Frontiers of Architectural Research 12 (2023) 1–14

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.keaipublishing.com/foar

RESEARCH ARTICLE

Physiological and cognitive discontinuities: From mythical mediation to implicit discretization of architectural design tools

Damien Claeys

Louvain Research Institute for Landscape, Architecture, Built Environment (LAB) and Faculty of Architecture, Architectural Engineering and Urban Planning (LOCI), Université catholique de Louvain (UCLouvain), Brussels, Belgium

Received 20 March 2022; received in revised form 19 May 2022; accepted 16 June 2022

KEYWORDS
Architecture;
Design;
Representation;
Discretization;
Discontinuity;
Digital;
Analog;
Uncertainty

Abstract In architectural design, representation tools are often compared according to their alleged effects on the creativity of designers. Moreover, their mediating capacities are often mythicized, to such an extent that one might surmise the direct transmission of the mental images from the designer's consciousness to an external representation. In this speculative essay, we demonstrate that the process of representation at work in architectural design originates from the designer's consciousness natural cognitive ability, rather than from the use of a specific mediation tool between the designer and his environment, between the mentally constructed architectural project and its representation. The effects of any tool of representation—analog or digital—on our perceptual apparatus depend primarily on the cognitive mechanisms affecting the discontinuous flow of internal representations formed by our consciousness. In other words, we propose to shed a new light on these limitations through the heuristic modeling of an architectural project designer confronted with his own cognitive biases, and the limits of the representation processes. In the present essay, the discontinuities and uncertainties inherent to the processes of representation are reintegrate in the models.
© 2022 Higher Education Press Limited Company. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The study of the mechanisms of representation in architectural design processes is not a new research topic. Already in *De Re Aedificatoria* (1442-1452), according to David R. Scheer (2014, p. 2), Leon Battista Alberti introduces in his "epochal book" the idea that "the architect's role is to design, not to build". At least from that time: "Drawing became essential to architecture as the expression of architectural ideas, the architect's work product and the link between thought, design

E-mail address: damien.claeys@uclouvain.be.
Peer review under responsibility of Southeast University.

https://doi.org/10.1016/j.foar.2022.06.008
2095-2635/© 2022 Higher Education Press Limited Company. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

and construction." (pp. 2—3). As summarizes the formula "*dessin à dessein*" (Le Moigne, 1977/2006, p. VIII), the Renaissance concept of *disegno* is at the same time drawing *and* designing, linking by the body activity, the mind, the eye and the hand. Moreover, the practice of drawing "trains the architect to think in *representational* terms" (Scheer, 2014, p. 3). The marks displayed on a paper both represent ideas when drawn, and induce new ideas when perceived. So that: "In learning to draw, the architect learns how representation works and gains direct experience of the interplay between an idea and its visible expression." (p. 3).

From the assumption that architects think mainly in representation terms, many researchers try to understand the architectural design processes by studying the impacts of using various representation tools or the representations that the designer[1] produces by using them (Ching, 1990; Carpo, 2001, 2017; Picon, 2010). But, very few architectural researchers consider this topic by starting directly from the functioning of the designer's own thinking. For example, Harry Francis Mallgrave (2011, p. 1) try to "look at the remarkable strides currently being made in neuroscience" and "begin to lengthy process of discerning what this new knowledge might have to say to architects and many others involved in fields of design". Despite the recent use in architecture of artificial neural networks and generative artificial intelligences (Chaillou, 2021), the latest developments in neuroscience focused on the human brain are not yet well integrated into architectural design research.

With a original viewpoint, the present speculative essay intends to illustrate the fact that the representation processes at work in architectural design are primarily the result of the inherent cognitive abilities of the designer's consciousness, rather than the product of a specific medium enabling the interaction between the designer and his environment, between the mental conceptualization of an architectural project and its representation.

The method used is the invalidation of the two main disciplinary myths evoking the direct transfer—with the help of representation tools—of an internal image of the brain onto an external mediation support. Then, starting from the principle that reality is a mental construction, the existence of physiological and cognitive samplings shows that these processes are discontinuous, which does not avoid the designer's consciousness having the impression of processing a continuous flow of thoughts. Finally, the need to discretize reality in order to be able to apprehend the real world in good conditions is expressed in the voluntary choices of architects to create discontinuities in the expression of the images they produce and between the different states of the architectural design process.

1. Mythical mediation of representation tools

Research describes the mechanisms of representation underlying architectural projects by analyzing the representation graphic tools and their alleged impact on the creativity of the designer. When associated with doctrinal contents, most studies in this field contrast one representation tool with another, weighing the positive and negative effects of each *medium* on the designer's creativity.

In architecture schools, the debate about the *media* seems to culminate in the opposition between analog and digital tools. Opposed here for the purposes of reasoning, two authors are often put in front to personify these two positions:

- on one end of the architectural spectrum, the analog practices epitomized by the Finnish architect Juhani Pallasmaa (2009), who asserts that "human consciousness is an embodied consciousness". Since we are "connected with the world through our senses", hence: "Our hands and our whole body possess embodied know-how and wisdom." He furthermore opined that architecture is "the product of the thinking hand". Although his stance on the matter is not well defined, he writes: "What I am especially afraid of is the false precision and the apparent perfection of a digital image, which contrasts with the natural imprecision and hesitation which is characteristic of drawing." (p. 91) According to him, "every meaningful artistic experience" blurs "the boundary between the self and the world" (p. 15). From the analog perspective, the distance between the real world and realities seems thus to fade away thanks to the creative act;.
- on the other end of the spectrum, the *digital* practices, notably promoted by the American architect Greg Lynn (1999, p. 10). Lynn deplores the fact that in conventional design methods "the abstract space of design is conceived as an ideal neutral space of Cartesian coordinates" or "a dimensional space of idealized stasis" (p. 11). Besides, he asserts, "The availability and rapid colonization of architectural design by computer-aided techniques present the discipline with yet another opportunity to both retool and rethink itself as it did with the advent of stereometric projection and perspective." (p. 41) Lynn promotes dynamic 3D modeling, using tools originally designed to create special effects in the film industry or technologies deployed in the nautical and aeronautical industry, to create streamlined prototypes. From the digital perspective, the distance between the real world and realities seems to disappear thanks to the dynamic flows of 3D modeling.

However, this debate is (un-)consciously grounded in our representation constructs, which relies on two antagonistic myths (Claeys, 2018a; 2018b):

1. the myth of *analog drawing* according to which "the natural movement of the hand ensures an intuitive representation process, as an immediate transfer takes place from the mind to the mediating body, and from the body to the representation tool, resulting in a perfect dialogue between the designer and the real world";

[1] The word designer is used here in the broadest sense of the term, it can either refer to a woman or a man, but also to an AI-equipped machine or any hybrid form between machine and human.

2. the myth of *digital drawing* according to which "the immediacy of the commands guarantees the continuity of the representations (working in real time) and the transfer by total immersion guarantees a dialogue with a perfect double of the real world (working at real scale)".

Because of the intentionality of consciousness, the perceptual process from the environment to the brain is more unconscious (without being totally unconscious), while the process of acting on it is more conscious (without being really conscious). Hence, the myths of representation (analog and digital) are rather related to the more conscious process (and which seems therefore more obvious process) of voluntary transfer (by the body itself or by a digital copy of the real world) of an internal representation to an external representation, than to the opposite.

It seems obvious that no designer really believes that he can produce a perfect copy of a mental image on an external medium (analog or digital). But considering that a myth is an imaginary story shared by the members of a group justifying a social practice, the existence of this kind of myth allows a group of designers to justify the preferential use of a representation tool rather than another according to shared values, such as the haptic dimension of a pencil or the fluidity feeling of a 3D animation.

Without denying the sociocultural and professional importance of the existence of these myths including representation tools, the study of design processes can be extended to that of the cognitive abilities of the designer's consciousness. The purpose is to study the cycle including both the (more) conscious process of action and the (less) conscious process of perception. The effects on our perception of all the tools of representation—analog and digital—depend on the cognitive mechanisms affecting the discontinuous flow of internal representations formed by our consciousness. The influence of every—analog or digital—design tool is subjected to the cognitive mechanisms influencing the discontinuous flow of internal representations generated by our consciousness.

