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VARIABILITY

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Variability

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The 15th issue of the ArchiDoct e-journal addresses the concept of **variability**; a concept that is closely related to those of difference and change. While constant change is a persistent characteristic of current societies and cultures, it is by no means a property that we first encounter in the 21st century. Already since the 1960s theories of difference – more often than not within a post-structuralist framework – started to emerge and shifted our focus from the concept of 'being' towards that of 'becoming'. The modern idea of certainty, supported by all kinds of standards, was juxtaposed with postmodern processes of fluidity and constant transformation.

However, it was indeed the 21st century and the almost total dominance of digital media that – at least on the surface – brought those ideas into everyday practice. Architecture of course is also affect by that process. One can therefore initially identify three main concepts in relation to the production of architectural form within the context of the fluidity described above.

The first is that of the **Variable**: Architectural form is produced through the manipulation of variables. Specific properties are identified and then varied in order for different results to arise. The second is **Variation**: architectural form is produced through constant transformation of an initial form, generating this way an extended family of forms. Variation can be smooth or uneven. The third concept if that of **Variety**: Architectural form is produced having in mind the generation of different spatial conditions. The architect envisions specific situations and manipulates form in order to accommodate them.

All those three modes of operation however, when used separately, function as a repetition of different, existing modes of architectural production. Variations echo ideas of typology where specific characteristics are (pre)defined and the new is created through their alteration. Variables advocate a more scientific approach where architecture is understood as a more or less objective field and can be analyzed accordingly. They result in situations where form is produced within a very limited range

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of predefined solutions. Varieties represent the idea of the architect as an auteur, where his mastery allow him to generate form and authorize it at the same time.
Variability on the other hand – while closely related to all three, both etymologically and conceptually – implies a slightly different property: that of *the possibility to be different in an unpredictable way*. More specifically, it represents the claim to difference and change through almost illogical and definitely difficult to control actions. While a property that in many cases was typically undesirable – precisely because of its unpredictability – variability might be the key to a new approach to the production of architectural form. One that combines the properties of Variations, Variables and Varieties and moves beyond the standards and the uniformity ultimately imposed by digital technologies though them.

The 15th issue of ArchDOCT therefore, features essays that examine the concepts of change and difference in all three initial versions of Varia-; and most importantly in their combination in variability.

In that context, the good practice example has the title "**Variability: Architecture and its Fight with Chaos and Opinion**". It explores the theoretical background of the concept of Variability and expands on the ideas set forth in this editorial. It starts with the work of Deleuze and Guattari in order to make clear how the concepts of variation, variety and variable can be related with different modes of production of subjectivity – different disciplines – and how architecture and design can be at the intersection of those three. It claims that if architecture needs to move beyond the homogeneity created by the use of digital tools, it has to embrace variability and its chaotic properties and reinvent itself.

The first essay by **Constantinos Miltiadis,** from the Departments of Design and Architecture of Aalto University in Helsinki, is entitled "**Oblivious to Gravity: Virtual Architecture between disciplinary dead ends and complex intersections**". It explores the domain of Virtual Architecture through the lens that is formed by the fact that in its case digital media are means for both

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designing and experiencing space. It forms a theoretical discourse of key issues behind Virtual Architecture with a focus on aesthetics while at the same time it underlines the fundamentally transdisciplinary nature of all relative research. Variability in this case, is a result of the replacement of the Cartesian-Euclidean understanding of space by the spatiotemporal model of the Riemannian non-Euclidean geometry.

The second essay by **Chrissa Papasarantou**, from the Department of Architecture, University of Thessaly, has the title "**The notion of Mixed Embodied Presence as a variable for generating mixed environments**". It concerns the design and the experience of mixed reality and mixed environments. The concept of Virtuality is again at the heart of the research and of the text. It proposes the concept of Mixed Embodied Presence as a new concept that would allow us the better understand how mixed experiences are formed, through a mainly corporeal approach. Variability emerges inevitably through the physical interaction. The presence of the human body at the center of the experience introduces unpredictability that ultimately affect the production and design of mixed spaces.

The third essay by **Ioannis Mirtsopoulos** and **Corentin Fivet**, from the Structural Xploration Lab (SXL), Ecole polytechnique fédérale de Lausanne (EPFL), Switzerland, has the title "**Design space exploration through force-based grammar rule**". It transfers our interest in form-finding techniques that concern the design of spatial structural systems. It proposes a design framework that goes beyond computational tools as a mere digitalization of existing processes that through force-based grammar rules can produce structural systems that go beyond any know structural typologies – and beyond typologies at large. The research illustrates that variability can be produced when a ruled-based approach is used instead of a variable-based one.

The fourth essay by **Sergio Garcia-Gasco Lominchar**, from the Universitat Politècnica de Valencia, comes under the title "**Affonso Eduardo Reidy and the Aterro Do Flamengo Pavilions.**

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Structural Concrete Shells During Modern Revisionism". Like the previous paper, it also concerns structural variability, but this time in a historical context. More specifically through the study of the last three works built by Affonso Eduardo Reidy, designed in 1962 for the urban project of Aterro do Flamengo, in Rio de Janeiro. By displaying a revisionist attitude towards modernity and modern architecture the three examples make clear that structural variability and exploration is independent of the tools used and frame late modern architecture in a different context from the one that we are used to.

Finally, the fifth essay by **Olympia Ardavani**, from the Hellenic Open University, has the title "**Alternatives to artificial lighting: Varying patterns of bio-light in architecture**". It returns to the immaterial qualities that were explored by the first two essays, only that this time the focus in on light. It is based on the fundamental hypothesis that light contains variability by default. In other words, light possesses some of the 'chaotic' properties of variability. Those properties can be enhanced and taken to a new level through the genetic modification of plants in order to become able to emit light. The living and the non-living, the material and the immaterial, fuse in order to produce new, hybrid lighting environments.

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Variability: Architecture and its Fight against Chaos and Opinion

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Abstract

Digital tools have dominated architectural production for the last 20 years. However, the initial euphoria that accompanied digital design experimentation, and which understood digital media as a liberating force that would free architecture from the bounds that were imposed by extreme standardization and the principles of modern architecture, did not keep its promise. Architecture did not escape externally imposed standards; on the contrary, as the relationship of architecture to digital media is maturing we start to realize that digital tools and protocols are based on even stricter, no-tolerance standards that inevitably produce an undifferentiated homogeneity.

In that context, variability becomes a key concept that can help us (re)invent architecture's unpredictability. Variability, a property that we usually try to eliminate in our attempt to control every aspect of the design process can provide the tools that will help architecture regain it's mythical stature by resisting command and uniformity.

Keywords

Variabilty; Variation; Variaty; Variable

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Digital media and tools were initially welcomed in architectural design as a liberating force. As the means that would free architecture from standardized modes of production – a desire made apparent with the term *non-standard architecture* that was used to describe experimental processes in design through digital media at the early '00s (Migayrou, 2003) – and that would take us away from mass production towards mass customization where each item would be different; a dream of a condition where each product would *vary*. However, common practice with digital tools showed that that was not necessarily the case.

Greg Lynn (cited in Cramer & Guiney, 2000) was already commenting while looking back at the results of the first experiments with digital design at Columbia University that

> (t)hey all looked the same. It's the technology. We were figuring out the limitations of the software. It happened in every other industry: for a while all cars looked like Taurus. It'd be naïve to think it wouldn't happen in architecture.

In other words, Greg Lynn identifies a homogeneity in the produced results which he attributes to the technology, and more specifically, to the unfamiliarity of the architects with that specific technology. However, the development of the relationship between architecture and digital media proved that his observation was not only true for those first experiments, but was also *persistent*. That is to say that homogeneity didn't change as the relationship of digital media and architecture was maturing. On the contrary, as concepts like performance and optimization became more and more related with digital design, homogeneity was constantly enhanced. After all, it was the technology that was responsible. However, not because of the unfamiliarity of the architects with that technology but because of the very nature of that same technology (Gourdoukis, 2019; 2018).

Variability therefore, becomes of interest in that context. As the means to counter the sameness and the homogeneity produced by digital design tools.

Variations, Varieties, Variables

In 1991, Gilles Deleuze and Felix Guattari published the last book that they wrote together[1]. '*What is Philosophy?*' (Deleuze & Guattari, 1994), which was bound to be the last book for both of them, features an extensive examination of philosophy, art and science as the three main modes of thought – the three main vehicles for the production of subjectivity. At the same time 'What is philosophy?' serves as a summary of their work; a distillation of some of their main concepts presented

1. In fact, the book was mostly written by Deleuze: "*Partly because of Guattari's depression, the last book bearing both their names, WhatIs Philosophy? (1991), was written by Deleuze. But Guattari's signature was there for a reason: as a friend said, 'Guattari is in it throughout, in the way that aspirin in water is everywhere.'*" (Shatz, 2010)

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perhaps in their most clear and simple version. In the context of the current discussion, this work has to offer some very useful insights in relation to variability.

In the conclusion of the book, under the title '*From chaos to the brain*', the authors present a very vivid analogy of the way they think of the world and the functions that philosophy, art and science fulfil within it: The world they claim, is made out of chaos. Out of '*infinite variabilities*' against which people need just a little order as the means of protection. They create therefore rules – 'resemblance, contiguity, casualty' – that will keep things together and will impose the desired order. All those rules form our opinions, 'a sort of 'umbrella', which protects us from chaos' (Deleuze & Guattari, 1994). Our world is able to exist under this protective umbrella, seemingly regulated but while chaos is still all around – even if hidden from 'plain view'. However, while that umbrella might be necessary – or better: unavoidable – in order for civilization to exist, Deleuze and Guattari insist that, contrary to what one might assume, the aim of philosophy, art and science is not to help us create the rules that will bring some order into chaos. Philosophy, art and science are not – or should not be – part of the fabric that creates the protective umbrella.

On the contrary, 'philosophy, art and science require more: they cast planes over the chaos' (Deleuze & Guattari, 1994). Their function and ultimate aim is to create holes in the umbrella in order to let some chaos in. The philosopher, the artist and the scientist need to delve into chaos, fight with it and return with what each one of them is able to. The philosopher therefore returns from chaos with *variations*. Variations that derive from the variability of the chaos, and they are therefore still infinite, however they are connected to each other through a plane of immanence. The artist on the other hand, returns with *varieties*. Different sensations that are connected together through a plane of composition. Finally, the scientist brings back from chaos *variables*. Variables allow fluctuation while they eliminate any unwanted, unpredictable variability. They are able to create functions because they are related to each other through a plane of reference. Consequently, philosophy aims at the formation of concepts, art at the formation of sensations and science at the function of knowledge. Accordingly, through philosophy we arrive at concepts and conceptual personae, through art at sensations and aesthetic figures and through science at figures and partial observers (Deleuze & Guattari, 1994).

For Deleuze and Guattari therefore, philosophy, art and science are fundamentally creative disciplines. Each one of them must disrupt established ways of thinking and operating in order to generate something new. They exist not in order to provide safety against chaos, not in order to generate rigid sets of rules that would create a closed system to exist within. On the contrary they exist in order to constantly challenge the certainty of opinion that functions as an almost religious Urdoxa.

One can argue that architecture stand between those three major disciplines. As an amalgamation of science, art and philosophy, is therefore more that all other disciplines an act that deal with variability. The architect too must cross the chaos and return with some variability that will somehow combine variations, varieties and variables. And while recent processes in architecture have dealt separately with all three of them, they were doing so in a mimetic way. Architecture through a more scientific approach is looking at variables, through a more artistic approach at varieties and through a somewhat more philosophical approach at variations. But in all three cases it was trying to keep out the unpredictability that variability implies. Variations, varieties and variable are for architecture the means to control and command. The vehicle that will help the architect to tame the savage variability that he/she has to encounter.

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From Weather Prediction to Command and Autonomy

However, when Deleuze and Guattari argue that the role of philosophy, art and science – and if we try to extend it, of architecture too – is to be always creative and expand our ways of thinking and understanding, they don't actually imply that this is what those creative disciplines usually do. The play with variability in order to produce respectively variation, variety and variables, is what happens when philosophers, artists and scientists operate in extraordinary ways and push the envelop of what we understand – that is when they manage to create a hole in the umbrella and let some chaos in. 'Then comes the crowd of imitators who repair the umbrella with something vaguely resembling the vision, and the crowd of commentators who patch over the rent with opinions: communication' (Deleuze & Guattari, 1994). So the real enemy of the philosopher, of the artist and of the scientist – and we shall add again: of the architect – is not chaos itself; but rather the imitator and most importantly the commentator: 'It is as if the struggle against chaos does not take place without an affinity with the enemy, because another struggle develops and takes on more importance – the struggle against opinion, which claims to protect us against chaos itself' (Deleuze & Guattari, 1994). It is therefore the umbrella that all creative disciplines have to fight against. All the pre-established sets of rules and opinions that claim to provide safety and explain the order of things.

