically adapting to the changes in environment. The design plane models serve as the reference for adaptation of implementation plane systems.

Our adaptation architecture draws its inspiration from a well-studied and widely used concept from control theory – Model Reference Adaptive Control (MRAC) [1] shown in Fig 2. The Model captures the desired reference behaviour of enterprise. The Enterprise is the complex system of systems to be controlled - viewed principally as input-output transfer function and possibly persistent side-effects. The Monitoring & Sense Making component constitutes the core technology infrastructure to observe and discern input and output of enterprise. The Controller component constitutes the core technology infrastructure that, together with the Monitoring & Sense Making component, nudges the Enterprise as close to the Model as possible thus achieving a model-guided data-driven justification-based human-in-the-loop adaptive response.

In manufacturing domain terminology, the fixed point of the design plane model is a *digital twin* of the enterprise. A digital twin mimics the behaviour of a system in order to support what-if analyses and to arrive at appropriate responses

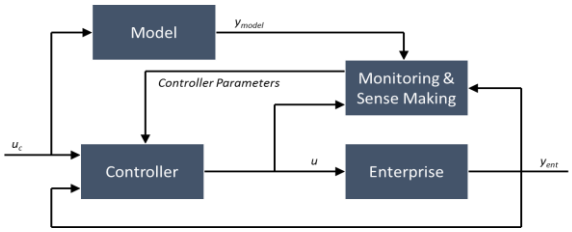


Fig 2. Model driven adaptive enterprise

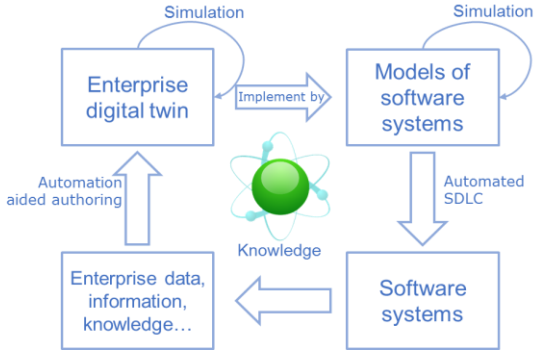


Fig 3. Model-based architecture for adaptive enterprise

to various contingencies that may arise in a plant.

Future enterprises are systems of systems with complex interactions operating in a dynamic environment. Given the structural and behavioral complexity, detailed understanding is possible only in localized contexts [2]. At the same time, events occurring in one context influence the outcomes in other contexts. Lack of complete information coupled with inherent uncertainty make holistic analysis of systems intractable. As a result, decisions pertaining to system design and implementation are unlikely to be globally optimal. Non-availability of complete information and inherent uncertainty make traditional optimization approaches impractical. Therefore, in many cases a simulation-based approach is the only recourse available for arriving at a "good enough" solution by navigating the solution space [3]. However, considering the open nature of the problem, an exhaustive navigation of the solution space is infeasible. It calls for intelligent navigation of the solution space guided by domain knowledge and learning from past experience. Figure 3 provides a pictorial representation of proposed line of attack that hinges on: (i) model-based machinery to help define enterprise digital twin, (ii) simulation machinery what-if and if-what analysis, (iii) model-based machinery to help implement the system right, (iv) a mechanism to map the two sets of models along with a means to derive one from the other, and (v) a learning loop to enable continuous improvement over time.

B. Enterprise Digital Twin

An enterprise digital twin is a set of purposive analyzable and simulatable models representing the enterprise in order to mimic real-world phenomenon. A variety of Enterprise Modeling (EM) languages exist that provide information-capture and analysis support across a wide spectrum of sophistication. Majority of these languages can be traced to Zachman framework [4] advocating that capture of the *why*, *what*, *how*, *who*, *when* and *where* aspects leads to the necessary and sufficient information for addressing a given problem. Thus it can be argued that a complete specification of an enterprise is possible using the Zachman framework, however, there exists no support for automated analysis as the information is captured typically in the form of texts and pictures. It can be observed of the existing EM languages that: the languages capable of specifying all the relevant aspects of