According to the French neurologist Lionel Naccache (2020, p. 44), "at the entrance of our perceptual pathway, our retinas receive a continuous flow of visual information" and "the product of our conscious perception is also subjectively structured as a movie-like continuous stream" but, between these two continua, "there is a discrete image sampling mechanism". In the light of these new insights, he postulates the existence of three stages in our visual perception: "objective continuity - discretization of images - perceived subjective continuity".[2]

Having laid the foundations of our perceptual system, we formulate a *first hypothesis* about the analog tools of representation: the discrete sampling process of the mental images perceived by our consciousness dispels the analog myth. Thus, the assumption, according to which a *direct* translation of an internal mental representation into an external concrete representation occurs through the performative act of the body using a representation tool, is erroneous.

By drawing an analogy, the significance of this seemingly trivial hypothesis and the questions it raises about the representation in architectural design become apparent. On the figure below (see Fig. 1), numerous pictures capture the movement of a hand drawing a circle with white chalk on a horizontal surface. This series of pictures was taken by the famous British photographer Eadweard Muybridge (Adams, 2010), using the technique of chronophotography to record successive motions. When looking at these photographs, one could easily imagine an architect drawing a geometric shape on a planar surface. Besides, when the gaze follows the succession of these fragmented pictures, it can easily reconstruct the smooth and continuous motion of the drawing hand. By analogy, this series illustrates that the human perceptual apparatus constitutes a sort of chronophotograph of the real world. When visualizing the scene, our consciousness recreates a *fictional continuity* of a motion on the basis of *discontinuous* sensory data. This stands in absolute contradiction to our natural sense of immediacy and questions the belief in the direct perception of our environment!

Our *second hypothesis* relates to the digital representation tools: in fact, the digitization of information in the form of binary data, the operating speed of digital machines, the dot pitch,[3] and the response time[4] of any screen shatter the digital myth of generating a perfect replication of the real world, which could be perceived in real time. Regardless of whether you are using a computer or a virtual reality headset, if the speed of the device decreases, the displayed image may become blurry or jittering; by the same token, if the response time decreases, image persistence or a drop in the image quality may appear; all of sudden the designer is reminded of the artificial character of the fictional space he is exposed to or in which he is immersed.[5]

Digital devices create the illusion of a smooth-running functioning, but nothing in the operation of digital graphic representation devices is *per se* continuous or smooth. In order to create a graphic illusion on the screen or an immersion in the virtual reality headset, a series of data encoding and decoding processes are necessitated—these processes involve a wide range of components including external data acquisition devices, computer processors, graphics cards (processing images and converting input

[2] The identification of the different brain areas involved in these three stages is the subject of numerous studies, whose outcome may sometimes be contradictory.

[3] Calculated in millimeters, the dot pitch is the shortest distance between two pixels on a screen.

[4] Measured in milliseconds, the response time of a screen relates to the amount of time it takes for a pixel to shift from gray to white to gray again. A long response time may result in the blurring of the image displayed. Response time should not be confused with the display resolution of a monitor, which is the total fixed number of pixels that a display can show.

[5] Graphic performances may vary due to many factors which lie beyond the reach of the designer (driver updates, activation of the hardware acceleration, number of elements displayed, geometric complexity of the shapes drawn, etc.).

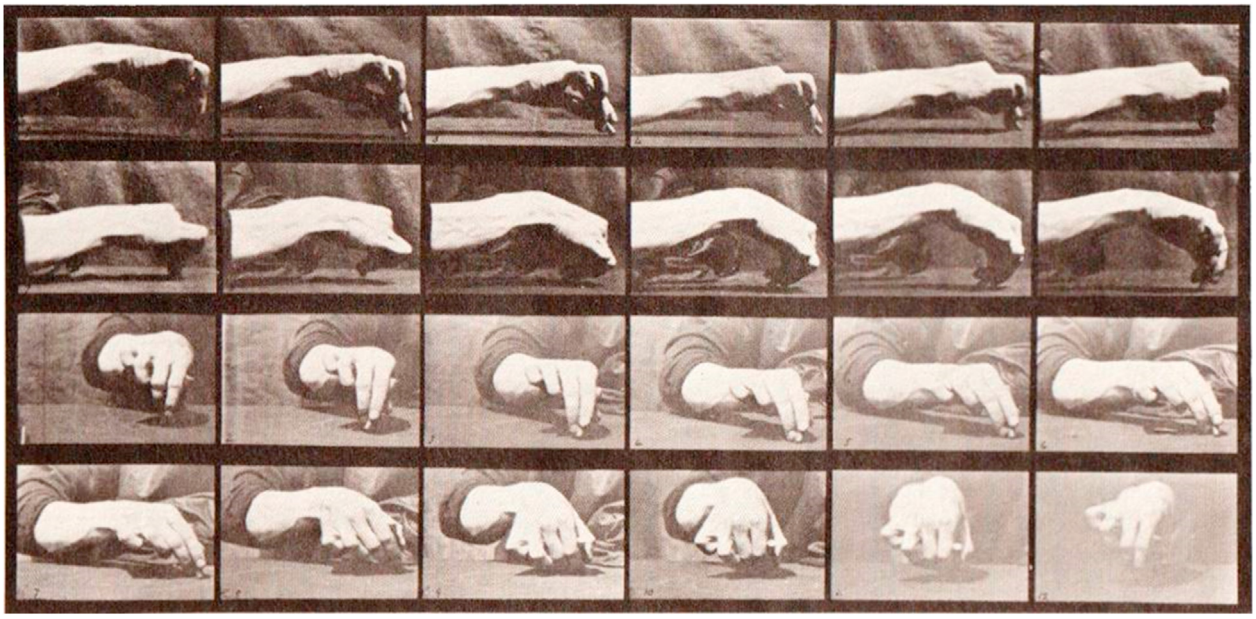

Fig. 1 Eadweard Muybridge, Movement of the hand, drawing a circle in 24 images, *Animal Locomotion*, 5# Males & Females (Draped), Plate 532, 1872—1885.

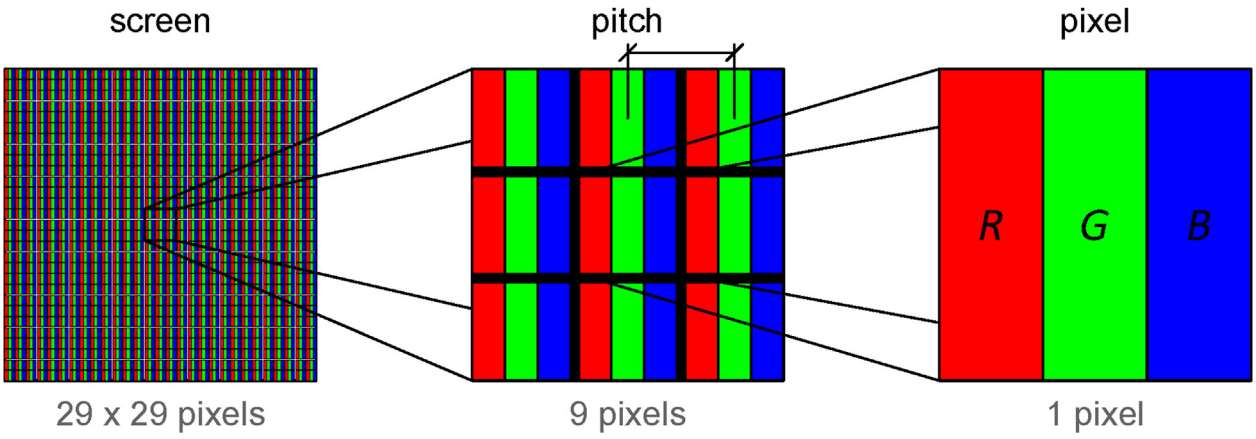

Fig. 2 Display device and pixels (composed of three colors (RGB): red, green, and blue).

signals to make them displayable[6]), external display devices (showing, in turn, the generated images according to their own settings). From the graphics card memory to the monitor, the signal cannot be transmitted at once, the image must undergo multiple scans, a black mesh grid is displayed, then the pixels are filled with color, lighting, and texture (Fig. 2). Finally, this operation is repeated multiple times according to the frame rate and the screen refresh rate—both of which impact the smooth rendering of objects in motion.[7]

The analog and digital myths being dispelled, how can we demonstrate that the fundament upon which these myths rest, namely the continuous stream of thoughts, is

[6] A graphics card consists primarily of a Graphics Processing Unit (GPU), video memory, and a monitor connection. It is capable of creating an image that can be displayed on a screen by translating machine language (binary data) into a signal that can be used by a monitor. Graphics cards house conventional memory in order to interact with the rest of the system, but more importantly, it contains a memory with a sequential access pattern, which stores the images processed by the GPU until they are displayed.