Therefore, a simple observation on philosophical, artistic and scientific practices is enough to convince us that not all philosophy, art and science operate in the ideal way that Deleuze and Guattari describe. On the contrary, more often than not they seem to operate in order to enforce and confirm already established concepts, sensations and knowledge. Let us consider therefore an example from the field of science that illustrates clearly how one can follow the direction of dealing with chaos and returning back from it or choose instead to support existing causes and create closed systems that always verify themselves. [2]

2. Thomas S. Kuhn has analyzed extensively how most scientific work is in fact just trying to reconfirm the rules that define its field of refence instead of trying to move beyond that (Kuhn, 1962).

The story begins shortly after the end of World War II, when a team of mathematicians and meteorologists under the instructions of John von Neumann started to work on a method for numerical weather prediction. Weather forecasting up to that point was based on a more empirical method. The idea for a mathematical model for the prediction of the weather was initiated by British scientist Lewis Fry Richardson in 1922, who proposed that mathematical models can be used in order to forecast the weather. While his attempts failed to provide results, they formed the starting point for the work of Von Neumann and his team that was to follow.

While work on the project was up to a certain extent a cover up for the work conducted in parallel in relation to thermonuclear power and

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weapons, von Neumann seemed to genuinely believe in the importance of the project as he was seeing in the ability to predict and control the weather the possibility for a more efficient weapon. In a note containing the institute's proposal to the navy he was writing: 'the most constructive schemes for climate control would have to be based on insights and techniques that would also lend themselves to forms of climatic warfare as yet unimagined' (cited in Dyson, 2012). He was also genuinely convinced that weather and climate could and would be predicted and controlled as he was confidently noting: 'The part that is stable we are going to predict. And the part that is unstable we are going to control' (cited in Dyson, 2012). As mathematical models for weather prediction required a very large number of computations, the infrastructure of the Institute, including the ENIAC, was used to that end. Slowly the models started to deliver results as to short term prediction. Initial calculations took 24 hours in order to make a prediction for one day. In other words, calculations were predicting the weather at the same time that is was developing. Soon enough however, prediction times were shortened and the research team managed to develop a model that predicted the weather accurately enough for a period of 40 days, after which it was becoming unstable.

At the same time, Norbert Wiener, aware of the project on weather prediction, was insisting that forecasting of weather and climate in a long term timeframe through the use of physics and mathematics was impossible, as the atmosphere, he was claiming, was not a deterministic system (Wiener, 1956). Jule Charney, a member of Von Neumann's team recalls: 'I remember at that time receiving reports from that Norbert Wiener had regarded von Neumann and [me] as practically gonifs – thieves. That we were trying to mislead the whole world in thinking that one could make weather predictions as a deterministic problem. And I think in some fundamental way Wiener was probably right' (cited in Dyson, 2012).

Today it has be proven that weather prediction while possible in short term, is impossible in medium term[3], for a time greater than approximately 30 days. While prediction of climate in a long term is still under debate, it looks like Wiener was closer to the understanding of atmospheric phenomena. What is of importance here however, is not necessarily who was right and who was wrong, but the very different approaches between the two men, von Neumann and Wiener. A difference in approach that underlined what proved to be of much greater importance for today's society: the development of the digital computer.

Francisco Varela has shown (1989)[4] that the different approach between von Neumann and Wiener underlines the whole history of the development of the digital computer going all the way back to its beginning. He dates the beginning of this story in March 1946 and in the now famous 'Macy Conference on Cybernetics', which gathered most of the top

3. The unpredictability of the atmosphere was proved by Edward Lorenz, shortly after von Neumann's death.

4. French translation of: Francisco J. Varela, Principles of Biological Autonomy (North Holland, 1979). Varela's mention on the differences between von Neumann and Wiener appear on the 10th chapter of the French version which does not exist in the original, English version of the book.

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scientist of the post-war era, and gave birth to concepts like biological computations and reasoning systems. Both von Neumann and Wiener were present and held a leading role in the discussions. Varela quotes the account of the conference's president as to the contributions of the two men. On von Neumann he noted:

> We met for the first time in March 1946 with the intention to develop our interest in mathematics and in methods of treating facts and ideas that had concerned us in our fight against post-Hegelian ideologies. The first topic was presented by von Neumann. He described the idea of computers running on a Boolean mode and having as their base the number 2. His general thesis was that such machines could calculate any number and resolve any logical problem, provided it has a solution (cited in Varela, 1989).

Then on Wiener's contribution he says:

> The afternoon of the first day was introduced by Wiener, who in counterpoint, said von Neumann machines, faced with a paradox, enter into endless oscillations (...). Then he began to describe the evolution of machines, from the days of Alexandria until the arrival of the steam engine of Watt; but it differed from all previous controllers, for it had some knowledge of the environment (...). From this, he developed the concept of reflex and then finalized activity (cited in Varela, 1989).

Varela then goes on to commend on the 'striking difference' between the two approaches. 'One talks about a procedure that can solve any problem; the other focuses on the relationship between knowledge and purpose' (Varela, 1989). Von Neumann was looking at processes and operations as ways to solve a problem. Wiener instead was preoccupied with independent, autonomous activities able to generate themselves. 'The view of von Neumann is primarily concerned with heteronomous systems specified from outside. The view of Wiener is primarily concerned with autonomous systems, specified from within' (Varela, 1989).

In this juxtaposition between the two opposing positions 'it is the von Neumann approach that became predominant. It gave birth to information technology, and is associated with the development of most of the engineering sciences; it is this approach that provided the most frequently used metaphor for the brain, that is to say the computer. It promoted the idea of information processing as a central concept of cognitive science and as major task that living systems and machines have to perform one way or another. In fact, these ideas are so prevalent today that any questioning of their validity seems only 'philosophical'' (Varela, 1989). Norbert Wiener's approach on the other hand remained on the sidelines until very recently. And while Wiener's work gave birth to cybernetics, the influence it had on the development of the computer and digital media was very small compared to that of von Neumann.

Digital computers therefore, until today, are based largely on the principles defined by von Neumann's approach. This means that they are designed and built in order to work in accordance with those principles. But maybe even more importantly, von Neumann's ideas defined to a large extend the approach to computation at large. It is an approach that operates on the idea of the 'black box'. There is always some input and some output but what happens in between is not of equal importance. It is an approach that sees computation as a rational process, defined by specific rules and that operates in order to produce solutions to a problem. It operates in a serial manner, where Wie-

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ner's approach favors parallel processes. In other words, it follows a series of consecutive instructions with clearly defined succession where in Wiener we find operations and actions that can happen at the same time and can be related or unrelated to each other. As the example of weather prediction points out, von Neumann's approach operates in terms of prediction while Wiener's is open to uncertainty and unpredictability and one could argue, *variability*. The first is based on closed deterministic processes where the second on open, non-deterministic ones. Von Neumann understands the brain as a computer, Wiener on the other hand the brain as a neural network. Von Neumann's approach is following top-down processes while Wiener's allow bottom-up processes to be established.

The vast differences between the two approaches have also made themselves apparent in relation to the social and political situations of the time, underlining their political aspect. Von Neumann was a central figure in the Manhattan project and a pivotal character for the development of the thermonuclear and the atomic bombs. He was enjoying his relationship with the military and the power and influence that it provided to him. Shortly before his death he advised a preventive nuclear attack on the USSR. Wiener on the other hand, while during World War II worked for the US military for the development of radars and servo mechanisms, he openly criticized the development of nuclear weapons and the use of science for military aims, acts considered as unpatriotic at the time [5].

5. For a much more detailed account of the relation between John von Neumann and Norbert Wiener see Steve J. Heims, John Von Neumann and Norbert Wiener: From Mathematics to the Technologies of Life and Death (Cambridge, Mass.: MIT Press, 1980). Heims in this book makes the point that von Neumann represents an amoral approach to science while Wiener a moral one.

To summarize, we could identify von Neumann's approach as one based on command, heteronomy and serialism; Wiener's one is based on autonomy and parallelism. Von Neumann favors regulation, prediction and control while Wiener openness and bottom-up creation.

Chaoid Variability

The importance of the example of Von Neumann's and Wiener's approaches is twofold. On a first level it illustrates how science can operate according to the process that Deleuze and Guattari describe, as in the case of Wiener. He uses variability as an inherent element of his approach in order to produce variables. The result is an open system that expands our understanding and becomes creative. On the other hand Von Neumann develops a scheme that aims to create stability, control and predictability. It also illustrated that evolution and 'progress' is not defined only by the approaches the push the envelope of existing knowledge. It was von Neumann's approach that became the dominant one and defined the development of the digital computer.

On a second level however, the difference between von Neumann and Wiener is important because it illustrates the principles behind digital tools and how they affected creative processes. The von Neumann ap-

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proach, by dominating the development of digital tools, established them as the means that would eliminate variability. The tools that will remove unpredictability as a property that is unwanted, but above all dangerous, both on an operational and on a political level. Even in the case of the weather: is has to be predicted so it can be used (as a weapon). All variability is dangerous; a threat to established rules, forms and institutions.

When following that line of thinking, we can note that Von Neumann's approach is clearly following the project of modernity. It is based on 'rationality', determinism, a clear relationship between cause and effect, top-down processes defined and controlled from the outside. Computers and computation therefore followed a similar route. Wiener on the other hand proposes elements that contrast with several of those values. Autonomy, bottom-up processes and systems where meaning emerges from the interaction of its elements, from the inside, instead of being imposed from the outside through representation. While his approach didn't prevail in the beginning, the principles he defined started slowly to find their way into the scientific community and emerged on the surface when digital computers started to connect to each other and subsequently were organized into networks. The result was that computers – even though as units were built on the von Neumann architecture, operating serially on the principle of the black box – when part of a network they gained the ability to operate in parallel in relation to one another. And when many of them were operating at the same time, bottom-up, self-organized properties started to emerge. Through that condition, modernity came under dispute. And again, a little bit of chaos manages to come through the umbrella of opinion.

Therefore, as the computer as a tool is a result of the principles of modernity, it should have been expected that not only it follows, but it imposes too those principles on what it produces. That might explain how the products of digital design have a tendency towards uniformity and homogeneity. The digital computer, itself a product of standardization, operates through even stricter standards which define the results – and in that sense the name non-standard architectures might have been a very unfortunate idea.

Thinking of design as the process of crossing the chaos, of creating holes to the protective umbrella of opinion in order to let some of it in, might be an appropriate answer. And then, what becomes of importance is to figure out what the architect is bringing back. If chaotic variability is transformed into chaoid variation by the philosopher, chaoid variety by the artist and chaoid variable be the scientist, into what does the architect transform it? Since architecture exists somewhere between the three, then its product might be after all *variability itself*. Chaotic, infinite variability transformed into chaoid variability that is defined and held together through a plane of construction.

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Essays

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Oblivious to Gravity: Virtual Architecture between disciplinary dead ends and complex intersections

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Abstract

Design media have an intimate relationship with architecture, and also serve as the means of its practice. With new technologies, and especially virtual reality, a new rhetoric of design media is becoming increasingly possible. That is, media being used as means both to design and to experience space. Such rhetorics expand the formal manifestations of architecture besides building, as well as the horizon of what can be design as well as what can be aesthetically experienced as architecture.

This research is concerned with the topic of 'Virtual Architecture.' That is architecture specific to the virtual domain that is experienceable, however unbuildable. As an alternative mode of computational design, Virtual Architecture is concerned with a latent domain of architectural experience that is not attainable through traditional practices of building but only accessible through the virtual dimension, and as such its design is not restricted by the concrete physical world.

The aim of the paper is to construct the research foundations for 'Virtual Architecture,' through the assembly of knowledges from multiple epistemic domains. It sets off by highlighting disciplinary limitations and challenges as well as the potentials of transdisciplinary practice that are central to this research. It proceeds by reviewing relevant literature domains and precedents from architecture and game studies, identifying and examining their limitations. Furthermore, it describes practical constraints in the design-investigation of media-specific virtual environments which require a shift of paradigm in design media. More specifically, that is the replacement of the Cartesian-Euclidean understanding of space to the spatiotemporal model of Riemannian non-Euclidean geometry that treats 'space' as a variability. Lastly, it describes how design knowledge can contribute in experimental studies of virtual environments for the investigation of space-related aesthetics capacities.

Keywords

Virtual architecture; Virtual reality; Design media; Aesthetics; Computational design.

Note

The title "*Oblivious to Gravity*" is a reference to the building-sound-compositions series of composer and sound artist Gerriet K. Sharma. See {kA}: keine Ahnung von Schwerkraft (2010-2015).