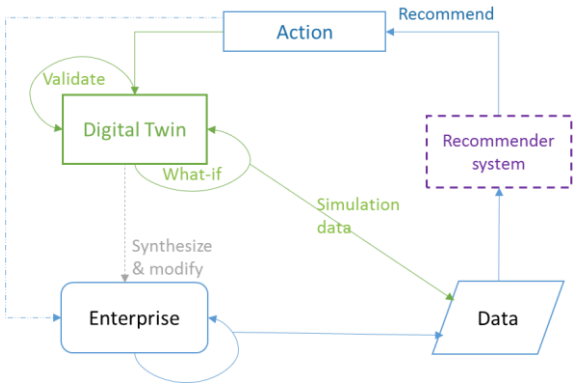


Fig 4. Assured recommendation using digital twin

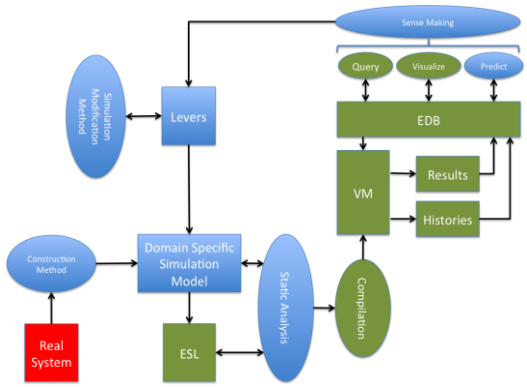


Fig 5. ESL Workbench

an enterprise for organisational decision-making lack support for automated analysis [4, 5, 6], and the languages capable of automated analysis can only address a subset of the aspects required for decision-making [7, 8, 9]. Moreover, the system of systems nature and the large size of modern enterprises means that an understanding of an enterprise – structural and behavioural – is available only locally, from which the overall behaviour needs to be derived. Also, even the local understanding can have an element of uncertainty.

The Actor model is a mathematical model of concurrent computation wherein an *Actor*, in response to a message that it receives, can: make local decisions, create more actors, send more messages, and determine how to respond to the next message received. Actors may modify their own private state, but can only affect each other through messages (avoiding the need for any locks) [10]. We have developed an Actor-based modelling language, ESL[2], to specify an enterprise as a set of autonomous encapsulating units that interact with each other by exchanging messages [11]. We have developed a component abstraction to model the fractal nature of system of systems [12]. We have extended the actor-based paradigm to enable modelling of uncertainty [13]. Through a set of case studies, we have validated the adequacy of ESL to specify complex system of systems for decision-making [14, 15].

C. Using the Digital Twin for Design and Control

An Adaptive Enterprise design process aims to use information to nudge observed measures to achieve designed goals. Domain knowledge and experience are captured in a set of purposive models i.e. Digital Twin. The digital twin facilitates the design process through simulation. It is essentially an iterate-till-saturate process wherein one starts with an initial configuration of capabilities and progressively nudges the measures using levers till the desired objectives are met. We use pattern matching to extract measures of interest from the execution trace produced by simulation to check whether the goals are met. We use machine learning techniques to analyze the effects of modifications introduced to measures as regards achieving the desired goal. This learning element leads to continuous improvement of the design process over time.

Decision-making processes involve analyzing past data to come up with a set of recommendations for achieving the desired objectives. In a complex system of systems, one only has visibility of a local context in arriving at such recommendations. One would like to know a-priori the ramifications of a recommendation at the system level – whether it will achieve the desired goal, whether it will adversely impact other goals *etc*. A digital twin helps answer these questions by simulating the recommendation as shown in Fig 4. In addition, a digital twin can help improve the decision-making process itself by exploring the solution space through what-if scenario playing. Moreover, over time, synthesis of these explorations can help improve the overall operation of the system itself.