[7] The frame rate of a display—usually expressed in frames per second (FPS) and sometimes in hertz (Hz)—refers to the number of images per second that can be displayed on a screen. Whereas the screen refresh rate—also expressed in hertz (Hz)—corresponds to the number of successive images displayed on the screen per second, that is to say the number of times per second that a screen refreshes the displayed image. In order to a generate a smooth the motion, a minimum of 60 Hz is required for monoscopic graphics, while stereoscopic graphics demand a frame rate of at least 120 Hz.



Fig. 3 Pieter Jansz Saenredam, *Allegory of the cave*, 1604.

nothing more than an illusion, the mere product of physiological and cognitive mechanisms in our consciousness?

2. Reality is a mental construct

A first answer to this question was already formulated in antiquity: The reality on which human beings base all their decisions is a mental construct. In the 5th and 4th centuries BC, Plato presents his famous Allegory of the cave in *The Republic* (2004, Book VII) (Fig. 3). He states that human beings have been imprisoned since childhood in a cave (sensible world), where they can only see shadows cast on the wall, and believe these to be the real world because they only rely on their sensory perceptions to apprehend the truth. However, they need to progressively leave the cave in order to discover the truth and escape the world of appearances. Human beings cannot access the intelligible reality (Ideas) with their eyes, but through their mind's eyes. Therefore, they need to adjust to the sunlight and abandon past habits, yet this journey requires great effort since the sharing of experience and knowledge turns out to be an arduous undertaking: affected by the limits of its perceptual organs, the body becomes the cave of the soul. Symbolically, the soul embarks on an ascent from the sensible world to the intelligible world of Ideas, through a series of stages—a succession of attempts to find out what the real world is.

Assuming reality is a mental construct and that "there is no absolute reality, but only subjective and often contradictory conceptions of reality" (Watzlawick, 1976, p. 140), reality can no longer be considered as "real", nor exist as one singular reality. The consciousness of each individual generates its own reality, which evolves dynamically according to the individual personality and life experiences. The distinction between the *real world* and *realities* is an inherent feature of the human condition; besides, the "*homo doublement sapiens*" (Claeys, 2019a)[8] (re)configures constantly an "augmented real world" (Claeys, 2013).[9] This augmented real world is "a double of the real world co-constructed by human beings—described as

[8] Since in the taxonomic classification of the genus *homo*, "*homo doublement sapiens*" (Claeys, 2019a) became *homo once sapiens*, in other words *homo sapiens sapiens* ironically became *homo sapiens*.

[9] Building on the terms *réalité augmentée* (*AR*) and *réalité virtuelle* (*VR*), we have defined in French the concept of "*réel augmenté*" in order to describe the *natural* cognitive ability of designer to create his individual reality. A conceptual distinction is drawn between *réel* and *réalité(s)* or, in other words, between *réel* (*R*) and *réel augmenté* (*R*′). Unfortunately, the literal translation of these concepts proved to be arduous, since *real* and *réel* seem to convey different meanings in French and in English—the word *real* designating both *réel* and *réalité(s)*. By the same token, we draw on the terms augmented reality (*AR*) et virtual reality (*VR*), in the English translation of this essay, in order to render the concept of *réel* and *réalités* by the following terms: *real world* (*R*) and *augmented real world* (*R*′). We also clearly distinguish the concept of (human) augmented real world from the "augmented real reality" (ARR) coined by the American researcher Ray Kurzweil (2005a), who asserted in a TED Talk that: "By 2010 computers will disappear. They'll be so small, they'll be embedded in our clothing, in our environment. Images will be written directly to our retina, providing full-immersion virtual reality, augmented real reality. We'll be interacting with virtual personalities."

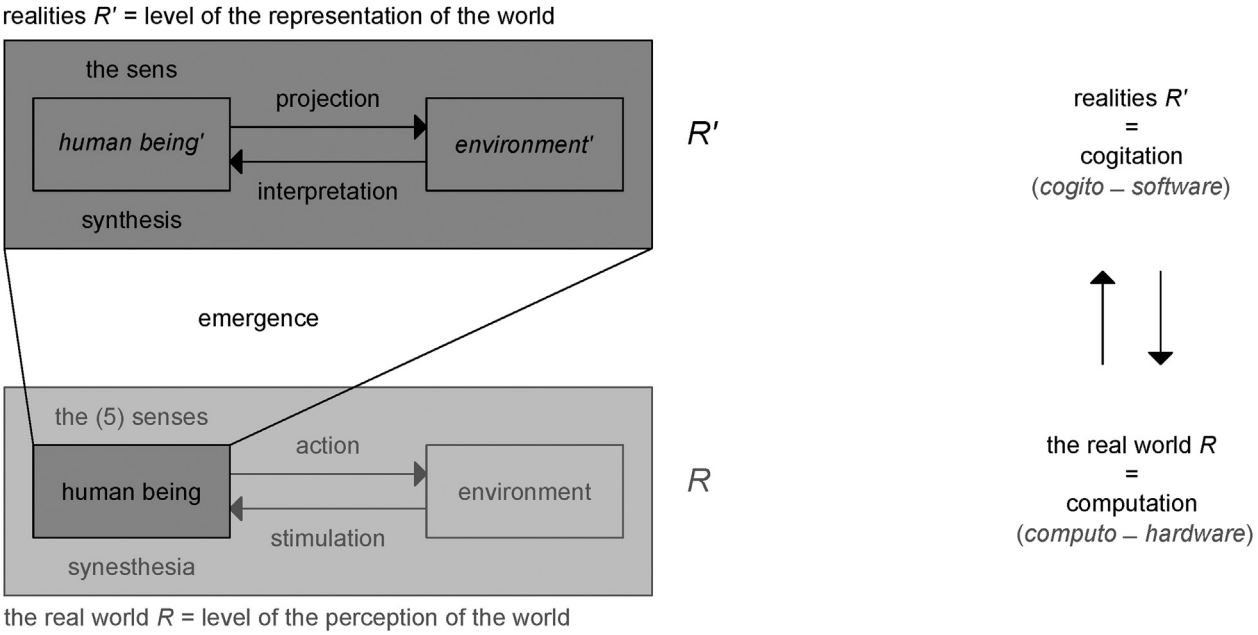

Fig. 4 Damien Claeys, The dynamic emergence of *R'* from the interaction of the body with the context in *R*, 2018.

augmented—against which, impertinently, the real world resists as soon as it is challenged. It contains several partitions—that do not belong to the real world—such as the perceived, conceived, lived, mythical, objective, subjective, intersubjective realities …" (Claeys, 2013). The semi-immersive *augmented reality* (*AR*)—addition of virtual objects into a real environment—, and the immersive *virtual reality* (*VR*)—virtual creation of a real environment[10]—both require technical and material resources (real machines) to superimpose information on the real world, thus creating stimuli that can potentially excite the body's external sensory receptors and, as a result, complete the user's perception of the world. By contrast, the augmented real world is generated directly—naturally—within the human consciousness.

In order to put this process into a nutshell, we propose the following heuristic model (Fig. 4). It features a dynamic loop generating the augmented real world *R'* which emerges from the activity of another dynamic loop in the real world *R*:

- a first stimulation/action loop is at work between the environment and the biological body of human beings. Physical stimuli—*inputs*—can emanate from the outside (the context) or the inside (the body). These stimuli excite the receptors of the sensory organs—both the external receptors (eyes, ears, skin, tongue, nose) and the internal receptors (visceral sensitivity of the organs, skin surface, proprioception of joints and muscles)—by modifying the state of the sensory nerves. After processing the raw inputs, the body triggers the *synesthesia*[11] of the senses to induce a psychological *sensation*;
- a second interpretation/projection loop is active between the mental image of the environment and the perception of the body in relation to this environment. The brain decodes the psychological sensation by initiating a process of external and internal perception (our perception makes the sensation intelligible by attributing a meaning to its trigger); then it operates a *synthesis* of the sometimes-contradictory information stored in its various memories and the information decoded by the perception processes, before deciding on the future course of action.

