3-DIMENSIONAL GEOSPATIAL ANALYSIS AND VISUALIZATION FOR URBAN ENVIRONMENTAL ASSESSMENTS: A CASE STUDY OF A NEIGHBORHOOD LOCATED IN THE BRUSSELS CAPITAL REGION

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INTRODUCTION

Urbanization presents opportunities and challenges, particularly in the context of achieving the Sustainable Development Goals (SDGs).[1] Ensuring that cities are inclusive, safe, resilient, and sustainable[2] requires framing innovative urban planning processes. This paper presents an interactive and participatory3-Dimensional geospatial analysis and visualization framework, for the development of urban environmental assessments. The framework allows for the evaluation of environmental impacts linked to land use and reallocation strategies, to streamline urban planning scenario testing informed by environmental considerations. A case study is presented for a neighborhood in the Brussels Capital Region (BCR), where environmental indicators are integrated on a 3-Dimensional, parcel-by-parcel basis. These indicators encompass representations of the built environment, green spaces, soil, and geology, providing essential support to experts and developers in the decision-making process.

Environmental assessments are necessary for identifying potential environmental impacts that are a priority for consideration in urban decision-making processes.[3] These assessments play a vital role in contributing to the development of sustainable urban proposals.[4] However, the understanding and adoption of urban environmental assessments remains a significant challenge for many stakeholders. To tackle these challenges, this research proposes revisiting and refining the interfaces used for the analysis and evaluation of urban environmental assessments, with the aim of enhancing their accessibility to a broader audience. A particular emphasis will be placed on the parcel scale, given its importance in urban policy-making, along with a focus on both subsurface and aboveground urban assets. This approach aims to address the multifaceted nature of urban environmental systems more effectively.

Public Participatory Urban Planning Processes

In recent years public participatory processes have gained increasing recognition as pivotal in planning processes due to their ability to democratize decision-making and improve project outcomes.[5] Public participatory methods can also enhance public understanding of environmental challenges by providing platforms for education and dialogue,[6] bridging the gap between environmental and social aspects for a more sustainable and socially equitable urban development[7]. Participatory methods can not only foster environmental stewardship but also promote a sense of ownership among community members, which is crucial for the long-term success of environmental urban planning initiatives.[8] Participatory approaches enhance engagement and collaboration, leading to more sustainable and inclusive planning outcomes.[9]

Interactive Planning Support Systems (PSS)

Interactive Planning Support Systems (PSS) have become increasingly important in achieving the objectives of modern urban planning, particularly in fostering collaborative environments and facilitating informed decision-making. For instance, a study by McEvoy et al.[10] demonstrates how PSS tools, particularly in collaborative urban adaptation workshops, contribute to participant learning and better planning outcomes, albeit their impact is often more indirect and process-dependent. Similarly, Vonk et al.[11] and Pettit et al.[12] highlight the role of PSS in integrating various data sources and models to facilitate scenario planning and stakeholder engagement, which are crucial for achieving sustainable urban development goals. PSSs are essential tools that enable the sharing of knowledge and establish robust feedback mechanisms among stakeholders, ensuring that all voices are considered in the planning process.[13] Recent studies demonstrate that PSS significantly improve stakeholder engagement by providing accessible platforms for data visualization and scenario modeling, which help participants better understand potential outcomes.[14]

Moreover, through workshops and collaborative sessions, PSS can allow for in-depth analyses of results, enriching the overall quality of decision-making, and incorporating diverse perspectives and expert opinions into the planning framework. The integration of new Information and Communication Technology (ICT) ICT into smart cities enhances spatial planning through collaborative governance PSSs, as demonstrated by case studies from China, Finland, and the USA, highlighting that effective communication and transparency in decision-making depend on advanced technology and suitable institutional frameworks.[15] Additionally, research by Flacke et al.[16] underlines the importance of integrating PSS workshops into planning stages, as they provide critical insights that can guide the development of more sustainable and equitable urban environments.