D. The ESL Workbench

The ESL workbench[3] supports an Actor-based language for simulation-based decision-making [11]. The workbench is shown in Fig 5 and will be introduced as part of the tutorial. In order to provide a sense of the workbench features we describe a simple actor-based simulation that is represented, run and analysed using the key technologies. Fig 6 shows a shop with customers, assistants and tills. The shop owner has a goal of minimising disgruntled customers who leave the shop because they wait too long in queues to be served at tills or provided with help. Customers and assistants behave autonomously and there are different types of drivers for customer behaviour.

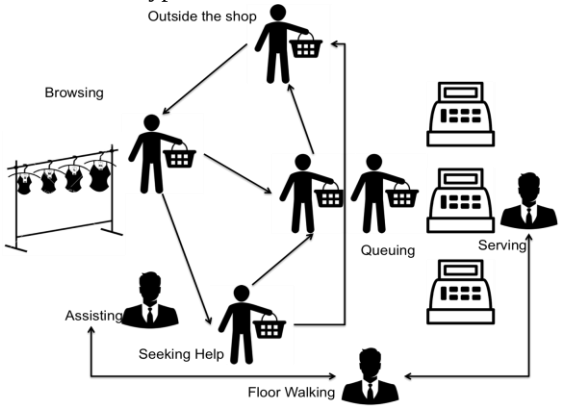


Fig 6. Shop Simulation

[2] http://www.esl-lang.org

[3] http://tonyclark.github.io/ESL/

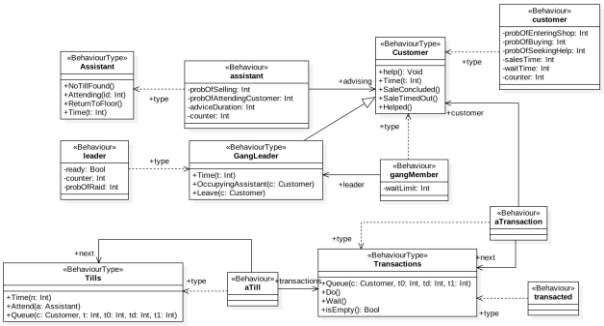


Fig 7. ESL Actor definitions

Figure 7 shows a model of actors that can be directly implemented in ESL. Each actor has a behaviour that can be modelled as a state machine. When implemented in ESL the model can be run to produce emergent behaviour that is subsequently analysed through the EDB component of the ESL Workbench. This includes visualisation of the simulation results and analysis of the simulation history [16]. The shop owner can speculate about the distribution of customers with particular types of behaviour and run the simulation multiple times in order to determine the outcome. The tutorial will use a number of examples similar to the shop simulation in order to introduce the participants to the ESL Workbench.

E. Model driven techniques for adaptive software systems

Modelling helps address software development and integration from a higher level of abstraction. Most prominent benefit delivered so far has been through automated code generation [17, 18]. The software system is specified in terms of the *what* and *how* aspects leaving out the details such as architectural decisions, design strategies, and implementation technology platform. A set of appropriate code generators transform these specifications into a platform specific implementation while adding details pertaining to the chosen architectural decisions and design strategies. The same specification can be used to deliver another solution with different choices for architectural decisions, design strategies, and implementation technology platform. Support for variability modelling & resolution at model level enables product lines [19, 20]. Model based code generators also benefit from model based code generation thus further improving productivity and agility [21]. Several manifestations of this technology exist[4], however, the focus so far has been on delivering a bespoke solution or at best a product line i.e., addressing largely static scenarios.

Software systems should reflect the characteristics of the enterprises they support. As enterprises are evolving into complex system of systems that need to quickly adapt to a variety of changes taking place in their operating environment, so should their supporting software systems. This puts new requirement of adaptiveness on enterprise software systems to be achieved through sense-n-respond architectures.