The first loop embodies the biological substratum—by analogy, a form of *hardware*—which works by "computation"; whereas the second loop is a cognitive emergence—by analogy, a form of *software*—operating by "cogitation" (Morin, 1986). Edgar Morin (1986, pp. 122–123) advocates a broader understanding of the Cartesian *cogito ergo sum,* and enriched this dictum with *cogito ergo computo ergo sum*. He thus emphasizes the existence of two interdependent dialogical logical levels: *computo*—the brain (trait of all living beings) and *cogito*—the mind (trait of all human beings).

There is no complete correspondence between the real world and the plurality of realities, but a dynamic shift

[10] Although virtual reality is always presented as *immersive*, in absolute terms, it can never be entirely immersive, since it is unable to create the "real reality", to quote the words of Ray Kurzweil (2005b).

[11] The term synesthesia stems from the Latin *syn-* (with, union) and *aesthesis* (sensation). It is used here in a figurative sense, as an analogy that can express in a nutshell the connection of the five senses. The real synesthesia is a neurological and involuntary phenomenon resulting from the reaction of sensory receptors to a stimulus coming from outside the biological body.

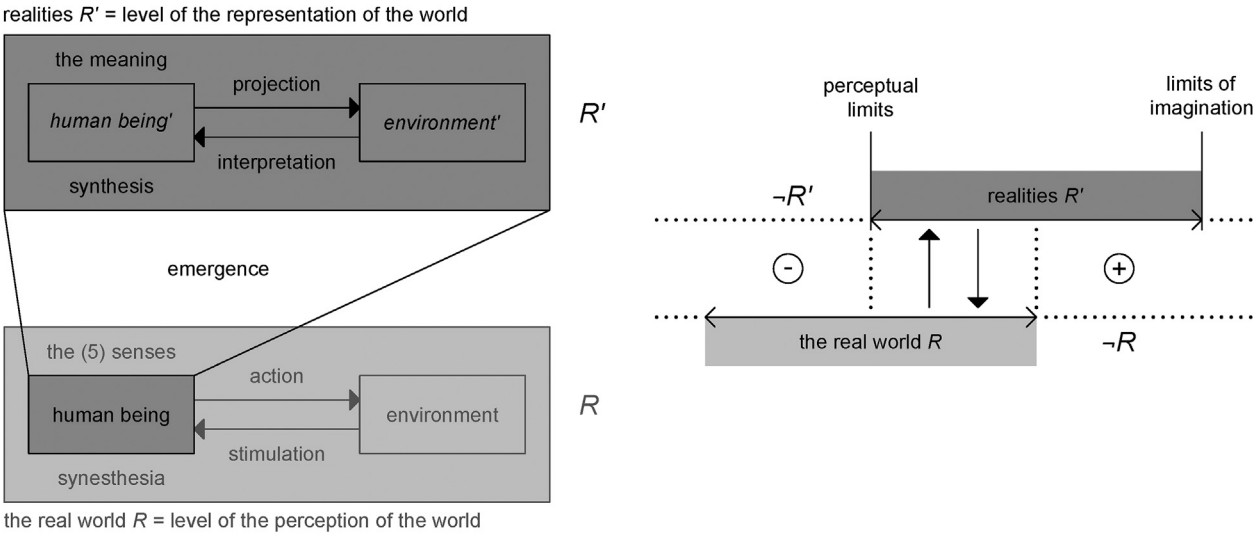

Fig. 5 Damien Claeys, The dynamic shift between *R* and *R*′, 2018.

between *R* and *R*′ (Fig. 5). Indeed, *R*′ is at the same time "*less* than the real world, since the processing of external information in our consciousness is subject to a cognitive limit; and *more* than the real world, given that our consciousness is capable of building an inner world that does not exist in the actual world" (Claeys, 2016). On the one hand, "the abstraction of parts of *R* seems to be inevitable, in order to prevent your mind from going mad"; on the other hand, "this reduction establishes a creative distance with *R*". Moreover, *R* and *R*′ evolve both dynamically, but at different paces. As a result of this divergence, "a double balance sets in—in the less and the more—instilling existential anxiety and a sense of uncertainty, and often rendering the logical structure and limits of *R*′ obsolete". The negative balance corresponds to the "non-augmented real world (¬*R*′): it is composed of the infinite possibilities of the imagination non-activated in *R*′, which are capable of calling into question the integrity of *R*′". By contrast, the positive balance corresponds to the "non-real world (¬*R*): it comprises all the impossibilities of the real world activated in ¬*R*′, which prove to be untenable as soon as *R* resists" (Claeys, 2019a).

Considering that the architect usually imagines in his head something that does not yet exist in that form or not at all in the real world (a building or any other element of the built environment), the main concern for the designer is his cognitive ability to dynamically modify the boundaries and positioning of his augmented real world, by reducing his perceptual limits and extending the boundaries of his imagination. Thus, during an architectural design process, the designer repeatedly confronts *R*′ with *R*—mainly through his representational tools—which allows him to progressively objectify the adaptation of the extent of the interval *R*′ and its presumed correspondence with the interval *R*. In elaborating an architectural project, the architect questions the non-real world (¬*R*) to reveal a possible extension of the real world interval (*R*).

This allows us to draw a first inference: unlike augmented and virtual realities, which require real technical resources, the *(human) augmented real world* is generated *directly* by our consciousness. Regardless of the kind of tool used (analog or digital), none of the representation tools can fill the dynamic gap between realities and the real world. On the other hand, the designer is able to progressively reduce this dynamic gap with the help of representation tools, by playing with the perceptual and creative limits and then questioning the non-real world to reveal potential evolution of the real world.

3. Physiological samplings

At first glance, the speculative scheme portrayed above, according to which the dynamic emergence of *R*′ derives from the interaction between the body and the context in *R* (Fig. 4), appears to suggest that the biological processes of *computation* and the cognitive processes of *cogitation* unfold in a continuous flow over time. But is it really the case?

We suggest here that the *computational* processes at work in the biochemical substratum of human beings are discontinuous.

Internal and external stimuli elicit a sensation, this sensory information is transmitted to a smaller number of neural pathways and then conveyed to the brain, but the conscious mind can solely process a restricted number of bits per second. Moreover, various sources of "noise" can interfere with the transmission of information in the nervous system of the human body.[12] This system consists of a dynamic network of neurons, animated by nerve impulses which travel along neuronal chains via chemicals, the so-called neurotransmitters, thanks to the action potentials generated by neurons. However, according to Thomas Boraud (2015, pp. 130–131):

- at the *molecular* level, slight variations in potential occur;

[12] In information theory, *noise* refers to the set of random disturbances interfering with the information transmission channel and degrading the information by distorting the message.

- at the *synaptic* level, "the release of neurotransmitters by exocytosis follows random processes: a spike will not systematically release the same number of neurotransmitters"[13];
- and at the *network* level, "these phenomena can be amplified by bifurcation processes, especially in networks that rely on populations of excitatory and inhibitory neurons interconnected randomly".[14] The human brain possesses a bifurcation ability based on stochastic and dynamic processes, however, as the process proceeds over time "the bifurcation will take the most likely path" since it requires less energy, "but due to the stochastic nature of the network, it may happen from time to time that it takes another path".

In the light of the above considerations, the transmission of stimuli to the brain must be discontinuous—although this discontinuity eludes us, since our conscious mind systematically erases any trace of the neural activity, so that the apparent continuity of cognitive acts suffers no interference.

Lionel Naccache (2020, p. 11) compares cognition to a form of "inner cinema"—he acknowledges at the same time that the cinematograph's analogy cannot reflect the degree of sophistication and complexity of cognitive mechanisms. Naccache's analogy is enlightening, particularly when one considers that the *magic* of the cinema works thanks to the projection of 24 images per second on a screen.

Without our being aware of this mechanism, the biochemical substratum of the neural system initiates a sampling process, reducing the continuous stream of information transmitted by the sensory organs to a sequence of static images with a frequency of nearly 13 frames per second.[15] The implications of this sampling process are not confined to the realm of perception. Consciousness essentially works at the pace of a "staccato consisting of a succession of discrete states that we perceive as a continuous mental flow" (Naccache, 2020, p. 189).

4. Cognitive samplings

We also suggest that the *cogitation* process occurring in the mind of a designer of architectural projects—a human being like any others—is also discontinuous.