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Architecture has a close relationship with design media. In the past few decades digital design media have replaced the analogue drawing board as the means of architectural practice. Design media also became part of the discipline's discourse as well as objects of research and development. However, beyond their conception and implementation as tools of practice lies the potential of such media to produce and materialize themselves experienceable space without the necessity for built form. Not only that, but contemporary media like virtual reality (VR) can produce spatial environments that are fundamentally unbuildable, yet experienceable. Thus, in the context of architecture a new rhetoric of design media is becoming increasingly possible: media being used as means both to design and to experience space. Besides expanding the formal manifestations of architecture beyond building, this use of media also expands the horizon of what can be designed and what can be aesthetically experienced, while serving as a more immediate means for architecture than building.

This essay is concerned with the topic of Virtual Architecture. With architecture as a starting point it sets out to draw affinities with other epistemic domains that overlap the subject. It proceeds to integrate knowledges and practices from these different disciplines, constructing the topic in the in-between area of their separation.

Introduction: Discipline & Potential

> Firmitas, Utilitas, Venustas
> Architecture is the art of building
> Architecture or revolution
> Everything is architecture

Aphorisms, like the ones above, often deprived of their authors, and out of both historical and textual context, are examples of values instilled in the architectural habitus. Besides the need of guiding definitions, what they also demonstrate is that the question of 'what architecture is' is rather impossible to answer, also perhaps a futile one. A more promising question would be 'what can architecture do.' However, to ask such a question of a discipline that is insistent to its tradition and furthermore centered around the practice of its protected profession, will inevitably be articulated in terms of its past. Thus, it can only yield answers as functions of its own heritage, the history, means and conventions related to the profession's practice.

Like deep roots, such conventions pull the conception of architecture to the immanence of its past. They operate as condensers, quasi-definitions of its relevance, to fall back to when tackling wicked questions of defining a field and its relevance. They form a certain center, in Derrida's terms (1993), the purpose of which is to organize and demarcate the field as well as to limit free-play within it. In other words, such abstract signifiers serve as a reference to keep a field together by limiting its historical evolution to linear progress.

Questioning that model, Wark asks what architecture is while introducing an undeniable rupture:

> All the architecture that we know of is architecture of the Holocene.(Wark, 2017)

Bypassing historical time Wark points to a geological 'event' as a means of drawing a line from all previous periods and their knowledge. What is to become of architecture when its primordial function to protect 'man' from the environment is challenged by the reversal of causal roles between

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'environment' and humanity? Affirming in that way a lack of precedents, Wark performs a gesture of asking for a more general and radical reconsideration of what architecture is, and therefore of what architecture can do.

Concerned with the unbuildable, the theme of Virtual Architecture questions core aspects of architecture's discipline. At the same time it does not belong to a single field but is rather constructed in the interweaving of multiple epistemic domains. Such a process Manning (2015) identifies as "research-creation:" a "transversal engagement with different disciplines, [that] incites a rethinking of how artistic practice reopens the question of what these disciplines […] can do." At the same time, Manning states, research-creations asks for new forms of evaluation and of valuation of the work we do.

Transdisciplinary research (TR), that this essay is concerned with, inquiries into disciplinary capacities. Questioning the rigid understanding of disciplined fields, it points to new ways of articulation between epistemic domains in order to generate new potentials. As Linder (2005) highlights, TR operates at disciplinary boundaries which is "also where we become most aware and in need of the tools, techniques and technologies of the discipline." It is thus not an abandonment of the discipline, but rather, an investigation of architecture's "undisciplined appearances" that are only expressed in states of 'transness.' Through a reconfigured practice, the aim of TR is to investigate and tame such appearances in order to uncover latent potentials.

Oblivious to Gravity: The case for Virtual Architecture

The focus of this essay is a particular facet of what architecture could do, that is, architecture specific to the virtual domain. For architecture as the epistemic field concerned with matters of experienceable space, the domain of the virtual offers an altogether new spatial substrate for exploration.

More precisely, it is concerned with what I would like to call inconstructible spaces. These are spaces that we humans are perfectly capable to experience, which however cannot be built in the physical world. What this statement implies is that there is a latent domain of experienceable spaces that cannot be addressed by a classical definition of architecture as the "art of building," as they can't exist in physical form and cannot be experienced as such. They can only exist and be experienced as virtual spaces. Consequently, this latent domain of spaces is analogous to an equally latent domain of spatial aesthetics. Therefore, a consideration of the set of experienceable post-physical-world spaces extends the horizon of what architecture can do. On the one hand, it extends what architecture can do as design knowledge pertaining to the design and study of spaces. On the other, it extends what architecture can do as affect, in the sense of the aesthetic experience it evokes.

The spaces particular to this research have to do with epistemological assumptions of architecture and design related to the theoretical and practical understanding of space. The working title "Oblivious to Gravity" is a twofold reference to this premise, both critical and speculative. As critique, it is concerned with the wider design discipline, which deeply rooted in their traditions and conventions, adheres to a working approximation of physical space as absolute. That is the space described by Newton in the 17th century and instrumentalized through a Cartesian model of Euclidean geometry. Contemporary design software, relying on an obsolete definition of physical space are thus, by and large oblivious to the macro-structure of space and the nature of the phenomenon of gravity as described by modern physics. That is to say that spatial design disregards the science behind the

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phenomenon it models[1].

As speculation, and in the context of architecture and design, this study is concerned with the replacement of the Newtonian-Euclidean understanding and model of space with a relativistic one. Its purpose is not to bring spatial design up-to-date with physics in order to better simulate the physical world, but rather to escape altogether the question of simulation as well as the visual prehension of space. The implications of carrying such a paradigm shift from mathematics and physics to spatial design are manifold. Chief among them for this context is that non-Euclidean geometry, the geometry behind Relativity Theory, allows for multiple spatial constitutions. Instead of taking space as a singular, uniform and flat entity, non-Euclidean geometry is concerned with a larger group of curved spaces. The speculative aspect of this premise lies in the induction of such properties in design practices as elements to design with. The adoption of a relativistic design framework as both a conceptual and practical tool, would enable design to experiment with and materialize experienceable architectural environments that are oblivious to the precise gravitational phenomena and shape of the concrete physical-world. The exploration of spatial configurations divergent from physical-reality is ultimately an exploration of what can be designed that is only constrained by its capacity to be experienced. It is thus, an exploration of spatial aesthetics and of the human capacity for spatial experience.

Virtual Architecture is therefore concerned with the shift from the design in space to the design of space. The use of design media in this context does not comply with their usual representational rhetoric, in which design takes place inside a provided simulation of space. Rather, this case utilizes media for their ability to create media-specific spaces themselves. This stance towards spatial media, that I have elsewhere called "choropoietic," (Miltiadis, 2019) is precisely an implementation in which their space-making properties are treated creatively[2]. The departure from Cartesian and absolute space to a plural relativistic model, opens up for research-through-design a new world of species of spaces.

Disciplinary dead-ends

Aspects pertaining to Virtual Architecture have been investigated within different disciplinary domains. Such precedents, besides from architecture also from game studies and experience research, follow different tangents and carry different methodologies, agendas as well as capacities and limitations. The creation of a research area in-between different domains requires a consideration of these previous contributions as well as their disciplinary limitations.

1. Design software available to architects (as well as game designers) adhere to a Cartesian model of Euclidean space, which are practically flat-earth simulations.

2. Such implementation is currently limited, and can be even considered as counter-intuitive, since design software have their own spatial rhetoric when it comes to their use, which is locked inside the aforementioned scientifically obsolete paradigm. Therefore, a new logic and means of their use is required as a framework in order to maximize their affordances for space-making.

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Architecture

> If Serlio had written his eight books of architecture today, he probably would have added a ninth book on computers.(Bertol, 1994)

What we can call 'Virtual Architecture' is certainly not a new phenomenon. An archeology of former research can resurface sparse but important work. In the late 1980s, the first wave of investigations into virtual space heralded VR as a promising emergent technology[3]. Architects were among the first to take up on this new technology producing research as intersection of theory and design practice. However, only textual work survives today.

Throughout the 1990s multiple architects published work relevant to the investigation of architecture in the virtual domain. A landmark treatise on the subject was published in 1992 by Marcos Novak (1992) which still remains an important account of the expressive and aesthetic premises of Virtual Architecture. Other notable contributors of this period were Daniela Bertol, Monika Fleischmann and Wolfgang Strauss, Gerhard Schmitt's lab and Peter Anders. In addition, a small number of symposia and architectural magazines gathered important accounts on the matter[4].

Paradoxically, these sparse however crucial contributions and growing interest into virtual architecture appear to climax around the end of the 1990s and then vanish. A key issue that cut these efforts short was the untimeliness of technology that appears as a probable cause for this halt. As we now know, VR would require another decade to come to maturity and to reach democratic accessibility[5]. At the same time, the emergence of "parametric design" in the 2000s grew to become the leading paradigm for computational architecture[6]. Since then, the term 'digital architecture' came to point to the implementation of a loose set of computational approaches in design or fabrication processes of architectural designs that intend to be built. Similarly, the popularization of VR in the last years, has seen its recruitment for purposes such as visualization, evaluation and marketing of building designs.
Experimental works of architecture concerned with unbuilt forms, that have been a historical part of the discipline, are largely absent from the focus of computational architecture and its discourse. As a blanket term 'digital architecture' came to overshadow other rhetorics of use of design and computational media which do not concern building as their final form. That is not to say that architects are not concerned with such use of media, but rather that such speculative applications are mostly considered outside of the normative domain of computational architecture and its discourse[7].

3. See for example Jaron Lanier's design-investigations outlined in Kelly (1989); also the 1990 "Virtual Worlds - Artificial Realities" symposium, Ars Electronica archive.

4. See the "Architectural Design" issues on "Cyberspace" edited by Martin Pierce and Neil Spiller (1996; 1999), and "Hypersurface Architecture" by Stephen Perrella (1999; 1998). For examples of edited volumes on the topic see Sakamura and Suzuki (1997) as well as symposia publications by "V2_ Institute for the Unstable Media."

5. The revival of VR is largely attributed to the 2012 Oculus Rift crowdfunding campaign, that reignited market interest into VR technology.

6. As a more accessible means of computation than programming, technologically more timely and concerned with building production processes and their automation, parametric design was quickly adopted in architectural processes, integrated in design software, as well as in educational curricula and discourse.

7. Since the so-called 'paper architecture,' experimental works of architecture were often met with hostility or resistance (see Woods, 1992). However, as Young (2017) discusses in the context of speculative design, its impact for the field of architecture and its discourse has been instrumental.

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Nonetheless, in a timespan of almost a decade, the above archeology of precedents into virtual architecture managed to comprise a very rich body of work on the topic that can be said to have already marked an implicit tradition. The theoretical investigations of these pioneers maintained an optimistic and visionary attitude towards core aspects and the future of architecture. Among key topics discussed were matters of aesthetics, materiality, ideation as well as the Cartesian dualism embedded in spatial design. Contrary to popular belief that VR as a medium concerns the mind and leaves the body behind, for most of these investigations the body had a central role. The understanding of VR as highlighted in these writings was to explore the poetic potential of architecture in the virtual, intimately correlated to the exploration of the capacities and potentials of embodied experience[8]. While the viability of similar investigations within the domain of architecture is presently questionable, this corpus of work is still highly prescient.

Game Studies

By the early 2000s, while architectural investigations in virtual space end, the videogame phenomenon came to the forefront as a champion across all entertainment media[9] and a contender for new form of literacy[10]. The field of game studies was then formalized as an interdisciplinary project devoted to the study of videogames, which has since grown to produce significant work on the new medium.

In the inaugural editorial article of the field's first academic journal, Espen Aarseth, a leading scholar in the field, pointed out:

> Computer games are perhaps the richest cultural genre we have yet seen, and this challenges our search for a suitable methodological approach. We all enter this field from somewhere else, from anthropology, sociology, narratology, semiotics, film studies, etc, and the political and ideological baggage we bring from our old field inevitably determines and motivates our approaches. (Aarseth, 2001b, emphasis in original)

As he highlights, the unprecedented videogame phenomenon leaves the question of methodology open. Therefore, game studies was constituted as a collective interdisciplinary effort open to scholars all coming from "somewhere else."

However, another event that marked the field was the shift towards matters of spatiality, which comes to question the particular understanding of interdisciplinarity.[11] Concurrently with tits foundation, a series of significant yet heterogeneous contributions claimed the centrality of space for videogames.[12] For Günzel (2010) who coined the "spatial turn in game studies" the matter of space in videogames called

8. Such concepts were further elaborated by feminist theorists such as Hayles (1999), Grosz (2001) and Gins and Arakawa (2002).

9. Since 2000 videogames has been gaining significant popularity and by the early 2010s the financial gains of the videogame industry surpassed that of the music and film industries.

10. Videogames have been discussed as a new kind and genre of literature, Zimmerman (2008); that is one of the most powerful elements of 'new media literacy,' Jenkins (2011), and to generate real knowledge Aarseth (2001a).

11. The examples of backgrounds given by Aarseth, a scholar originally of a literature background, betray the field's bias towards the humanities, which, for this particular inquiry becomes problematic.