Though MAPE-K architecture pattern has been much in discussion, it has not seen commensurate adoption in industry

[4] https://mastercraft.tcs.com/

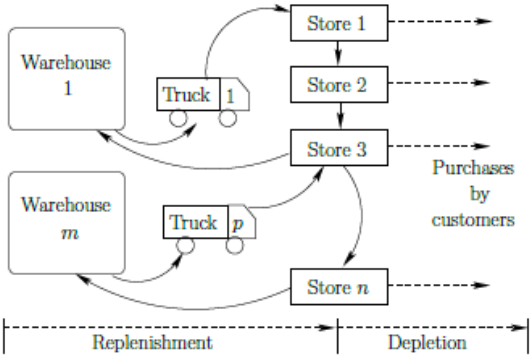


Fig 9. Schematic of stock replenishment in a supply chain

[22]. We propose use of digital twin to drive the adaptation using MRAC pattern of Fig 2. Digital twin serves as the *Model* i.e. reference behaviour of the system. The sensory framework and the pattern-matching infrastructure of ESL constitute the *Monitoring & Sense Making* machinery. The MAPE-K like infrastructure discussed above can provide the *Controller*.

F. Real World Use-cases

The tutorial includes several real-world use-cases demonstrating how adaptiveness can be imparted using digital twin models and associated processing machinery. Description of one such use-case follows.

Retail supply network is a complex system of systems comprising of manufacturing plants, wholesalers, distribution centers, retailers, stores, logistic providers etc. These actors are typically designed to operate in a manner so as to achieve their individual goals in a dynamic environment. Several solutions exist to help design such actors, however, there is no support available to tell a-priori the ramifications of local changes throughout the system. In other words, there is a need for a controller to guide a complex system of systems operate in a manner that is optimal in local contexts and yet robust overall. We have addressed this need for a subset of the retail supply network consisting of a set of Distribution Centers supplying goods to Shops as shown in Fig 8. The objectives of the system are: (i) to ensure stock availability, (ii) to optimize store space, (iii) to minimize wastage of perishable goods, and (iv) to minimize transportation costs. The solution needs to take into account the dynamics of shop-specific consumption behaviour, perishable nature of goods, carrying capacity of trucks, truck routes etc.

Existing literature that describes the use of Reinforcement Learning (RL) for controlling complex systems [23, 24], typically does so for systems which can be modelled analytically, simplifying the computation of step rewards and next state of the system. This is because RL is effective only when the (stochastic) transition functions closely approximate the real system to be controlled. In situations where the system cannot be described analytically, algebraic expressions cannot be used to compute rewards and transitions. An experimental approach can be used for training the RL agent when the system is non-physical (for example, is itself a piece of software as in the case of computer games) [25]. However,

training on the actual system is not feasible in the case of business-critical systems. Therefore, the development of (and integration with) a high-fidelity simulation model is crucial for effective training of the RL agent and controlling complex systems.

We created a digital twin of the supply network and simulated scenarios of interest to generate data to drive reinforcement learning for replenishment decisions at each shop. Thus, the digital twin helped realize a more comprehensive controller by enabling faster tuning of the same. This solution is being validated in a real life supply network [26].

III. Novelty of the Tutorial

This tutorial will introduce a new use of modeling to the conference. Tutorials at agent-based conferences often address simulation. The application of this field to enterprises and placing it in the context of information systems is novel.

This tutorial will introduce delegates both to a novel conceptual approach and to a novel technology platform that are designed to support adaptation through simulation-aided design and decision-making. In addition the delegates will be introduced to case studies that have been drawn from the real world and will therefore be of interest to both academics and industry.

IV. History of the Tutorial

Research underlying this tutorial has been evolving over past 3-4 years. We have presented it in tutorial form at several international conferences such as ESM 2017, ISEC 2018, MoDELS 2017 and MoDELS 2018 where it has been received well.

V. Required Infrastructure

The tutorial will require a standard room with a beamer. The ESL Workbench and example simulations will be made available to delegates.

VI. Sample Slides

Please refer for sample slides here.

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