City Information Modeling (CIM) is a transformative tool in urban planning, offering a holistic approach that integrates BIM, GIS, and comprehensive urban data, essential for meeting current and future demands through participatory and interactive environmental assessments.[17] CIM uses advanced 3D modeling to create comprehensive and interactive representations of urban environments, making data accessible and engaging for a wide range of stakeholders.[18] Web-based Geographic Information Systems (WEB-GIS) enhance these capabilities, and multidimensional web-mapping platforms further improve citizen participation by enabling better assessment of the spatiotemporal evolution of cities.[19]

The 3D visualization of urban development plans and within CIM protocols has been deemed important for facilitating public participation within urban planning process, as it helps stakeholders better understand and contribute to the planning decisions.[20] This approach enhances transparency and allows both policymakers and citizens to visualize and understand real-time urban dynamics, leading to more informed decisions and greater community involvement in shaping city development.[21]

Despite advancements in participatory methods and Interactive PSS, significant research gaps persist in their integration with environmental assessments. Key areas requiring further exploration include the development of 3D visualizations that encompass both above-ground and underground elements to enhance stakeholder engagement through comprehensive urban representations. There is also a need for studies on optimizing participatory processes to ensure effective stakeholder input in completing environmental data. Furthermore, the integration of participatory methods with environmental assessments, particularly in addressing both environmental and social factors, remains underexplored. Similarly, research on the application of interactive 3D interfaces for detailed, parcel-by-parcel analysis in environmental assessments is lacking. Addressing these gaps could significantly improve participatory urban planning, leading to more sustainable and equitable urban development. The current study developed a framework for a 3D WebGIS application that aims to improve participatory urban planning related to environmental assessments, leveraging 3D GIS capabilities throughout all stages of the process.

METHODOLOGY

The general framework

Data Collection and Preparation

A diverse set of data was compiled and formatted including: GIS cadaster data, soil data, 2D geographical information, 3D models, and LiDAR data. Additionally, Digital Elevation Models (DEMs) and geological data were collected to gain a comprehensive understanding of terrain features (e.g. Table 1).

Data Standardization and Integration

Following the data collection, the next step involved the standardization and compatibility assessment of the various datasets.

Spatial Analysis and Visualization

Once the data was prepared and standardized, we proceeded with the spatial analysis and visualization using GIS desktop software. This phase involved converting the data into 3-Dimensional.

User Interface Design

The final stage focused on designing an interactive user interface with the goal to create a seamless CIM experience into a unified 3-Dimensional WebGIS environment. Moreover, the data interpretation was enhanced by visualizing 3-Dimensional data through dashboards. To empower users further, interactive data download and customization features were included, facilitating tailored analyses and informed decision-making.

Case study: Brussels Capital Region (PAD Hyvaert neighbohood)

The case study focused in the PAD Heyvaert neighborhood outlined in the located South west of the Brussels Capital Region (BCR) (Figure 1). The Heyvaert district has evolved into an international hub for automobile-related businesses, since the late 1970s, replacing earlier slaughtering and butchering trades. The district now houses around 60 businesses over 60,000 m². However, this economic activity has led to significant environmental challenges, including pollution, poor housing conditions, limited green spaces, and mobility issues, negatively impacting the quality of life; initiatives aimed at renewing economic activity and creating collective, convivial spaces in the Heyvaert district are crucial for preserving its vitality.[22] Bossard et al.[23] explain that the transformation of this former industrial area into a mixed-use neighborhood aligns with city goals like reducing urban sprawl, improving quality of life, and enhancing resilience; the district's challenges, including soil contamination, private land ownership, heritage building protection, and densification, create an ideal setting to study the impacts of urban soil transformation.

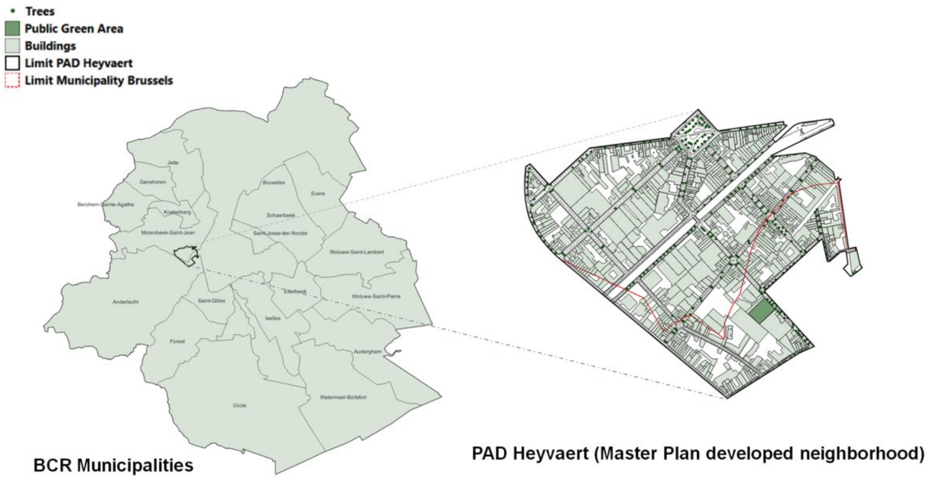

Figure 1. Case study: Brussels Capital Region (PAD Hyvaert)