12. Among influential analyses, Aarseth's (2001c) declared that "games celebrate their spatial representation as their central motif and raison d'etre." For further methodologically diverse examples see Stockburger (2007); Fernández-Vara et al. (2007); Wolf (1997); Jenkins (2004).

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for a paradigm shift in their study. Though, regardless of the importance of these contributions the "turn" did not come to any closure or conclusion, neither did it give rise to new 'schools' or methodologies of inquiry within games studies. What is left from this period is a loose set of contributions highlighting partial aspects of videogame spatiality. In short, the question of space remained unanswered. The lack of methodologies within game studies, appropriate for the study of spatial matters, appears as a probable cause for this investigative gap.[13]

While the inclusion of architecture and design-research in such investigations is promising, game studies appears to block entry to methodologies foreign to the humanities. Design, Aarseth previously acknowledged, is "the only powerful nexus among these diverse approaches" able to bring together "humanists, technologists, and social scientists." However, he paradoxically rejected such a prospect on the grounds that "design theory" is underdeveloped.[14]

Closing the door to the potential of an alliance with design-research, game studies' design taboo is a position detrimental to the field's interests. While blocking design-research proper, game studies remains methodologically and epistemically limited to the first only of Frayling's tripartite model of "research in arts and design,"[15] associated with theoretical-textual research. This type of research has a particular blindspot, since videogames are not predominantly programmed or typed anymore. Videogames are predominantly designed. The exclusive study of videogames as playable finished objects[16] disregards a connotation of the videogame related to its understanding as a medium as well, that is intimately associated with designerly practices and designerly knowledges. As Stenros and Kultima point out[17] a significant capital of videogame knowledge related to their design and production lies in a tacit dimension. This knowledge is rather elusive to the current state of the game studies field, as it cannot be easily activated or accommodated through 'scholarly' methodologies and textual means of output.

Eventually, we can ask whether 'playing research' as the overruling methodology of investigation, alongside knowledge stemming from fields like philosophy, sociology, media studies, etc. and a word-processor are enough for the study of videogames. Concepts, ideas and knowledge that require a sketch, a drawing, or a 3D model to be communicated, even a game-prototype in our case, can suggest otherwise. That "making sense" of videogames through text, of a medium that reportedly deals with concepts and knowledge that surpass the model of textual narrative,[18] might miss the point. Eventually, the "spatial turn" as a paradigm shift entails a shift in methodology as well, instead of reciting previous traditions under a new theme.

In light of these issues, the missing part in videogame-related means of knowledge production appears to be what Frayling (1993) described

13 The epistemic backgrounds at the initial phase of the field were adequate and compatible its previous hypertextual and interactive considerations of videogames. However, the technological and cultural evolution of the videogame phenomenon that brought about the spatial paradigm underlined once again the question of suitable methodology.

14 What Aarseth (2005) calls "design theory" is questionable. His account confuses game design as a commercially applied practice with the wider design discipline associated with the rigorous tradition of design-research. Aarseth has been vocal about his distrust toward what he identifies as designers, even though what he envisions for game studies is to resemble an architecture school (see Aarseth, 2014).

15 I use Frayling's (1993) tripartite model because of its particular relevance to the case of videogame research.

16 Gameplay as means of research (Aarseth, 2003) is one of the most accepted methodologies in game studies.

17 Stenros and Kultima (2018) discuss in length the negligence of design-research in the field and its discourse as well as the benefits of its legitimization.

18 As Aarseth (2001c) points out, videogame spatiality "is also a way to explore the partly unknown, to test models and hypotheses, and thus to construct and acquire new knowledge in a way narrative never could." See also Günzel (2010).

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as "research-through-design" (RTD). Loosely identified as the development and documentation of experimental designs RTD can be considered as a middle-of-the-road research mode, that can sit in-between the existing modes of knowledge production: videogame production and game studies research. Its addition to this constellation is highly promising, since it essentially institutes a bridge between these two domains and their practices, which up until now do not show signs of cross-pollination.

More pointedly, RTD engages with the form of literacy pertaining specifically to the videogame medium which does not yet take part in the epistemic domain of game studies. It is also a form of research that can work in intimate synergy with existing game studies constituents, enabling the exploration of theoretical concepts parallel to their implementation through design. Furthermore, RTD can emphasize research that is less concerned with commercial instances of videogames and more with applications exploring the medium's potential in ways that commercial research practices are unlikely to pursue. Lastly, the combination of theoretical and design- research is highly valuable especially in matters of spatiality.[19]

19 As shown by scarce such examples (see Jakobsson, 2003) design investigations have a particular advantage over theoretical research in addressing existing research gaps and producing new knowledge.

Transfusion

The nature of spatial experiences pertaining specifically to Virtual Architecture cannot be prehended by traditional disciplines. Thus, design requires a new operational spatial framework to account for practical and conceptual facets of such experiences as well as for their aesthetic dimension.

From Space to Units of Experience

The investigation into the design and affective capacities of space specific to Virtual Architecture lies on our capacity to design such novel forms of space. Thus, the question of design media and especially the particular space they afford to design practice is crucial. Design software have been criticized to reside in conceptual models of the past.[20] The role of architectural geometry is particularly significant in this context since it carries philosophical ideas and values that architectural design necessarily inherits.[21] Providing simulations of space as the framework within which design takes place, design media essentially suggest specific concepts of space and rhetorics of its use. However, more than current theories and mathematical models of space, the space afforded to design by contemporary design media follows its Newtonian-Kantian conception implemented through the Cartesian model of Euclidean geometry.

20 Mitchel (2016) discussed architectural software that are modelled after "academic classicists" and thus carry ideologies and values of the past. See also Mitchell (2001).

21 For Woods (1996) the implications of the Cartesian design framework reach beyond practical ones to also affect the conceptual view of architectural space. See also Spiridonis' (2019) analysis of values embedded in architectural geometry.

Instead of space, I use the notion of spatiotemporality. Adopted from relativity physics, spatiotemporality rejects space and time as a priori categories and fuses them into a complex. In the model of Krauss'

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"expanded field"[22] which defies partial and historical understandings, similarly in this case, spatiotemporality institutes a "complex" at the intersections of disciplinary aesthetics and knowledges pertaining to space and time. As in relativity physics, instituting new conditions of 'space,' enables new forms and new understandings of subjectivity and eventually collectivity. [23]

The framework intended for the design and study of these environments relies on models of non-Euclidean geometry. This 'strand' of geometry remains almost unknown to architectural circles, Spiridonis highlights (2019), and thus "cannot have any impact on architectural thinking." However, we can draw from Relativity theory the model of Riemannian manifolds used to describe spacetime,[24] which can benefit design in a number of ways. On the one hand, manifolds provide an instrument to conceptualize and design spaces divergent from the current presuppositions of space as uniform and flat. Riemannian geometry therefore, enables for design the capacity to treat space as a variability, opening up a larger set of curved environments. On the other hand, concerned with both metric and non-metric qualities of space, it also provides a model to qualify spatial constitutions and enable their individual characterization as well as comparative analysis.

Through Riemannian geometry we can articulate units of experienceable environments to investigate the 'elements' of Virtual Architecture. As elements, these units are constituted by the interrelations of primary entities of spatiotemporal experience. DeLanda describes such a unit as an intensive assemblage:

> A good example is the assemblage which a walking animal forms with a piece of solid ground (which supplies a surface to walk) and with a gravitational field (which endows it with a given weight). Although the capacity to form an assemblage depends in part on the emergent properties of the interacting individuals (animal, ground, field) it is nevertheless not reducible to them. We may have exhaustive knowledge about an individual's properties and yet, not having observed it in interaction with other individuals, know nothing about its capacities. (DeLanda, 2013, p. 66)

The environment as assemblage is formed by the three heterogeneous entities coming together (animal, ground and gravity). The reciprocal relationships between these entities, as with various human activities (e.g., walking, scuba-diving, sailing, hand-gliding and spacewalking) give rise to altogether different assemblage qualities. For DeLanda different configurations yield different capacities, affordances and affective qualities. Furthermore, the range of variability of the configurations between the entities comprising the assemblage denotes a larger set or family of

22 Krauss (1979) suggested the notion of the "expanded field" to escape historical and positive disciplinary definitions.

23 See Wertheim's (2010) analysis of the cultural implications of scientific revolutions pertaining to space.

24 Manifolds, that belong to differential geometry, were suggested by Riemann a way to articulate spaces that bypasses the parallel postulate problem of Euclidean geometry. See Riemann (1854); Keyser (1906); DeLanda (2013) pp. 1-48.

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instances of qualitatively different environments. That, a multiplicity or manifold, is a larger space that contains unique instances of spaces as environmental assemblages.

The concept of multiplicity, as a larger space that contains spaces, can help clarify the term 'virtual' in Virtual Architecture. In this context, 'virtual' is more closely associated to Deleuze's concept of virtuality[25] than to virtual-reality technology. For Deleuze, the virtual is not the less real, but rather the possible that has not yet been actualized. DeLanda (2013, p. 65) sums up the virtual as unactualized tendencies and unactualized capacities to affect and be affected. In the same way, Virtual Architecture is concerned with exploring and activating unactualized tendencies in the configurations of the environmental assemblage and investigating their affective qualities.

25 Deleuze's notion of virtuality stems from the philosophy of Bergson. See Deleuze and Parnet (2007).

Such environmental assemblages can be investigated computationally using game-development engines and also experienced through VR. Videogame engines provide a platform to design and explore virtual interactive environments, where the relationships between the elements of the environmental assemblage mentioned before, can be calibrated through design. While game engines are locked in a Euclidean-Cartesian paradigm of space, unconventional implementations or 'hacks'[26] can still be used to implement spatial curvature thus altering the properties of the "ground" entity. Aspects of phenomenological intentionality (related to what DeLanda mentions as "walking animal") can also be customized computationally. Furthermore, physics-systems implemented in game engines allow for gravitational laws to be altered through design, leading to the investigation of alternative laws of physics.[27] Eventually, while videogame engines provide a suitable framework for the design investigation of virtual environmental assemblages, VR serves to render such environments experienceable in real-time, providing furthermore an ideal means to stage experiments in order to study their affective qualities.

26 It is unclear at the moment if the operational application of non-Euclidean geometry can be implemented also as a lower-lever feature in these software (for example through custom ray-tracers or shaders) besides workarounds that involving higher-level physics and geometry programming.

27 See Meillasoux's (2015) discussion of the philosophical implications of such investigations, which he terms 'extro-science fiction.'

Experiment Space

Besides rendering virtual environments experienceable, VR technology also serves as an ideal framework for their experimental study. For the past two decades VR has been employed in experiments in the fields of cognitive sciences and experimental psychology, and particularly for studies pertaining to spatial capacities (see Diersch and Wolbers, 2019; Bülthoff et al., 2008). In parallel, multiple studies have produced evidence to suggest that videogame-play can improve cognitive skills and capacities, and especially ones related to spatiality (see Subrahmanyam and Greenfield, 1994; Bavelier and Green, 2016; Uttal et al., 2013).

With videogames as means to advance spatial skills and VR as an ideal tool to study them, the fusion of VR and videogames appears particular-

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ly promising to investigate the potentials of spatiotemporal experience and the advancement of spatial skills (see Dünser et al., 2006). However, and even though VR-related artistic as well as game development practices are often concerned with developing such sensibilities, there is a lack of systematic studies on the subject.[28] While existing literature provides adequate tools and methods to study the practice and qualification of spatial skills in virtual environments, research into more experimental spatial configurations is rare,[29] since most studies in the domain of experience-research aim existing applied skills.

Nevertheless, the capacity for experimental investigations within the context of architecture is particularly significant. First and foremost, architecture's interest in aesthetic qualities of spatial experience provides an antipodal mode of investigation in comparison to existing ones. Furthermore, design knowledges and practices allow for the study of experience of virtual environments in close feedback loops with their design. Especially in the case of parallel investigation of media-specific environmental scenarios in correlation with the exploration of the limits of spatial experience, the advantageous position of architecture over other disciplinary domains is especially pronounced.

28 To some extent, the lack of more speculative studies can be credited to the interdisciplinary requirements of such investigations to combine both scientific and artistic capacities.

29 For such examples see Warren et al. (2017); Vasylevska et al. (2015); Oman (2007); Liu et al. (2016).

Conclusion

This research-creation corpus for Virtual Architecture stands for fostering of a knowledge and a form of knowing that is at the same time theoretical, conceptual, designerly as well as practiced, experiential and corporeal. It is an exploration of what a reconfiguration of given disciplines and their knowledges can do, both for the disciplines themselves and for us as its practitioners and affective audiences. In this way, Virtual Architecture stands as an alternative to conventional computational literacy and practice in architecture.