The designer is affected by the phenomenon of "bounded rationality" (Simon, 1957, p. 196): he is immersed in an environment generating a vast amount of information, but his brain cannot process all the incoming stimuli. As a result, the designer has a very *procedural* rationality and uses *routines* to make the majority of his decisions. In addition, the designer must adapt to the "natural complexity" of his environment, which exceeds his cognitive capacities, by means of "simplexity" (Berthoz, 2009)—a neologism concatenating the words *simplicity* and *complexity*. The designer proposes effective solutions that enable him to view issues in a different light and he uses simplifying principles (without distorting the complexity of the real world) to quickly process information before acting (taking into account the past and anticipating the future). Then, the designer reasons like a *statistician* (Dehaene, 2012): he reconstructs a probable reality on the basis of prior experiences (memory) and the ambiguous inputs interpreted by his mind (perception). He infers in a *dynamic* and *optimal* manner the probability of an event, drawing on the results of previous probability assessment of similar events and environmental inputs.

Finally, the designer is hampered by, at least, three further interwoven cognitive limitations, thus avoiding overloading the brain and engendering further uncertainty (Claeys, 2015; see Fig. 6):[16]

- *incompleteness*: in the conception of any architectural project, the designer is well aware of performing a design activity. However, he cannot understand the origin or the mechanisms underlying this cognitive ability. Incompleteness thus stands for the uncertainty arising from the impossibility for the designer to comprehend his own ontological structure;
- *self-reference*: within the same context, different designers would project different representations according to the meaning and significance rooted in their experiences throughout their lifetime. Self-reference refers to the uncertainty associated with the unique structure of the designer's self-referential;
- *indeterminacy*: the designer is not able to process at a glance every single information related to a project, he has to choose a restricted number of data, thereby overlooking some of the information available. He

[13] The following brief description of the brain architecture gives an insight into the complexity of the human nervous system and the neural processes underlying the emergence of thoughts and the mental construction of a human augmented real world *R'*: the human brain contains approximately 10^{11} neurons (100 billion), while a neuron consists of 10^4 connections (10,000), in consequence, the total number of connections in our brain amounts to 10^{15} (1 million billions!).

[14] As stated by Thomas Boraud (2015), a bifurcation describes "a process in which a small change in a physical parameter produces a major change in the organization of the system".

[15] By experimentally inducing the illusion of a wheel rotating backwards (wagon wheel illusion), a first team of researchers (Purves et al., 1996) demonstrated that consciousness essentially constructs its perceptions through the prism of a discrete sampling of visual information. They estimated that the frequency of this discrete processing varies from 2 to 20 images per second. More recently, another research team (VanRullen et al., 2006) experimentally conducted the same experiment, recording in addition the brain activity of the participants with an electroencephalograph, which allowed them to determine that the frequency of projection on the "scene of our consciousness" (Naccache, 2020, p. 30) is about 13 images per second.

[16] This triple uncertainty comes respectively from: (1) Kurt Gödel's incompleteness theorems (1930); (2) Humberto Maturana's and Francisco J. Varela's (1972) autopoiesis theory; (3) Werner Heisenberg's uncertainty principle (1927). These three uncertainties are notably correlated by the means of trialectics, an approach created by Gérard Gigand (2010).

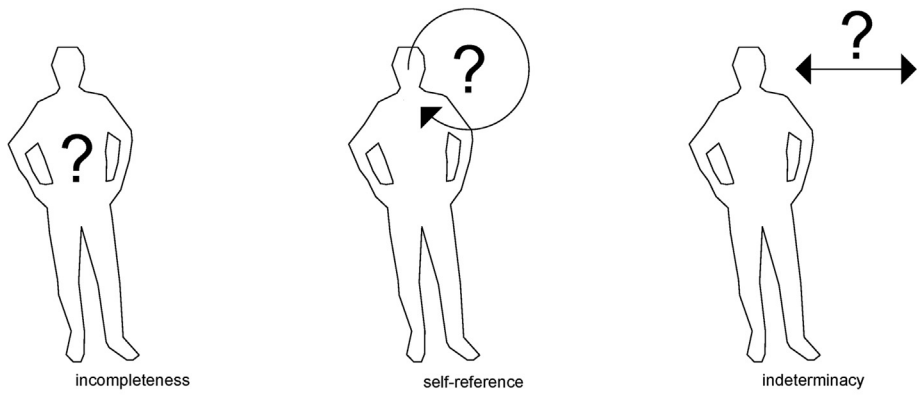

Fig. 6 Damien Claeys, *Triple uncertainty: incompleteness, self-reference and indeterminacy*, 2015.

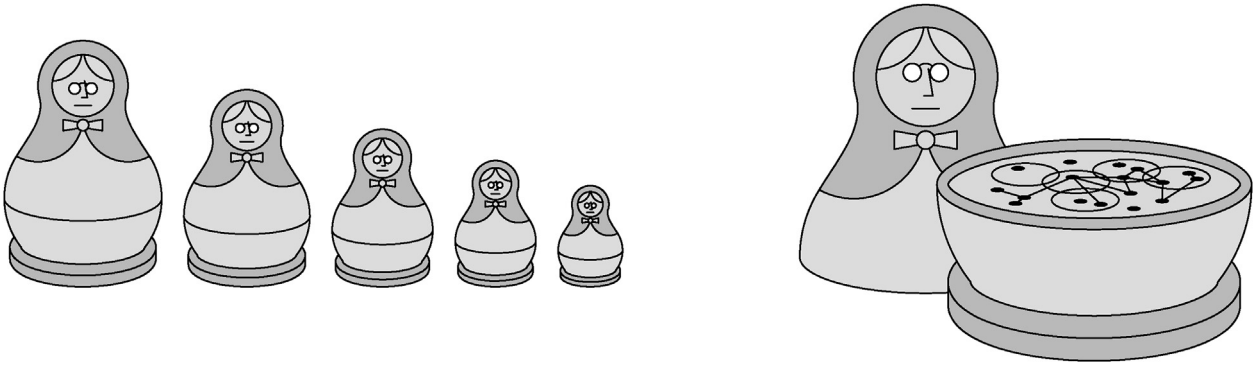

Fig. 7 Damien Claeys, *Russian dolls symbolizing the differences between logical levels*, 2013.

selects the relevant data and organize them. An obvious corollary of this selection is that the data not considered forms a disorder, in other words, it engenders a potential incubator of uncertainty. Indeterminacy relates to the uncertainty associated with the subjective limitations of the data amount considered by the designer.

Subjected to many cognitive limitations, the designer (inter)subjectively constructs his own reality—his human augmented real world *R′*—and structures it into different "levels of reality" (Nicolescu, 2009, pp. 51—52). Between these different levels dwells another discontinuity, since a level consists of "a set of systems invariant to the action of a number of general laws" and "in shifting from one to the other, there is a breach of the laws and a breach of the fundamental concepts". Human beings therefore necessarily graduate the structure of their human augmented real world *R′* and, in particular, the designer must represent the ongoing architecture project at different "logical levels"[17] (Fig. 7). Thus, when designing a project, the choice of the appropriate scale of the drawing consists in "selecting a level of information that is relevant to the level of organization to be investigated" (Lepetit, 1993, p. 127). Moreover, a standardized scale—the one used by practitioners—is relevant if it enables the representation of the coherence of the elements of a given logical level.

Although these both types of processes seem *a priori* fluid, the cognition of human beings *naturally* relies on discontinuous processes—emanating from equally discontinuous biological processes—that are dynamically reconstructed by the consciousness in the form of an augmented real world, creating the illusion of a continuous stream of information. This human augmented real world is structured in different logical levels that are confined to the limits of cogitation (limits, which are constrained by the limits of computation). In order to compensate for its perceptual limits, the consciousness actively navigates between the different levels of information of the augmented real world *R′*, trying thus to render *R* intelligible to reach an optimal decision and subsequently take action with the body in the real world.

That being stated, it allows us to make a second deduction: reality is an (inter)subjective construct, distinct from the real world, and springs from the limits of computation (sensory organs, brain …), as well as those of cogitation ("bounded rationality", simplexity, statistical analysis, incompleteness, self-reference, indeterminacy). Cognitive processes are founded on fundamental discontinuities and reality is structured in different levels of coherence. Navigating between the different levels of information by the use of scales of

[17] A logical level is a (inter)subjective logical space of the augmented real world *R′* containing a set of elements of the same type and/or a set of interrelated elements (Claeys, 2013).

representation enables us to produce different representations of the augmented real world and thereby increase its intelligibility.