The Data sources

The data used to build up the Geodatabase combined different data sources: i) raster data such as DMT or tif to define each stratigraphic layer, ii) vector 2D data such as points and polygons, iii) vector 3D point cloud or multipatch data and iv) environmental data such as report or studies to compute new attributes (Figure 2, Table 1). For each type of data different procedures were performed to create the Geodatabase as shown in Figure 2.

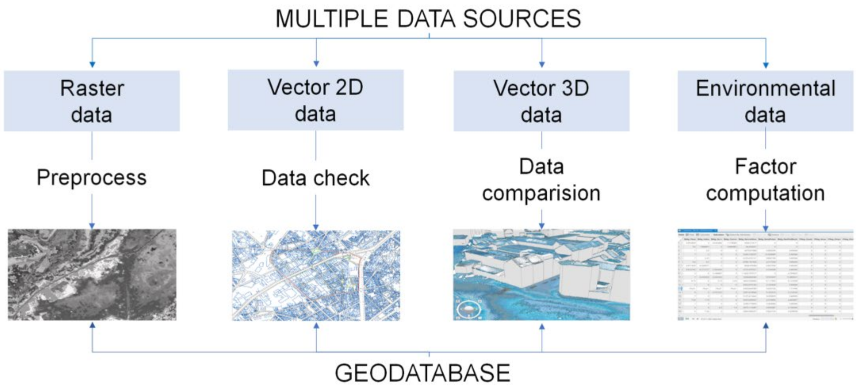

Figure 2.The data sources

Data type	**Dataset title**	**Data source**	**Year Adquisition**	**Format**
Geological stratigraphic rasters (height)	uhrbc1_quaternaire	Brussels Enviroment	2020	TIF
Geological stratigraphic rasters (depth)	uhrbc1_quaternaire_epa	Brussels Enviroment	2020	TIF
Digital terrainmodel (res.10m)	Topo_lidar_srtm801_ajust	Brussels Enviroment	2021	TIF
Digital terrainmodel (res.1m)	UrbDTM_2021_147170	UrbIS	2015	TIF
Statistical sector boundaries	UrbAdm_STATISTICAL_DISTRICT	UrbIS	2015	SHP
Municipality boundaries	UrbAdm_MUNICIPALITY	UrbIS	2015	SHP
Region boundary	UrbAdm_REGION	UrbIS	2015	SHP
Block boundaries	UrbAdm_BLOCK	UrbIS	2015	SHP
Sidewalk boundaries	UrbAdm_SIDE_WALK	UrbIS	2015	SHP
Street axis	UrbAdm_STREET_AXIS	UrbIS	2015	SHP
Street boundaries	UrbAdm_STREET_SIDE	UrbIS	2015	SHP
Bridge footprint	UrbAdm_BRIDGE	UrbIS	2016	SHP
Building footprint	UrbAdm_BUILDING	UrbIS	2017	SHP
Land data use	Pras_Affectations_2018	Perspective Brussels	2018	SHP
Block boundaries and data	Bpn_CaBl	Cadastre | SPF Finances	2023	SHP
Parcel boundaries and data	Bpn_CaPa	Cadastre | SPF Finances	2024	SHP
Building footprint and data	Bpn_ReBu	Cadastre | SPF Finances	2025	SHP
Building Type	typo_batiCanalDROIT_OK_20190528	Barbara Lefort	2019	SHP
Tree point mantained by B.Enviroment	tree	Brussels Environment	2020	SHP
Tree point mantained by B.Mobility	trees	Brussels Mobility	2022	SHP
Tree point mantained by Communes	UrbTop_BG0101P	UrbIS	2015	SHP
Vegetation boundaries	vegetation_2020	Brussels Enviroment	2020	SHP
Vegetation canopy boundaries	vegetation_2020_canopy	Brussels Enviroment	2020	SHP
Public green areas boundaries	public_green_area	Brussels Enviroment	2021	SHP
Green projects boundaries	green_projects	Brussels Mobility	2022	SHP