The research programme of Virtual architecture evokes processes of questioning and unlearning the historical and disciplinary traditions, the modes and origins of our sensing and understanding, in both the domains of design and experience. Its purpose is to unhinge notions of space and time from disciplinary biases, and mend the fragmentary understandings of the aesthetic. This disciplinary abstraction is a gesture of generosity[30] toward the potential of our sensory and sense-making capacities, and also of architecture as art and artistic expression unbounded by disciplinary and historical traditions. Through the exploration of media-specific spatiality Virtual Architecture aims to uncover promising new spectra of expression and creativity: new ways of knowing in latent capacities of intelligence and sensibility waiting to be discovered.

30 See Bühlman's (2017) discussion of abstraction as generosity.

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The notion of Mixed Embodied Presence as a variable for generating mixed environments

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Abstract

During the last years, the insertion/ invasion of technology has led to the redefinition and re-approach of architecture and its immanent aesthetics (Fox and Kemp 2009). The emerging new realities and spatialities, and especial those of mixed reality and mixed environments, are considered as the origin of the transition of architectural culture towards new technologies. In this sense, an alternative framework for approaching and analyzing the variability of such spaces and realities is introduced through the lens of Mixed Embodied Presence, a proposed notion that reflects aspects of both the senses of presence and embodiment. The ultimate goal is to highlight the various embodied and spatial aspects that are emerged and can affect the production and the design process of mixed environments, and therefore the generation of different spatial conditions.

Keywords

presence; embodiment; mixed environments; design framework

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1. Introduction

To etymologically define space means to primarily define its nature (Tschumi 1996, p. 29). During the last years, it is more than obvious that space – and especially architectural space – is not perceived as a solid and immobile frame, but rather as a fluid state that is constantly changing due to various accommodated or/and afforded activities (Iacucci and Wagner 2003, p.150). Traditionally, architecture is considered as the effort of enhancing the user's spatial awareness, through the construction of a tangible reality that articulates individual and collective experiences (Tuan 1977, p.100). However, a number of issues regarding mobility/movement and stasis are raised due to new potentials that emerge from the fluidity of modern nomad culture (Fox and Kemp 2009, p.29) which leads to a transition of traditional design methods, towards more interdisciplinary practices (Somol and Whiting 2002, pp.75-76). This phenomenon is, on the one hand, driven by the way that technology affects and reforms the sustained interactivity between an embodied entity and the structured environment, and on the other hand, by the reinterpretation of, until recently common grounded, notions of space and time (Tuan 1977, p.53; McLuhan 1964). The introduction of technology has led to the reconsideration of architecture and its immanent aesthetics (Fox and Kemp 2009) and to attempts of creating alternative environments and realities (Bock, 2008 p. 275). Thus, the emerging new realities and spatialities, and especial those of mixed reality (and consequently mixed environments), are considered as the starting point of shifting architectural culture towards new technologies.

In this context, it is argued that the role of the architect is to re-examine and redefine architectural design, in the light of the activities that take place in these new generated (mixed) variabilities/typologies. Therefore, an alternative design framework, that will be able to correlate the emerged spatial variations to the active embodied presence, as well as to calibrate aspects of reality with representations of virtuality, is examined. In this direction, the present research proposes the notion of Mixed Embodied Presence, and the underlying parameters, as an alternative design approach and tool, that can adequately capture and record the coherent experience of a user, in a combined environment of physical and digital entities. This concept was primarily based on two fundamental questions that are raised in the context of the PhD research: a) whether or not the experience of presence in a mixed environment can be considered as a new sense, different from the one shaped in a real or a virtual space, and if so, b) is this phenomenon inextricably related to the embodied and kinesthetic senses that are triggered and activated in such an environment?

Through the previous questions, more than one variables are denoted; namely the notion of presence, the notion of embodiment, as well as the spatial conditions that determine the nature of interactivity. Therefore, to further analyze these variables, literature review was performed on the two aforementioned notions (i.e. presence and embodiment) (Papasarantou and Bourdakis 2012) as well as on the various conditions and aspects that are related to spatiality (i.e. physicality and virtuality). Apart from shaping the definition of the notion of Mixed Embodied Presence (Papasarantou 2013), the following hypothesis was formed: if the sense of presence – namely the conscious embodied experience of space – is related to kinesthesis and the formation of perception (which is based on someone's memories and performed actions in a place), then the recording and the combination of their interrelated parameters, can probably lead to some kind of "mapping" of the shaped experience in this intermediate space (i.e. the space that is consisted by physical and digital aspects). Thus, and in the light of this hypothesis, all the above parameters will be presented in the following sections, in order to highlight the numerous embodied and spatial aspects that emerged. The ultimate goal is the creation of a taxonomy that can be applied to the production and the de-

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sign process of mixed environments, generating various spatial conditions through the lens of mixed embodied presence.

2. Mixed reality: variation of spaces and emerged needs

The initial step toward the scope of this research is a brief presentation on what is perceived as mixed environment.

In the context of the PhD research, an extended and thorough literature review was performed on the fields of real/physical and virtual space, and specifically on the variant ways that these spatial conditions have been defined, over time. Both of these spatial conditions are rather complex and therefore, a simple or common definition cannot be conveyed. In short, as real/physical space can be conceived an area of specific dimensions and geometry, and at the same time, a subjective place that is shaped according to user's sensory, kinesthetic and perceptional skills. As virtual can be characterized a technologically-based abstract space where familiar elements are embedded in imaginary and uncanny places/landscapes, as well as one that manages to immerse user by capturing her/his senses and by making her/him feel present in this imaginary field.

As a result, a number of keywords, detected to better describe reality and virtuality, were highlighted and gathered in the following table (Table 1). The main purpose is an initial approach towards the definition of mixed space, based on the expected outcomes from the aforementioned literature review.

<table>
<tr><th colspan="2">Space</th></tr>
<tr><th>Real/Physical</th><th>Virtual</th></tr>
<tr><td>geometrical/ dimensional</td><td>abstract/imaginative</td></tr>
<tr><td>neutral and ideal</td><td>technological</td></tr>
<tr><td>subjective</td><td>feasible</td></tr>
<tr><td>existing</td><td>immersive</td></tr>
<tr><td colspan="2">perceived</td></tr>
<tr><td colspan="2">experiential</td></tr>
<tr><td colspan="2">kinesthetic</td></tr>
<tr><td colspan="2">embodied</td></tr>
</table>

Table 1.
Keywords describing reality and virtuality

It is noted that even though there are rather discreet and, in the core, different characteristics for both spatial situations, there is however a common ground where these two conditions converge. The keywords included in these fields (i.e. perceived, experiential etc.) are highly corelated to the presence of a human body, which is perceived as a vehicle of embodied and kinesthetic skills as well as a carrier of lived experiences. Therefore, an initial hypothesis is that an analysis on spatial

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variations oscillate between reality and virtuality should be primarily based on the variable of embodiment. This assumption was investigated through literature review that is performed on theories related to mixed environments. Some of them are briefly presented in the following section.

Mixed reality is a rather complex spatial condition. According to Milgram's "Reality-Virtuality continuum" (Milgram et al 1994, p.283), presented in Figure 1, as mixed environments can be considered all the realities and spatialities included between the extremes of real and virtual environments, that combine proportional views of physicality and digitality (Drascic and Milgram 1996, p.123; Harrison and Dourish 1996, p.72). In these environments, physical and digital objects and entities co-exist and interact in real time (Benford and Giannachi 2013, p.3). Therefore, the nature of a mixed environment is determined by the hosted objects and entities, as well as by the nature of the accommodated and afforded activities.

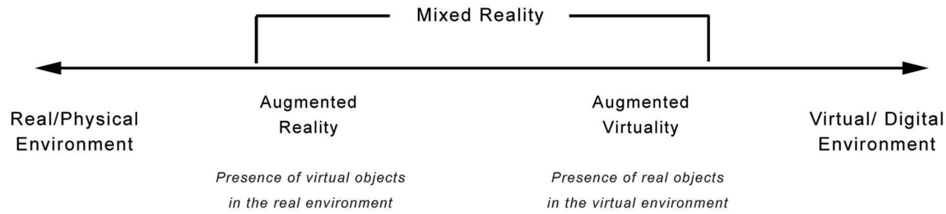

Figure 1.
Representation (by the author) of Milgram's "Reality-Virtuality continuum" diagram

In an effort to describe mixed reality, some researchers borrow terms and parameters that usually applied to physical space, such as boundaries and tangibility. For Rogers (Rogers et al 2002, p.679) the term "boundaries" is implemented to delineate the transition from the real world to the virtual one, and vice versa. In this sense, boundaries are characterized by the parameters of permeability, situation (which is described as "the boundaries spatial properties") and dynamics, and are utilized to denote the occurring transformations as far as perception, action and cognition are concerned. For McGarrigle (2012, pp.36-37) it is the boundaries that should be demolished so as the new generated spatialities and realities to be discovered, and the underlying conditions that differentiate their meaning and their experiential dimensions to emerge. After all, as Weijdom (2017, p.7) argues, the experience of mixed reality is strongly related to the user's cognition and her/his lived experience. Therefore, in this context, it can be perceived as a rather flexible and adaptable spatial condition/variation, which can be determined by the user's embodied engagement, sense of presence and interaction.

In comparison to traditional or virtual spaces, there are some significant advantages on using mixed environments. The enhancement of learning processes and user's experience, as well as the improvement of cooperative work are considered to be among them (Rogers et al 2002, p.677). The reason is not totally obvious, but it is argued that it is the outcome of the proliferation of the sense of embodiment due to the combined qualities that are embedded in a mixed environment (i.e. combination of familiar objects with technologically enhanced spatial conditions). Therefore, it is sustained that the nature of interaction hosted and provoked in mixed environments is in accordance with peoples' performed actions and interactions, on a daily basis (Rogers et al 2002). This is also one of the reasons that mixed reality is closely related to the development of the field of interactive

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architecture. The aim of interactive architecture is the creation of a responding space capable of behaving, interacting and being adaptive; qualities that are compatible to a (human) embodied entity (Fox and Hu 2005, p.92). Moreover, it is argued that architecture is constantly oriented toward the creation of spaces that can balance the possible emerged needs of the inhabitants to their preferences, as far as design is concerned (Diniz 2008). In addition, a successful smart environment is considered the one that stops putting emphasis on the implementation of plain technology, and is rather oriented towards the emerged, from the presence of human factor, needs, namely her/his activities and her/his carried experiences (Fox and Hu 2005).

Therefore, it is argued that the exploration and study of mixed environments through the lens of the variables of presence and embodiment, is rather essential. For this purpose, the present research introduces the notion of Mixed Embodied Presence.

3. Introducing Mixed Embodied Presence as the declared variable for mixed environments

The notion of Mixed Embodied Presence is the outcome of questioning whether or not a mixed interactive space, in which the human body is introduced as the link between real and virtual environment, can lead to a mixed experience of presence that is related to bodily senses, memory and kinesthesia. After the extraction of parameters – derived from relevant literature review – that are related to presence, like bodily awareness, memory, information, attention and interaction; and to embodiment such as perception, kinesthesis, and sensory system; a taxonomy was created shaping the basic guidelines for the investigation of primary hypothesis, in materialized paradigms of mixed reality (Papasarantou 2013; Papasarantou and Bourdakis 2012). Through this taxonomy the following definition for Mixed Embodied Presence was shaped.

Mixed Embodied Presence is defined the coherent sense of presence that derives from the progressively embodied engagement and interaction in an environment consisting of physical and digital aspects. It is considered as a measure and a design framework that is related to the parameters of embodied interaction, and specifically to the nature of interaction and the nature of interface as well as to the parameter of co-presence, in the light of socialization and the sense of shared awareness deriving from the mediated or immediate presence of other users in the interactive environment.

Towards justification/verification of the variable

After the extraction of these two main parameters (i.e. embodied interaction and co-presence), and their underlying characteristics, an experiment was designed (Papasarantou and Rizopoulos 2015; Papasarantou et al 2014) to test whether or not the notion of Mixed Embodied Presence can actually suggest an alternative and meaningful framework for analyzing and/or generating mixed spatial complexes. Therefore, a virtual environment illustrating an imaginary exhibition place, was produced. The participants (32 in total) were informed that the curator mistakenly placed some paintings that were planned to be included in another exhibition. Their task was to move around the exhibition space and spot these paintings.