5. Discretizing reality to apprehend the real world

Affected by his cognitive limits, the designer apprehends the real world by discretizing it with subliminal processes. Metaphorically, he tries to rise to the knowledge of the real world *as* if he were climbing the rungs of a ladder.

Similarly, in the engraving entitled "L'Allégorie du trait" (Fig. 8) in his book *Premier tome de l'Architecture* (1567—1568, Book III), Philibert de L'Orme glorifies the architect who extricates himself from the dark cave of the Middle Ages to elevate to the splendor of the Renaissance, thanks to his knowledge and his tools. A Latin sentence encloses the engraving "*Artificem doctum discrimina mille morantur, dum celer ad palmam quœrit ab arte viam*"—Philibert de L'Orme provided himself the following translation: "By a thousand sorrows and a thousand impediments, the learned and wise Craftsman will be hindered, if by his Art, knowledge, and instruments, he seeks towards the Palm the passage." (50v-51r) The cave evokes a place of study, contemplation, and solitude; the sharp stones scattered on the ground symbolize difficulties and obstacles; the Palm indicates the goal that the architect must pursue in order to obtain glory, honor, and victory. In the eyes of Philibert de L'Orme, architects must acquire a secret know-how, the *art du trait* practiced by the medieval master masons since the end of the 12th century—then regarded as a mechanical art. As a result, architecture would attain its new status as a liberal art, master its building sites and achieve glory and honor (Potié, 1996). The *art du trait* then became a science of architecture under the patronage of Hermes Trismegistus, whose bust stands above the woodcut between the caduceus, symbolizing the mercurial character of sciences and arts, and the trumpet of fame, that a craftsman can hope to earn thanks to his skills. There is a clear parallel between the depicted scene and the progressive ascent to the different spheres of knowledge epitomized by Plato's allegory of the cave.

Beyond the mythical stories and classical allegories of architectural treatises, extricating oneself step-by-step out of the cave to walk towards the light, climbing the rungs of a ladder, a key idea emerges, the development of structured methods aiming at acquiring knowledge and getting closer to the full consciousness of the real world. These positive representations of the architect—acting by the force of his intellect with his theoretical corpus (treatises) and his representation tools (compass, square, template)—unequivocally demonstrate that architecture is a liberal art whose respectability is guaranteed by the architect's ability to think, to represent, and to project edifices *prior to* their building.

This allows us to make a third deduction: the classical allegories of architectural treatises converging in the allegory of the architect extricating himself progressively out of the cave to elevate towards the light convey this main



Fig. 8 Philibert de L'Orme, Allégorie du trait, *Premier tome de l'Architecture*, Book III, Paris: F. Morel, 1567—1568, 51v.

message: one acquires knowledge with method. Switching between the different logical levels is an incessant attempt to reduce the dynamic discrepancy between the *real world* and *realities* in order to design architectural projects while being fully aware of the interdependent character featuring the phenomena of the real world.

6. Suspended or successive states?

Cognitive discontinuities impact the design process of architectural projects. The word *process* stands for *moving forward, step-by-step, to achieve something*[18]; whereas the word *conception* (design) means *to seize with the mind*.[19] In this light, a *design process* literally represents a step-by-step journey to produce an architectural project by connecting multiple levels of knowledge. The concept of dynamic information processing can be summarized in one

[18] The word *process* comes from the Latin *procedo*—composed of the prefix *pro-* (before, forward, advancement) and the verb *cedere* (to walk, to advance, to turn into, to give way, to succeed, to achieve, to become).

[19] The word *conception* (*design*) stems from the Latin *conception*—composed of the prefix *con-*coming from *cum* (with) and the verb *capere* (to take, to hold, to understand, to perceive, to seize, to captivate…).

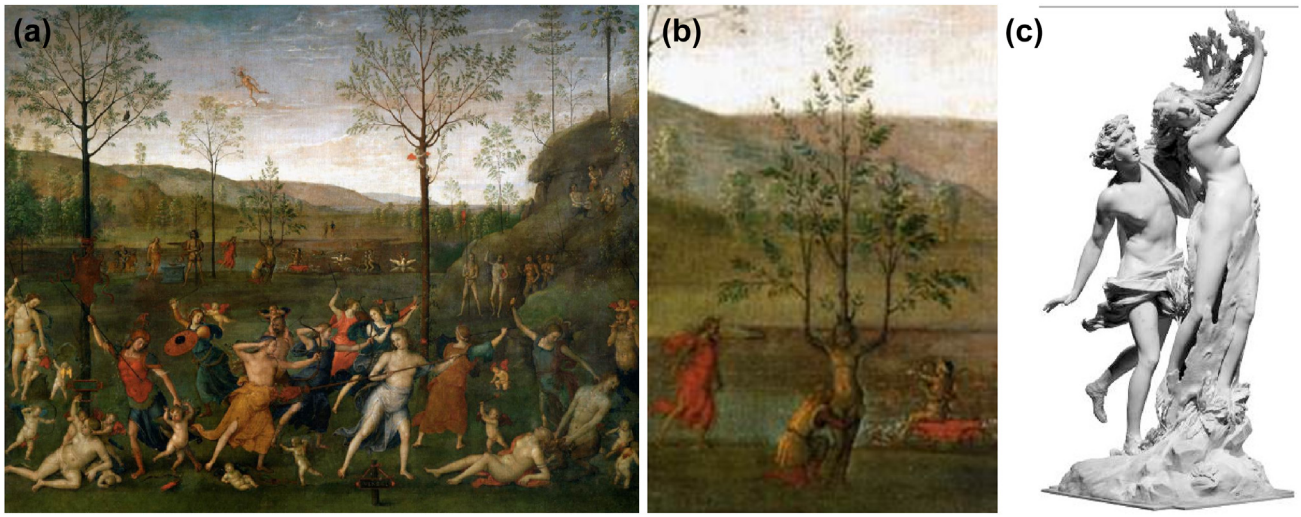

Fig. 9 (a) Perugino, *The Battle Between Love and Chastity*, 1503; (b) Detail of Perugino's painting representing the myth of Daphne and Apollo; (c) Bernini, *Apollo and Daphne*, 1625.

sentence: Within a given context, the architect *directs* an architectural design process to enable the *emergence* of a solution in the form of an architectural project. The designer himself creates a discontinuity in the architectural design process—the progression in the journey—to make it intelligible to his eyes and those of other human beings. He therefore punctuates this process with graphic representations (models, plans, sections, elevations, diagrams, speeches, gestures …).

A love story with a tragic ending illustrates how these discontinuities can be used by the designer. Depicted notably in Ovid's *Metamorphoses* (n.d.; Book I, 452—567) in the 5th century BC, this mythical story features four main characters: the nymph Daphne, the god Apollo (or Phoebus), the god Eros (or Cupid) and the river god Peneus.

Seeking revenge on Apollo—who mocked the small size of Eros's bow and boasted about the grandeur of his own bow and his talent as an archer eclipsing by far the one of the god of love—, Eros fires two arrows simultaneously: a golden one strikes Apollo and makes him fall in love with Daphne; a lead one touches Daphne and instills in her a strong aversion for love. As Apollo follows her tirelessly, Daphne, exhausted, implores her father, Peneus, to help her. Her father hears her plea, and when Apollo is about to touch her hair, Peneus, transforms his daughter into a laurel tree (Ovidius Naso, 1992).[20]

This myth describes a process, a passage from one state to another state, when Daphne, a nymph, turns into a plant, a theme that has been pictured by artists in diverse ways. For example, the *Lotta tra Amore e Castità* [*The Battle of Love and Chastity*] (1503) by Pietro di Cristoforo Vannucci (known as Perugino), commissioned by Isabella d'Este for her *studiolo* in the Ducal Palace in Mantua, depicts a battle in which chastity triumphs over love (Fig. 9a and b). In the background, various mythological scenes, including the myth of Daphne and Apollo, portrayed the victory of chastity—a high moral virtue—over lust. The art of the Renaissance is timeless, it must abstract itself from the world to enter the realm of immutable essences. The story is summarized in a single image, the subject is frozen and successive phases of metamorphosis are captured (Daphne is a nymph up to the neck, then vegetal above the neck). Different stages of the transformation process are represented in successive layers within the same picture.