3D beta version model	CTU_URB_A_3D_147170	UrbIS	2020	SKP
3D ground model	UrbAdm3D_146170_Bu_Ground	UrbIS	2020	SHP
3D outerceiling model	UrbAdm3D_146170_Bu_Outerceiling	UrbIS	2021	SHP
3D roof model	UrbAdm3D_146170_Bu_Roof	UrbIS	2022	SHP
3D solid building model	UrbAdm3D_146170_Bu_Solid	UrbIS	2023	SHP
3D wall model	UrbAdm3D_146170_Bu_Wall	UrbIS	2024	SHP
Point cloud data	UrbLiDAR2021_147170	UrbIS	2021	LAS

Table 16. Data types and data sources

Processing the data

GIS software was used for data manipulation, database preparation, and visualization including 3D representations. The data were imported into ArcGIS Software and formatted to guarantee compatibility. After the relative transformations, the spatial analysis, and geoprocessing of the data, the final database 3D Cit-is Database was generated. This database was used for the publication in the 3D Web GIS interface, to guarantee full operability to visualize and interact with 3D urban data.

A critical stage in theproject involved defining the attribute table, which is essential for extracting detailed information from various spatial datasets, including underground layers, buildings, and roofs. Each dataset—such as those for soil, streets, buildings, and greenery—is paired with an attribute table that provides geometry details and associated environmental factors (Figure 3).

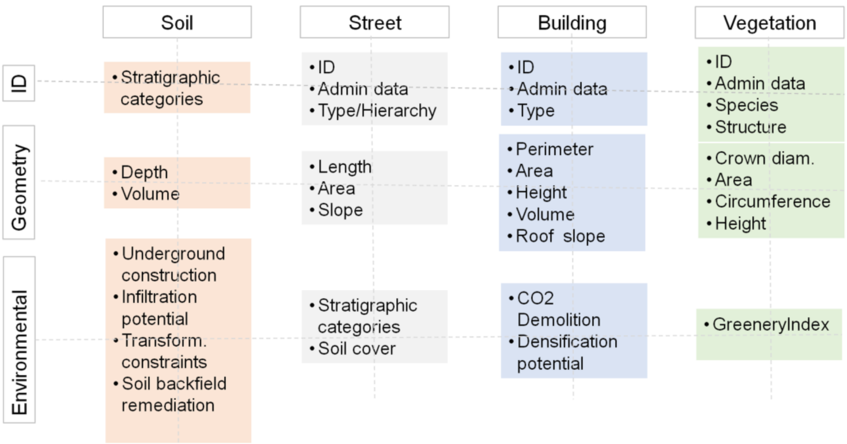

Figure 3. The attribute table

The result: The *Beta 3D Cit-is WebApp*

ArcGIS Online provides the capabilities for creating interactive 3D maps that enable users to navigate within a web browser. This interactivity aims to increase user engagement to deepen their comprehension of geographic information.

The Scene Viewer suitable for 3D visualization, was chosen as the platform for constructing the 3D Cit-is WebApp. All data have been integrated into the scene interface as layers and have undergone adjustments for the visualization including layer style changes (colors and symbology, as well as properties like attribute appearance, transparency, etc).

The WebApp was constructed using the ArcGIS API 4. for JavaScript. This platform offers a range of interactive map options. The chosen template for this purpose was the monitor template, which includes dashboard properties.
Using the monitor dashboard layout, we assembled a combination of widgets that help organize, track, and display data visualizations. This resulted in WebApp - Dashboard.
The WebApp – Dashboard consists of two pages:

A. The WebApp

The first page provides the Model visualization and the information about its components (Figure 4); by clicking any object (e.g. buildings, trees, subsoil layers, street/sidewalk segments) within the 3D view, the information relative to their geometrical and descriptive characteristics appears as a pop up.
The 3D Toolbox widget[24] adds 3D effects and analysis tools to the scene. For example, it provides the option of the daylight and shadow cast in any location.
The Daylight tool employs simulated real-world sunlight and shadows to illuminate the scene, thereby providing a daylight simulation based on the user's specified date and time.
The Shadow Cast generates shadows from 3D input features by sunlight for the selected date and time, providing a mode for analysing shadows (e.g. calculating the amount of time that a given location is in shadow).
Clicking on the button named PARCELS, the data associated with each parcel can be visualized. This button will open a WebApp - Dashboard showing the parcel level statistics.