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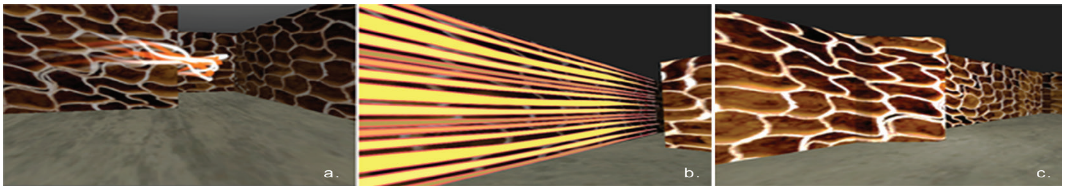

FIgure 2.
Indicative screenshots from each condition of co-presence, a. somatic echo, b. video-trail, c. deformation

The environment was displayed through Oculus rift. Embodied interaction was implemented through the use of a Kinect camera which turned users' locomotion on physical space, to a steady-paced walking inside the virtual environment, as well as through the use of a USB mouse which enabled users to select the divergent paintings. Moreover, three different conditions for denoting the parameter of co-presence were designed, namely a. the condition of somatic echo, b. the condition of video-trails and c. the condition of deformation (Figure 2). In detail, in the condition of somatic echo, another moving entity was present to the environment in the form of 3d colorful trails. In the condition of video-trails the co-presented entity was represented as a 2d colorful waveform, displayed as a moving texture on specific walls of the digital environment, while in the condition of deformation, specific (digital) walls were deformed creating a moving 3d folding pattern. In all cases, the initial intention was the creation of abstract dynamic representations that might be perceived as embodied metaphors of an anthropomorphic embodied entity, or as social (abstract) entities that try to establish some kind of communication with the user. For this reason, all the conditions were enriched with an audio pattern. Also, the activation of each condition was based on the proximity of the user.

A between-groups design was implemented. Therefore, each participant was engaged in only one of the aforementioned conditions of co-presence. After completing their interaction with the environment (and the embedded entities), each participant filled – among others – a Mixed Embodied Presence questionnaire, which was compiled in the context of PhD research. Also, after the end of the entire procedure, a short conversation with each participant was made.

4. Towards the determination of an alternative framework for generating various mixed spatial conditions

Through this experimental process, a number of interesting hypotheses and outcomes, concerning the spatial and embodied qualities that could characterize a mixed environment, emerged. Several aspects, regarding lived and spatial experience, communication, as well as learning processes (in an informal way), are also highlighted.

The main hypothesis that is formed, as far as the criterion of lived experience is concerned, is that a virtual environment can, to some extent, be perceived as real when entities that perceived as somatic echoes are co-presented. In this case, the comprised spatial experience tends to be characterized as hybrid and not as virtual. A significant parameter toward this direction is the active participation of user's body, which – in the context of the experiment – was implemented as a navigation medium (i.e. simulation of body locomotion to walking process).

As far as the communicative aspect is concerned, it is highlighted that the enhancement of an environment with dynamic entities (waveforms, deformations) is perceived as an attempt of the envi-

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ronment to establish a form of communication (with the user). It is also noted that the parameter of co-presence can be crucial for the proper communication and comprehension of the general concept that is attempted to be conveyed through an interactive environment. The learning process is approached in the light of getting familiar with the interactive methods. It is noted that when the co-presented entity was perceived as an embodied metaphor (i.e. echo condition), users were able to feel faster professional, as far as the navigation methods are concerned, and therefore felt the entire interaction process as more natural.

A key question that is set after the extraction of the aforementioned outcomes and hypothesis is, how these data can be interpreted to spatial conditions or/and to designing methods for generating a variety of mixed spaces.

The following table (Table 2) is a revised version of a diagram that was created after the performance of literature review on the notions of presence and embodiment (Papasarantou and Bourdakis 2012). The corresponding highlighted parameters were utilized as a common ground upon which the definition of Mixed Embodied Presences was formed. The additional column, entitled as Space, includes elements that are related to the spatial interpretation of the aforementioned common ground, as well as to the results of the experiment.

Presence	**Space**	**Embodiment**
Awareness	Co-presence/co-habitation *(C)*	Perception/ Movement/ Position
Memory	Representation of familiar activities and events *(C)*	Bodily + mental existence/ Kinetic memories
Information	Integration of spatial *(SE)* or narrative *(C) triggering points* / Co-presence *(HF)*	Orientation/ shared communication
Sensory centers	Tangible objects Wearables Co-presence *(SE)*	Kinesthesia/ visual perception/ Proprioception/ Empathy
Mechanisms of obtaining knowledge	Content/ Embodied engagement *(SE)* / Orchestration of movements/ Co-presence *(HF)*	Technology/ Imagination/ Behavior /Perception/ Sensory cooperation
Realism	Representation of familiar actions and events *(C)*	Experience of being/ Sensory aspects
Interaction	Co-presence (as part of –informal– learning processes) *(HF)*	Spatial and bodily correlations/ Body toward other bodies/ Body toward itself

Table 2.
Spatial interpretation of Mixed Embodied Presence (SE: Spatial Elements, C: Concept, HF: Human factor)

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These parameters stand as propositions for the design process towards the generation of various mixed environments, and are organized in three categories:

a. elements and/or qualities that can compose a spatial condition
b. embodied entities that are present in a space
c. issues related to the general concept that stands behind a design approach

It is highlighted that the selection of (design) methods for representing the incorporated (to the environment) information is significant. Specifically, it is argued that representation should be related to memory, and especially to the user's embodied and kinetic memory. The implementation of familiar (physical or virtual) activities and events, is also noteworthy in order to produce spaces that are able to reflect upon user's previous experience, facilitating their easier adaptation to the new/designed environment. In this context, the parameter of realism is also critical. Regarding the parameter of orientation, and the way that the incorporated elements (physical or abstract) act as stimuli and triggering points, another important aspect is the way that information is spatialized. In this line, co-presented embodied entities and the developed cooperation with them, in an implicit or explicit way, have significant contribution, while promoting a sense of shared awareness and communication.

Another notable condition is the nature/content of the represented information (i.e. whether is physical or digital), since it is argued that it affects user's behavior, and the extent of engagement toward medium, as well as the developed mechanisms for obtaining knowledge. In this direction, it is also important the nature of interface (i.e. tangible objects, wearables etc.) that is implemented since it determines the sensory centers that are stimulated (i.e. vision, proprioception etc.), and the embodied skills that are applied (i.e. kinesthesia, gestures etc.).

The human factor, in the light of the embodied engagement and the orchestration of bodily movement, is also crucial, as far as interaction and mechanisms of obtaining knowledge are concerned. However, in this case, it is not only the user's body that is taken into consideration. The manner that co-presented (embodied) entities are included in the designed environment is also essential. Therefore, it is sustained that apart from perceptual cues, a mixed environment should also contain trigger points that boost the embodied engagement and sensory cooperation, promoting the formation of a shared communicated experience. This experience stems from the proper spatial and bodily correlation, as far as interaction is concerned, turning the entire experience to a sense of shared awareness; a rather meaningful aspect for informal learning environments. Again, the parameter of co-presence is significant, since it affects the learning process as far as the interaction methods are concerned. In this direction, co-presence is related to the so called "actor-observer effect", leading to the development of alternative kinesthetic behaviors (i.e. mimicking or avoiding performing the same actions). This observation is considered crucial, especially for designing an environment that will be used by a wide range of people, with differences familiarity to the use of technology (such as a museum or an exhibition space).

5. Discussion

The present paper is part of on-going PhD research, seeking an alternative design framework for analyzing and generating mixed environments through the lens of presence and embodiment. In the context of this research, Mixed Embodied Presence (namely the coherent sense of presence that derives from the progressively embodied engagement and interaction in an environment consisting

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of physical and digital aspects) is proposed as a notion and a variable that can reflect a variety of embodied and spatial aspects that can contribute to architectural design towards the realization of such environments. Apart from literature review, an experiment was run, so as to verify the hypothesis formed on the ground of this proposition.

Through the experiment, a number of parameters and hypothesis referring to the spatial and embodied qualities that could characterize a mixed environment, were highlighted. These outcomes were interpreted to spatial conditions and designed methods through an analysis in the light of the notion of presence and embodiment; parameters that were utilized as a common ground upon which the definition of Mixed Embodied Presences was formed.

To summarize, and in the light of the notion of mixed embodied presence, the parameter of co-presence is considered as a crucial variable, concerning the generation of mixed environments. It has been argued that, this parameter can enhance the coherent lived experience of a mixed environment, due to user's active embodied engagement, provoked from her/his interaction with other participant embodied entities. In this direction, the orchestration of movements in the designed space, is also significant. Moreover, the mediate or immediate embodied interaction can lead to the comprehension of the materialized spatial concept, in a meaningful way. Furthermore, co-presence can affect the learning process, as far as the familiarization of user with the incorporated interactive methods is concerned, which also leads to the creation of a seamless (i.e. not disrupted from the different spatial aspects) and more natural interaction.

Another notable variable that is highlighted is the determination of the way that the included elements and artefacts (physical and digital) are spatialized. This decision is considered as vital since it can provoke a variety of behaviors, while triggering and activating sensory skills that promote the formation of a coherent lived experience. Enriching spatial elements with dynamic qualities (i.e. displaying interactive videos on a wall) can enhance the proper communication of the spatial content; something that can be also perceived as an intention of the environment to establish some kind of communication. The aforementioned design gesture is not only related to the way that information is spatialized, but also to the selection of the proper medium that will produce an essential interaction between user and environment.

The suggested taxonomy does not only aim to function as an alternative design framework for mixed environments (in the light of mixed embodied presence), but also to enrich the design process of the emerged new technological-driven realities and spatialities, with the unpredictability of embodiment and embodied presence.

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Design space exploration through force-based grammar rule

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Abstract

Design exploration frames the process of understanding design as a challenge and helps taming its complexity. It is a creative, but also paramount, process, that flourishes diversity, emergence and variability. The approaches used during this exploration stage can widen, or narrow, the domain where design variants can be found. Computational tools have shown their great potential to explore design in a fast way. However, the digitalization of the process is not sufficient to ensure the generation of radically new designs and subsequently not guaranteed to explore the full range of the design space. The design of architectural forms, that are structurally relevant, shares the same challenges and risks. Additionally, it introduces equilibrium constraints.

This paper presents a design framework, which fuses force-driven grammar rules for the generation of unprecedent spatial structural systems that go beyond any existing catalogues of mathematically known structural typologies. Operating on a rule-based level rather than on a variable-based level, allows the incremental transformation of the model and the backtracking to previous steps, while static equilibrium is always retained. The acquired transformations are possible to be slightly or highly constrained along with the designer's intended exploration preferences.

Keywords

grammar rule, graphic statics, static equilibrium, structural exploration, structural design

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Introduction and problem statement

Design is an ill-structured problem [Simon 1973] characterized by open-ended expectations, emerging constraints, non-quantifiable features, the absence of global optimality and contradicting solution paths. As design is a "wicked problem" that "one cannot first understand, then solve" [Rittel and Webber 1973], it requires gaining knowledge about it. Designers tame this complexity through the creative processes of design exploration. Design exploration frames the systematic, iterative generation of design candidates. Ultimately, during this process they aim to gain and/or extend this knowledge. Traditionally, this knowledge only sources from the designer's own experience, fact that leads to the generation of resembling designs, which only represent a tiny fraction of the prospective design candidates. This tendency for premature design fixation is typically followed by lack of creativity.

Recently, the generation of architectural forms became assisted by parametric workflows. Parametric logic allows the variation of a finite set of numerical values within predefined domains, usually set by constraints [Mueller et al 2013]. Though this approach offers the possibility to alter design candidates in an automated way, it is not sufficient to automate the generation of radically new design candidates. Thus, the design freedom and exploration are limited by the available input parameters and the way their parameterization leads to the solution. Moreover, current design workflows seldom provide instant structural feedback. On the other hand, mainstream approaches to design spatial architectural forms that are structurally relevant consist, either, in adapting known geometries, or in searching the optimum solution of well-defined problems. The domain of structural forms in-between is yet to be explored.

Consequently, prospective ways for architects and engineers to improve the structural design process may consider the:

- Computational approaches that tackle the emerging constraints and ease the generation of alternative pathways; rather than computerized approaches that focus on drafting.
- Investment on rule-based rather than on variable-based design; parameters freed from predefined domains that structure the design logic itself.
- Integrated workflows of structural evaluation within the creative process; avoided structural feedback as a discrete and disconnected subsequent step, and structurally informed generations.

Following these principles, this paper presents a force-driven grammar rule, for the generative, interactive and conceptual design of planar structures. Its successive application within an algorithmic framework operates as a form-finding engine, capable of generating numerous design candidates in static equilibrium within a given design domain. Overall, this computational method shows premises to: (a) provide instant feedback on developed axial forces, (b) explore alternative conceptual structural designs and (c) unveil new typologies of structural systems.

Current state of research in the field of force-driven conceptual design

Computational methods, which allow designers to generate and explore the design space more quickly, while handling the design challenges incrementally, interactively, and in a creative way, are needed. This has become clear to researchers that are consistently contributing towards this direction. Current generative solvers are of two main kinds: iterative methods, when convergence is key (e.g. for form-finding of a mathematically approved design solution), and heuristics, when explora-

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tion is key. In both cases, the ultimate objective is achieved through numerical modification to the variables, rather than through generative rules that re-establish the topology of a structure and its variables' relationships (see chapter "Rule-based design | Shape grammars"). The former ones provide a global optimum. However, plenty of these approaches are not applicable when the number of design variables (e.g. the number of bar elements) increases, due to unmanageable computation time. This does not mean that they are unsuitable for structural design, but rather play a limited and very precise role in the design process [Fivet 2013]. On the other hand, recent research projects focus on generating a diverse set of near-optimum solutions [Martini 2011] [von Buelow 2012] [Mueller 2014], rather than aiming at finding the single optimum solution. These approaches allow designers to balance mathematical optimality with non-mathematically expressed and non-predictable criteria.