By contrast, the baroque sculpture *Apollo and Daphne* (1625) by Gian Lorenzo Bernini depicts the myth in a substantially different fashion (Fig. 9c). In a single work, the artist captures a frozen state in the process of metamorphosis, concealing the existence of any past and future states. The movement of the figures is suspended, the bodies are in extension, the faces expressive, and the lines curved. The sculpture is designed to be viewed from every angle. It encapsulates the present moment by suggesting what might have happened before and after this very moment. Baroque art here encompasses the human time, the ephemeral and the appearances through which it lives through eternity.

This brings us to the analysis of the design process, each graphic representation being at the same time:

- an image revealing different definite states of the design process (see Perugino's Renaissance stasis) which creates a discontinuity, a succession of discrete steps directed by distinct operations to achieve a predictable suboptimal result;

[20] But the chaser "who followed, borne on wings of love, permitted her no rest and gained on her, until his warm breath mingled in her hair. Her strength spent, pale and faint, with pleading eyes she gazed upon her father's waves and prayed, 'Help me my father' […] Before her prayer was ended, torpor seized on all her body, and a thin bark closed around her gentle bosom, and her hair became as moving leaves; her arms were changed to waving branches, and her active feet as clinging roots were fastened to the ground—her face was hidden with encircling leaves…" (Ovid, *Metamorphoses*, pp. 61—62).

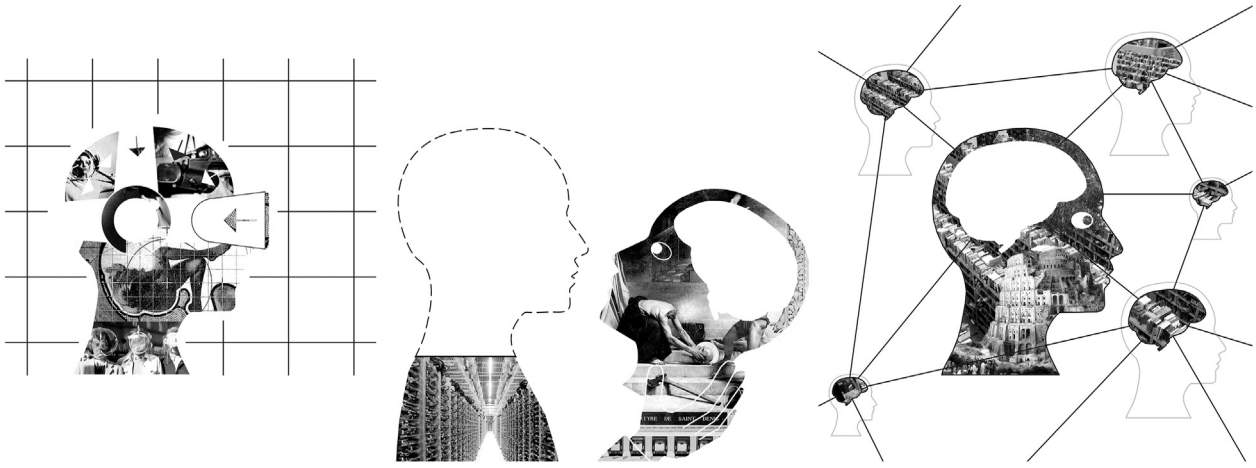

Fig. 10 Damien Claeys, Three portraits/collages of designers (1) immersed (filling the box), (2) externalized (box external to the body) and (3) networked (network of boxes), 2019.

- an image disclosing a suspended state of the process, suggesting the preceding and following states (see Bernini's baroque ecstasy), thus simulating continuity: a continuous movement towards an ideal hoped-for result, that cannot possibly be decomposed into distinct stages.

Regardless of the representation tool used, when designer produces an image at each definite state of the design process, he *intentionally* creates discontinuities by making at least three interdependent choices to set up the partial representation of the architectural project:

- *format/template*: extent/limit of the represented state (paper sheet, screen, cardboard);
- *scope/framing*: object/field of the representation (a layout, a project, a part, a detail);
- *scale*: level of detail of the represented state and associated graphic conventions.

And when designer configures the variation between the different states to simulate the process continuity by the link of each of the produced images, he makes at least three other choices:

- *generator*: initial state associated with the projective goal ahead of the design process;
- *number of iterations*: number of planned (or allowed) states in the process;
- *step*: regular (or not) temporal gap between the different represented states.

This allows us to make a fourth deduction: in the dynamic and continuous process of architectural design, the designer arbitrarily creates discontinuities (from a generator, he induces a succession of iterations, spaced by steps) by the use of graphic representations (at different formats, scopes and scales) in order to make his architectural project intelligible. Graphic representations are created by different tools (analog and digital) and they deceive the designer's senses: this is perfectly normal, it is part of their inherent functions!

7. Integrating mediational discontinuity

To conclude, it is worth taking another look at the Muybridge plate presented in the introduction showing successive phases of a hand drawing a circle, a hand in motion (Fig. 1). Shall we as well consider our sensory apparatus—the sensory apparatus of architectural project designers—as a form of chronophotograph capturing the real world?

As illustrated above, our human realities correspond to mental constructs; moreover, our consciousness naturally creates an augmented real world, whose structure is enlivened by the potential activation of an infinite number of imaginary possibilities and by real impossibilities. Irrespective of the representation tool used, the dynamic gap between the real world and our lived realities is unavoidable. The limitations of the computation and cogitation processes in our body substratum and our cognitive activity render any representation activity discontinuous. In order to prevent our "bounded rationality" from descending into madness, our brain reconstructs a fictional continuity of the phenomena we imagine on the basis of discontinuous sensory data. By analogy, our perceptual apparatus constitutes indeed a form of chronophotograph of the real world. Distortions of representation are inherent to the human condition and are not fundamentally linked to the use of a specific type of representation tool.

Regardless of the use of analog or digital tools—be it a pencil, a model, a computer or a headset—the designer's representation process in architecture cannot thus entirely close the gap between the real world and realities. Therefore, the myths of analog and digital drawing, are imaginary narratives to unite members of a profession and they generate emulation to advance knowledge about representation processes. But, they both rest on the implicit hypothesis of the existence of an immediate transformation of a mental image—from the consciousness—into a planar external representation (direct transfer from reality to the real world) or of a perfect copy of a mental image into an enveloping representation (from reality to a real simulation).

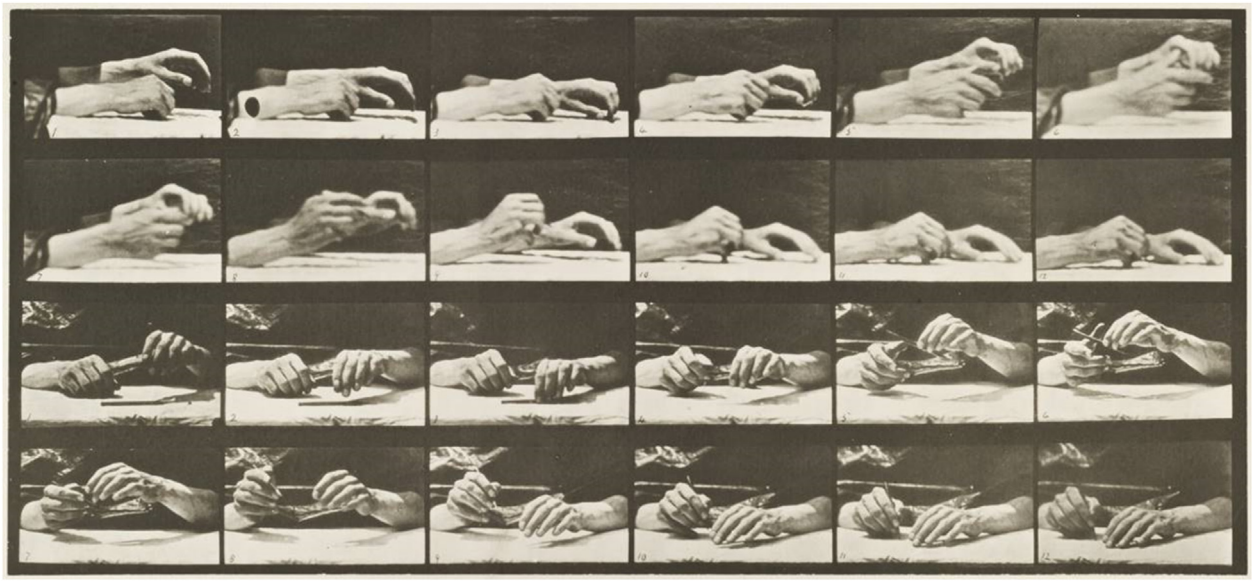

Fig. 11 Eadweard Muybridge, Movement of the hand; hands changing pencil, *Animal Locomotion*, 5# Males & Females (Draped), Plate 536, 1884—1886.