Figure 4. TheBeta 3D Cit-is WebApp

B. The WebApp - Dashboard

The second page provides the Model visualization and the summarized information for each parcel. In other words, it is a dashboard showing the parcel level statistics. In this case, another scene of the 3D model has been added, where only the parcels are activated to trigger the pop-up layer; clicking on a parcel, which appears as an extruded polygon (it has extruded from the bottom of the model towards a top of 120m above the surface), all its attribute table information pops up (Figure 5).
The layout of the scene is finalized by incorporating text, images, and interactive diagrams/charts, thereby enhancing the Model's interactivity; each kind of information appears in either a textual or diagrammatic way (Figure 5).
To the left of the dashboard, the parcel ID references, surface and perimeter values, soil, building, and vegetation information are included in the form of graphical tabular data. At the bottom of the

dashboard, the sealed and unsealed soil, and the built cover percentages are displayed for the parcel and block levels as pie charts. The index following the soil classification is displayed as a bar plot differentiating their Infiltration potential, and transformation potential. Also as bar plots, the densification potential computed as the *sqrt (building volume)/sqrt(plot area)*, and the greenery index computed as the *vegetation area/the parcel area*, are included for the parcel and block levels. Finally, for the parcel level, the max building, façade and vegetation heights are displayed.

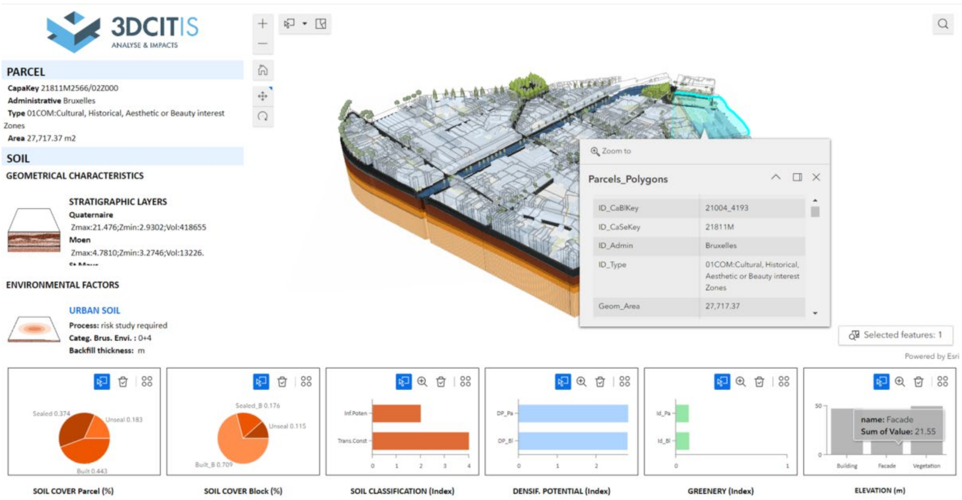

Figure 5. 3D Cit-is WebApp - Dashboard, second page

CONCLUSION

The presented approach of aggregating parcel- and block-level data has demonstrated significant effectiveness in addressing key project implementation priorities and parcel consolidation strategies. By facilitating comprehensive access to information, from subsurface layers to rooftop details, decision-making processes for urban stakeholders are enhanced. This is particularly impactful in areas such as water management, where a thorough understanding of subsurface conditions is critical, and in urban green infrastructure planning, where the integration of built and natural environments is essential.

Furthermore, the capabilities of our proposed interactive application for data download and visualization have shown considerable potential in enhancing participant engagement. This tool not only fosters a deeper understanding of environmental and socio-economic impacts but also empowers stakeholders by providing them with the means to explore and analyze urban environments in a more informed and participatory manner. Looking ahead, future studies will focus on further enhancing the interactivity and user-friendliness of the model, ensuring that it adapts to the evolving needs of stakeholders and urban planners. Additionally, we plan to expand the model's applicability to other densely populated urban areas, potentially integrating more complex environmental and socio-economic indicators.

ACKNOWLEDGMENTS

This research was conducted as part of the 3DCIT-IS project, supported by Innoviris (2020-2023).

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