The stage of conceptual design includes two crucial operations: (a) creativity evocation through the design exploration, followed by (b) impactful decision making. Tools that assist good decision making at this stage are of great help to designers [Harding 2012, 2017]. Overall, structural design exploration is assisted by novel methodologies that merge conceptual structural design approaches, i.e. graphic statics, with evolutionary algorithms, i.e. genetic algorithms, and rule-based design, i.e. grammar rules/ shape grammars, which effectively explore the design space. Through the use of design grammars and interactive fitness functions, [Byrne et al., 2011] have shown that Grammatical Evolution is capable of creating surprising and innovative designs. Ultimately, creativity in design "is not simply concerned with the introduction of something new into a design, although that appears to be a necessary condition for any process that claims to be labeled as creative. Rather, the introduction of "something" new should lead to a result that is unexpected (as well as being valuable)" [Gero 1996].

Graphical form-finding | Graphic statics

Static equilibrium is a basic requirement that all structures must satisfy. A handy way to handle networks in static equilibrium are graphic static methods. Graphic statics combine two reciprocal figures: a form diagram and a force diagram. The force diagram is a vector representation of the force magnitudes and directions within the network drawn in the form diagram. Static equilibrium of a sub-set of bars and nodes in the form diagram is shown by a closed force polygon in the force diagram. Methods of graphic statics were created in the 19th century, to analyze structures. Nowadays, combined with contemporary graphical and computational capabilities of computers, graphic statics gain new relevance for early-stage structural design. Rather than assuming that modern graphic statics are just a computerized version of classical graphic statics, [Ohlbrock 2020] [Lee 2016] developed methodologies that implement graphic statics to generate new structures. Both methodologies are mainly applicable to conceptual and early-stage structural design and ensure static equilibrium without considering the actual material. This means that post-processing is required to size the members etc.

Rule-based design | Shape grammars

[Stiny, Gips, 1972] introduced the term of shape grammars for design, inspired by Noam Chomsky's theories on generative grammars in language. "[Chomsky's] idea was that a grammar had a limited number of rules that could generate an unlimited number of different things, and the resulting language was the set of things the rules produced". The concept of rule-based design is equivalent to shape grammars and opposed to that of variable-based design. Briefly, variable-based design con-

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structs a model from scratch to completion in one go, whereas rule-based design transforms the model in incremental steps (Fig.1).

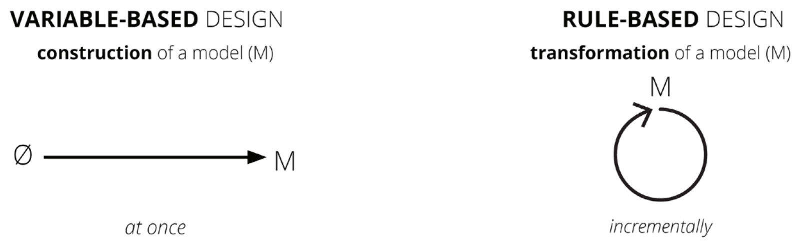

FIgure 1.
Variable-based design vs rule-based design

Variable-based design corresponds to assigning different values to a number of (geometrical) parameters [Strobbe et al. 2015], while rule-based design deals with alternation and rearrangement of design components. Consequently, the former approach is framed around variable relationships that have been predefined and alterations are only allowed at a numerical level, i.e. variables' numerical values. The latter builds purely on topological relationships, easing alterations because the designer has the freedom to reset the existing relationships (numerical or topological). Hence, variable-based design considers designs that are only constructed within human-defined, potentially arbitrary numerical domains, whereas rule-based design considers every possible design, within the design domain. Thus, rule-based design favors diversity, variability, exploration, as well as emergence [Mitchell 1993] [Stiny 1994], without excluding exploitation, if rules are accordingly defined. That said, it does not mean that variable-based design is not beneficial during the design process. It allows for parameterizing the construction of models, that reduces the aim and effort required for changes and reuse [Aish 2005] and eases the numerical tuning of a design (i.e. during optimization).

Shea and Kagan [Shea 1997] [Shea 1999] applied shape grammars to the synthesis of triangulated trusses. Simulated annealing was used to obtain the policy of transformations leading to the optimal shape. [Mueller 2014] applied structural grammars both randomly and manually to generate diverse sets of structural systems. Grammar rules in this case are context specific. [Chakrabarti 2011] reviewed the application of graph grammars (an abstract generalization of shape grammars) for design synthesis.

Method

Mitchell [Mitchell 1991] refers to shape grammars as functional grammars, when the generated design satisfies two conditions: (a) it is realizable using available materials and fabrication processes and (b) it meets specified functional requirements. The present work extends this idea: (a) its theoretical base builds on vector-based graphic statics, which is used to define the syntax of a universal grammar rule, and ensures the static equilibrium of the structure, and (b) a design candidate that satisfies equilibrium is likely to be realizable, provided that the required fabrication processes are available. Analytically, the proposed methodology aims at the transition from a disconnected network in interim equilibrium, to an assembled (complete) one in global static equilibrium. Throughout this transition, the designer has control over parameters that allow him/her to steer the design towards directions that satisfy emerging constraints and, hence, actively explore alternative design candidates that meet functional, or aesthetics-related, requirements. Considering qualitative aspects

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during the generation of networks is a great asset, because even though the generated forms are always in static equilibrium, not all of them represent meaningful structural forms.

As explained beforehand, the proposed method starts with a network (model object, m) comprised of forces in interim static equilibrium, and, eventually, discrete linear elements (bars). Bar networks consist of axially loaded members in compression or tension, are connected by nodes and are in static equilibrium. The interim equilibrium is ensured by a number of interim forces (pool of forces) that act on the network nodes only (applied loads or support reactions). The interim network is contained within a bounded territory, named as design space or design domain (Dd) that is also part of the model object. This domain defines the geometric space, where the network evolves when the designer applies the grammar rule. The complete network, as a result of the recursive rule application, is in global static equilibrium and is also contained within the design domain.

1. Force-driven rule syntax

The proposed grammar rule is force-driven and, thus, it is constructed to retain static equilibrium when applied. Its inception and originality derive from graphic statics (Fig.2). Static equilibrium is already ensured at a rule-level, which means that no additional adjustments need to be made to the existing model to force static equilibrium. This feature, allows the user to easily backtrack on previous steps/iterations of the model, as part of the design exploration process.

The rule is applied on a selection of interim forces, which are found in the pool and are coupled in various configurations to form force candidates (see chapter "Force candidate objects"). In every iteration, the user is invited to control the type of transformation that the rule application will have on the interim network (see chapter "Entropy rate"). The chosen type of transformation is usually only satisfied by a limited number of (feasible) force candidates. Again, the user has the possibility to actively select (see chapter "Ranking policy") the chosen candidate, among the feasible ones.

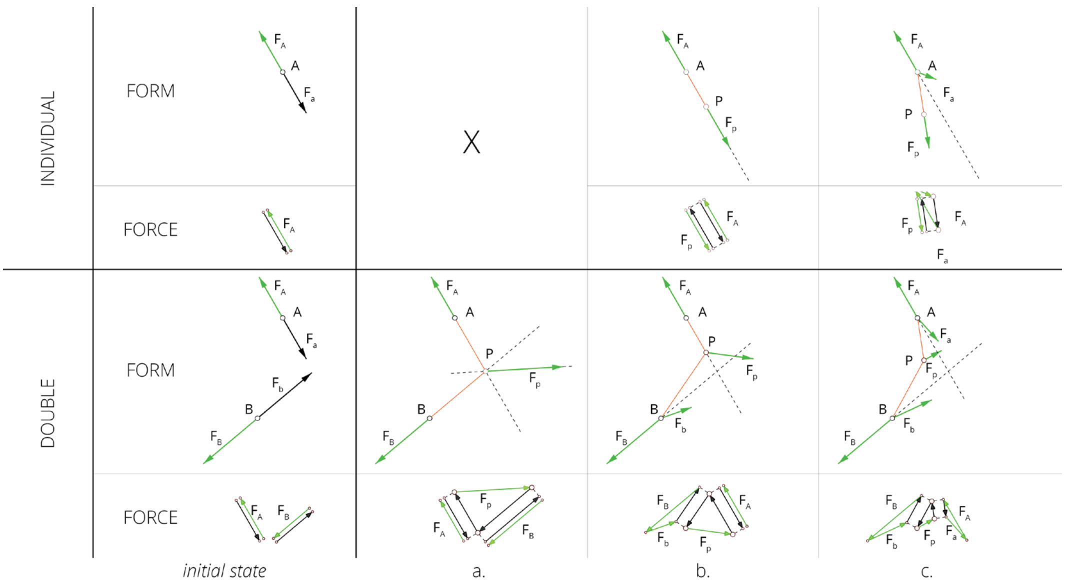

Figure 2.
Grammar rule syntax (a. convergence, b. stagnation, c. divergence)

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After, the rule is applied onto the chosen candidate, aiming to transform the network, according to the selected entropy rate. A network undergoes three different geometric transformations as a result of different entropy rates: converge, stagnate, or diverge, i.e. decrease, maintain or increase the total number of remaining interim forces. The interim forced are replaced by bars, adjacent to a new point (ptnew), and when necessary, new interim forces are introduced. These introductions are imposed by the necessity to keep an incomplete network in interim equilibrium. The process continues until no interim forces remain.

2. Force candidate objects

The force candidate objects represent all possible combinations of interim forces where the grammar rule is applied onto. In two dimensions, there are two types of candidate objects: individuals and doubles (Fig.3). Each type includes one or two interim forces, including all possible sequential configurations.

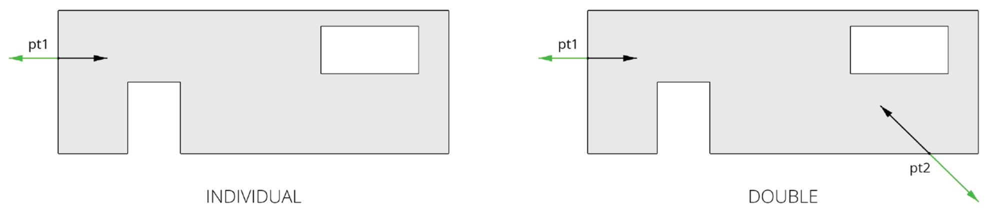

FIgure 3.
Types of force candidates; reflect the number of involved forces

Individuals refer to unpaired interim forces. Hence, the number of individual candidates is equal to the number of interim forces in the network. This candidate type does not allow the network to converge when the rule is applied. All other transformations are feasible though. Doubles refer to all possible couples of forces. The sequence of the forces forming a double candidate results in different allowable transformations under identical conditions. For that, all possible sequential configurations have to be considered. Doubles allow all types of transformations. The total number of prospective force candidates is calculated with the following expression:

$$no_{candidates} = \binom{n}{1} + \binom{n}{2} = n + n(n-1) = n^2$$

where n, the number of temporary forces.

For example, a network with three interim forces (i.e. A, B, C) has a total of 9 prospective force candidates, as shown at the table below. However, their feasibility to undertake the chosen transformation is not known yet.

individuals:	A, B, C
doubles:	AB, AC, BA, CA, BC, CB

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3. Designer-controlled parameters

The designer can actively control the way the network transforms via two variables: entropy rate and ranking policy. Analytically:

Entropy rate

The entropy rate controls the rule's application impact onto the system. The rule application includes the introduction of a new point too. The preferred type of transformation, constrains the domain where this new point is located at, either to a single point, or on a segment, or within a planar region. This strictly defined domain, called entropy rate domain (Der), refers to the new point's prospective location and is force candidate-specific, i.e. it directly depends on the anchor point and the direction of the forces formulating a force candidate object (see chapter "Entropy rate domain").

Ranking policy

The force candidate objects, which allow the rule application, namely, the feasible candidates, are sorted out according to designer-defined preferences that can be performance-, geometry- or aesthetics-related. These preferences are called ranking policies. The feasible candidates are ranked according to them. Examples of policies could be:

- Choose the two forces whose distance between anchor points is minimal/maximal;
- Choose the two forces that are the oldest (or newest) ones in the pool;
- Choose the two forces with maximal (or minimal) magnitude;
- Choose the two forces whose design space of new node has the largest (or smallest) area;
- Choose the two forces whose design space of new node has the narrowest (or widest) area;
- Choose the two forces whose orientations are the most parallel (or perpendicular);
- Choose the two forces that are applied the closest (or furthest) from the boundary of the feasible region;
- etc.