Mental images of the project are rarely clear in the designer's consciousness, unlike the representation tools that can produce accurate images. The challenge is therefore to understand how to transpose a succession of imprecise mental images with the help of successive use of representation tools, in the hope of iteratively refining the project during the design process. The choice of representation tools must therefore be variable according to the designer's skills in using them and the state of the design process and the discretization capacities of the chosen tool. With the advent of digital tools in architectural representation, each architect may potentially become an "immersed", "externalized" and "networked" designer (Fig. 10), designers must therefore "critically hybridize the abstract profiles with which they identify their design practices" (Claeys, 2019b) in an attempt to avoid the natural biases of the representation process and the "programmed obsolescence" of their profession (Claeys, 2021).

Fortunately, we have already developed this awareness of the discontinuity of our representations, since our self-reflexivity is able to try to mislead our own brain and thwart this imperceptible natural discretization of the real world. As soon as our realities are structured on the basis of several levels of coherence, we can stimulate the movements between these different levels of organization with the help of different scales of representations in order to make the real world as intelligible as possible, in an attempt to reduce the dynamic gap between the real world and realities.

Below, another Muybridge's plate is displayed (Fig. 11), in this sequence, the pencil moves from one hand the other. We can imagine someone passing a pencil from one hand to the other, or someone changing his pencil.

By analogy, this sequence demonstrates that in order to represent the world, one must be able, as an observer, to change or multiply one's *viewpoints* and observation *tools*.

Indeed, every designer of architectural projects must be able to combine formats, framing, and scales of representation to determine the rhythm he gives to the process of representation, to evaluate the type of external representations to be produced (models, plans, renderings, sketches …), to parameterize the routes between the different logical levels springing from the artificially established *scala projectus*, in order to apprehend the real world as accurately as possible. The designer must seek complementarities between the different types of observation tools to improve the numerous coding/decoding processes of the partial data available to him. He must alternate the different *media* of representation at his disposal to enrich his knowledge of the project he is designing.

Finally, there is no reason why the pencil should not be passed from one's hand to the hand of another person. The accumulation of experience with different *media* of representation, in assumed collaborative design processes, gives way to the multiplication of points of view on the architectural project being designed. Although co-designing obviously does not allow the complete *objectivity* of the project representation (the distance between the real world and realities may be infinitesimal, yet the gap remains), it does provide a partial *objectification* towards which to strive.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Adams, H.-C., 2010. Eadweard Muybridge: The Human and Animal Locomotion Photographs. Taschen, Cologne.
Alberti, L.B., 1442-1452. De Re Aedificatoria Libri Decem. Vatican.
Berthoz, A., 2009. La Simplexité. Odile Jacob, Paris.
Boraud, T., 2015. Matière à décision. Biblis. CNRS, Paris.

Carpo, M., 2017. The Second Digital Turn: Design beyond Intelligence, Writing Architecture. MIT Press, Cambridge, MA.
Carpo, M., 2001. Architecture in the Age of Printing: Orality, Writing, Typography, and Printed Images in the History of Architectural Theory. MIT Press, Cambridge, MA.
Chaillou, S., 2021. L'intelligence artificielle au service de l'architecture. Le Moniteur, Paris.
Ching, F.D.K., 1990. Drawing, a Creative Process. Van Nostrand Reinhold, New York, NY.
Claeys, D., 2021. Entre cogitation et computation : comment déjouer l'obsolescence programmée de l'architecte? In: Claeys, D. (Ed.), Anticrise architecturale : analyse d'une discipline immergée dans un monde numérique. Presses universitaires de Louvain, Louvain-la-Neuve, pp. 157—176.
Claeys, D., 2019a. Pour une co-conception écosystémique de l'architecture à l'ère de l'anthropocène. In: Roose, M.-R. (Ed.), Penser à partir de l'architecture: Poétique, technique, éthique. Presses universitaires de Louvain, Louvain-la-Neuve.
Claeys, D., 2019b. Trois figures architecturales post 1969: les concepteurs immergé, externalisé et en réseau. Lieuxdits 17, 25—35.
Claeys, D., 2018a. Discontinuités des processus de conception architecturale : crises de la représentation. Acta Eur. Syst. 8, 19—36.
Claeys, D., 2018b. De la crise de l'échelle en conception architecturale à l'opération fondamentale de mise à l'échelle du réel.
Claeys, D., 2016. Le fantasme du démiurge: l'architecte soumis à la tentation du pouvoir. Acta Eur. Syst. 6, 11—24.
Claeys, D., 2015. Concevoir un projet d'architecture: calmer les certitudes, gérer l'incertitude. Lieuxdits 9, 20—23.
Claeys, D., 2013. Architecture & complexité : un modèle systémique du processus de (co)conception qui *vise* l'architecture. Presses universitaires de Louvain, Louvain-la-Neuve.
Dehaene, S., 2012. Le cerveau statisticien : La révolution bayésienne en sciences cognitives. In: Chaire de Psychologie Cognitive et Expérimentale. Presented at the Cycle de cours 2011-2012 au Collège de France.
Gigand, G., 2010. Se cultiver en complexité: la trialectique, un outil transdisciplinaire, Savoir communiquer. Synthèse. Chronique sociale, Lyon.
Gödel, K., 1930. Einige metamathematische Resultate über Entscheidungsdefinitheit und Widerspruchsfreiheit. In: Anz. Akad. Wiss. 67, pp. 214—215.
Heisenberg, W., 1927. Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. Z. Phys. 43, 172—198.
Kurzweil, R., 2005a. The Accelerating Power of Technology, TED Conference. Montorey, CA.
Kurzweil, R., 2005b. The Singularity Is Near: when Humans Transcend Biology. Viking.
Le Moigne, J.-L., 1977/2006. La théorie du système général: Théorie de la modélisation. Presses universitaires de France, Paris.
Lepetit, B., 1993. Architecture, géographie, histoire: usages de l'échelle. Genèses. Sciences sociales et histoire 13, 118—138.
L'Orme, P., 1567-1568. Premier tome de l'Architecture. F. Morel, Paris.
Lynn, G., 1999. Animate Form. Princeton Architectural Press, New York, NY.
Mallgrave, H.F., 2011. The Architect's Brain: Neuroscience, Creativity, and Architecture. Wiley-Blackwell, Chichester, UK.
Maturana, H.R., Varela, F.J., 1972. De máquinas y seres vivos, Autopoiesis: La organización de lo vivo. Editorial Universitaria, Santagio.
Morin, E., 1986. La méthode 3: la connaissance de la connaissance. Seuil, Paris.
Naccache, L., 2020. Le cinéma intérieur: projection privée au coeur de la conscience. Odile Jacob, Paris.
Nicolescu, B., 2009. Qu'est-ce que la réalité? Réflexions autour de l'œuvre de Stéphane Lupasco. Liber, Montréal.
Ovidius Naso, P., 1992. Les Métamorphoses. Gallimard, Paris.
Pallasmaa, J., 2009. The Thinking Hand: Existential and Embodied Wisdom in Architecture, AD Primers. John Wiley & Sons, Chichester, UK.
Picon, A., 2010. Digital Culture in Architecture: An Introduction for the Design Professions. Birkhäuser, Basel.
Platon, 2004. La république. Flammarion, Paris.
Potié, P., 1996. Philibert de L'Orme: figures de la pensée constructive. Parenthèses, Marseille.
Purves, D., Paydarfar, J.A., Andrews, T.J., 1996. The wagon wheel illusion in movies and reality. Proc. Natl. Acad. Sci. USA 93, 3693—3697.
Scheer, D.R., 2014. The Death of Drawing: Architecture in the Age of Simulation. Routledge, London ; New York.
Simon, H.A., 1957. Models of Man: Social and Rational; Mathematical Essays on Rational Human Behavior in Society Setting. Wiley, New York, NY.
VanRullen, R., Reddy, L., Koch, C., 2006. The continuous wagon wheel illusion is associated with changes in electroencephalogram power at 13 Hz. J. Neurosci. 26, 502—507.
Watzlawick, P., 1976. How Real Is Real? Confusion, Disinformation, Communication. Random House, New York, NY.