4. Feasibility domain

Simply coupling interim forces to construct force candidate objects is not sufficient to apply the rule onto. A candidate is feasible, only if after the rule application the introduced point and the bars are contained within the design domain and the model retains its static equilibrium, namely if the feasibility domain (Df) is not empty. The way the Df is constructed, as well as the supplementary and supportive domains that need to be constructed per candidate, are described below:

I Entropy Rate Domain (D_{er})

The entropy rate domain describes the geometric domain where the introduced point (ptnew) must be located at, in order to achieve the chosen transformation after the rule application. Its size depends on the entropy rate. For *convergence*, the entropy rate domain explicitly consists of a single point in space ($D_{er, conv} = \{x, y, z\}$ and $\{x, y, z\} \in D_d$). As such, there is a unique solution for every feasible *double* (force candidate) that allows the network to converge (Fig. 4a). *Stagnation* is ensured for all points introduced along the segment that is defined by the force direction of the force candidate (Fig. 4b and 4c). For *divergence*, the entropy rate domain is irrelevant to the candidate type,

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and always equals the *design domain* ($D_{er, div} = D_d$) (Fig. 4d and 4e). In order the grammar rule to be applicable to a force candidate object, the following two conditions must be satisfied, among others; the *entropy rate domain:* (1) must not be empty ($D_{er} \neq \emptyset$) and (2) must be a subset of the design domain ($D_{er} \subseteq D_d$). If conditions (1) and (2) are satisfied, it is known in advance that a new point can be generated inside the design domain. However, this is not a sufficient condition to define whether the chosen transformation is feasible or not.

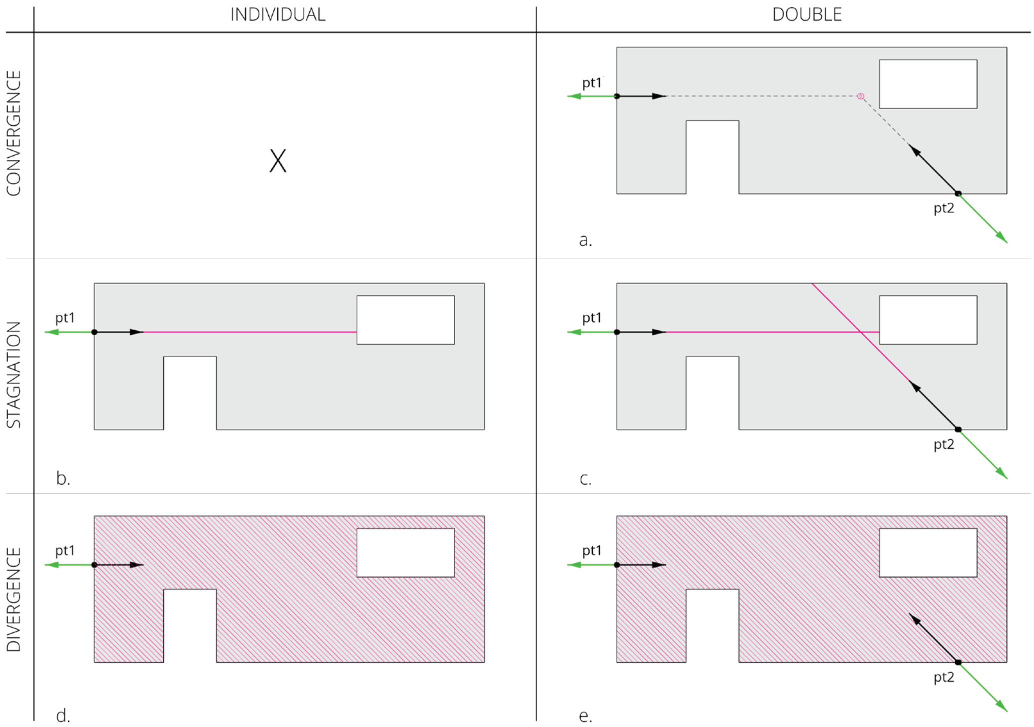

FIgure 4.

Entropy rate domains (magenta), green arrows are applied loads or reactions, black arrows are interim forces.

II Constructability Domain (Dc)

As the rule aims to replace the interim forces by new bars, the new point needs to be reachable ("visible") by the anchor points where the interim forces are applied to, i.e. one anchor point for *individuals*, two anchor points for *doubles*. Geometrically speaking, the segment connecting the new point with the anchor points must be uninterrupted by voids or non-convexities of the design domain. This new restriction defines a new domain, called *constructability domain* (D_c) and defines the region where the creation of two continuous segments, i.e. from one anchor point to the new point and from that point to the other anchor point (Fig. 5), is feasible. The *constructability domain:* (1) must not be empty ($D_c \neq \emptyset$) and (2) must be a subset of the *design domain* ($D_c \subseteq D_d$). If conditions (1) and (2) are satisfied, it is known in advance that the two bars can be built inside the *design domain.*

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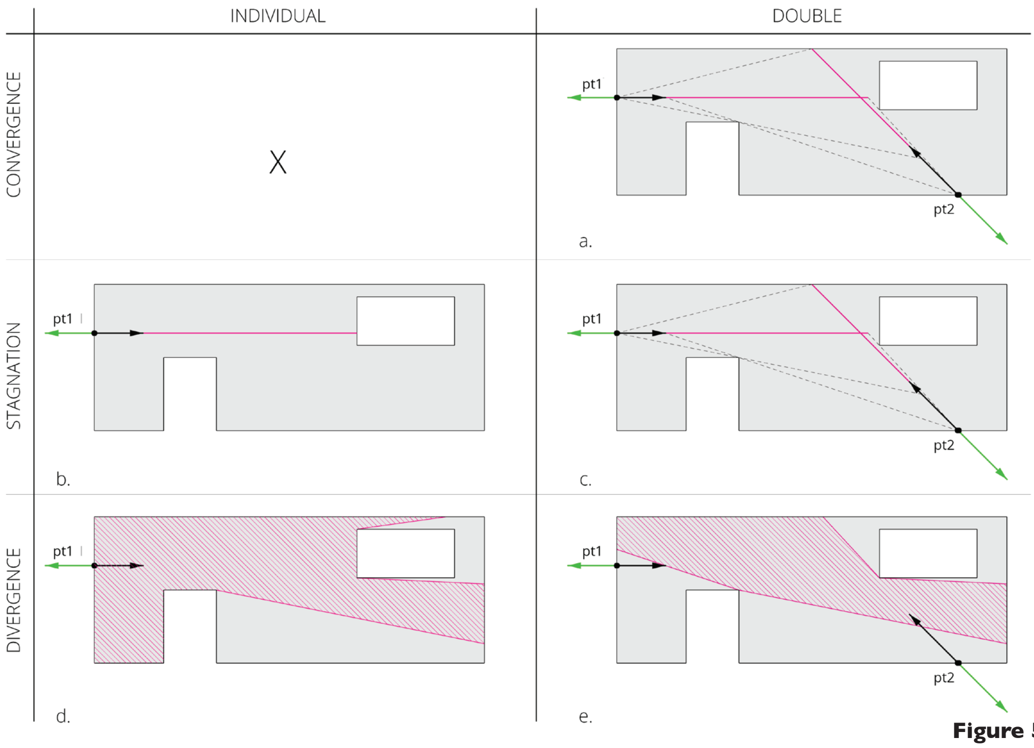

Figure 5.

Constructability domains (purple), green arrows are applied loads or reactions, black arrows are interim forces.

III Feasibility Domain (Df)

As part of the transformation, and in order for the model to retain its static equilibrium, a new point (pt_{new}) and one (Fig. 6b and 6d), or two (Fig. 6a, 6c and 6e), new bars (b_1 and b_2) are introduced. The bars replace some of the existing temporary forces. In order to ensure that the chosen geometric transformation is feasible, pt_{new} must belong to D_{er} ($pt_{new} = \{x, y, z\} \in D_{er}$). On the other hand, in order to ensure that the bars b_1 and b_2, adjacent to pt_{new}, can be built, they must belong to D_c ($\{b_1, b_2\} \in D_c$). These two requirements are met if, and only if, the intersection of D_{er} and D_c belong to D_d ($D_{er} \cap D_c \in D_d$). This intersection defines the candidate's *feasibility domain* (D_f) for a specific *entropy rate*. This means that the chosen geometric transformation of the model is only feasible if D_c is not empty ($D_c \neq \emptyset$). As D_{er} and D_c are candidate-specific, D_f is candidate-specific too. It is unknown whether a candidate can successfully lead to the chosen geometric transformation, before computing D_f. At the same time, more than one candidate might have non-empty D_f. In that case, they all qualify as feasible candidates and a force candidate will be selected according to the chosen ranking policy.

5 Model Update

The rule application results in transforming geometrically the model. The evident changes include: (1) the introduction of a new node (pt_{new}); (2) the iterative replacement of the interim forces by new bars in compression or tension, inherently retaining static equilibrium; (3) the introduction of new interim forces when necessary. Before the rule application, forces (both as individuals and as pairs) are sorted according to the ranking policies. Next, they construct a force candidate and its

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feasibility domain is computed. If the domain is empty, the next pair of forces, or individual force, constructs a new force candidate. The procedure continues (a) either until either the candidate's feasibility domain is not empty or (b) until all sorted forces have constructed a force candidate. In the former case, the rule application continues. The model is safely transformed retaining its static equilibrium and the involved temporary forces are eliminated from the pool of forces. This procedure continues until the pool of forces is empty. At that moment, the model is complete. In case all forces have constructed an unfeasible force candidate, the entropy rate has to get decreased. If the chosen entropy rate is convergence, the entropy rate updates to stagnation. If stagnation is chosen, the entropy rate updates to divergence. If divergence still does not yield a feasible candidate, the process is terminated. The decrease happens because a candidate has more chances to diverge than to converge. That can be explained by looking at the size of the respective D_{er} domains.

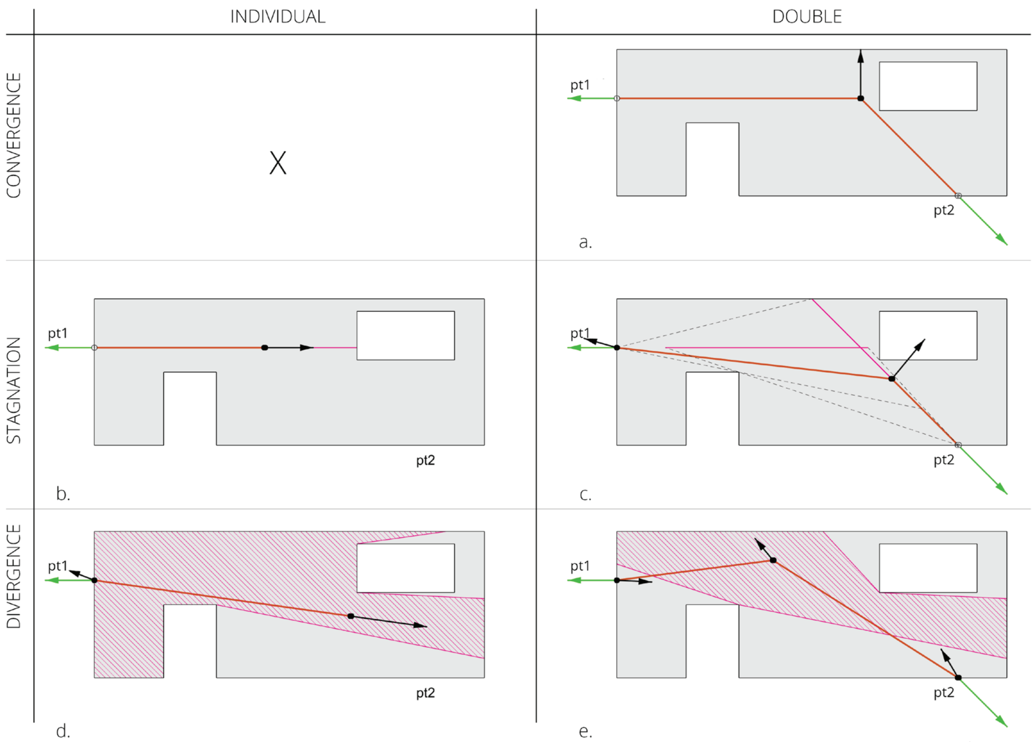

Figure 6.
Rule application results. Feasibility domains (purple), green arrows are applied loads or reactions, black arrows are interim forces, red bars are ties.

Application studies

The rule application on an interim model, consists in incremental transformations that complete the model and bring it in a state of global static equilibrium. This incremental procedure is shown below (Fig. 6). These transformations are highly affected by chosen *entropy rates*, chosen *ranking policies* and the nature of the design domain (e.g. presence of non-convexities or voids). Affected aspects include the total number of steps required to complete an interim network, the sequence of entropy rates, which might be altered if no force candidate is feasible for the chosen entropy rate, the topology

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and the geometry of the model, as well as the final aesthetics and the design freedom overall.

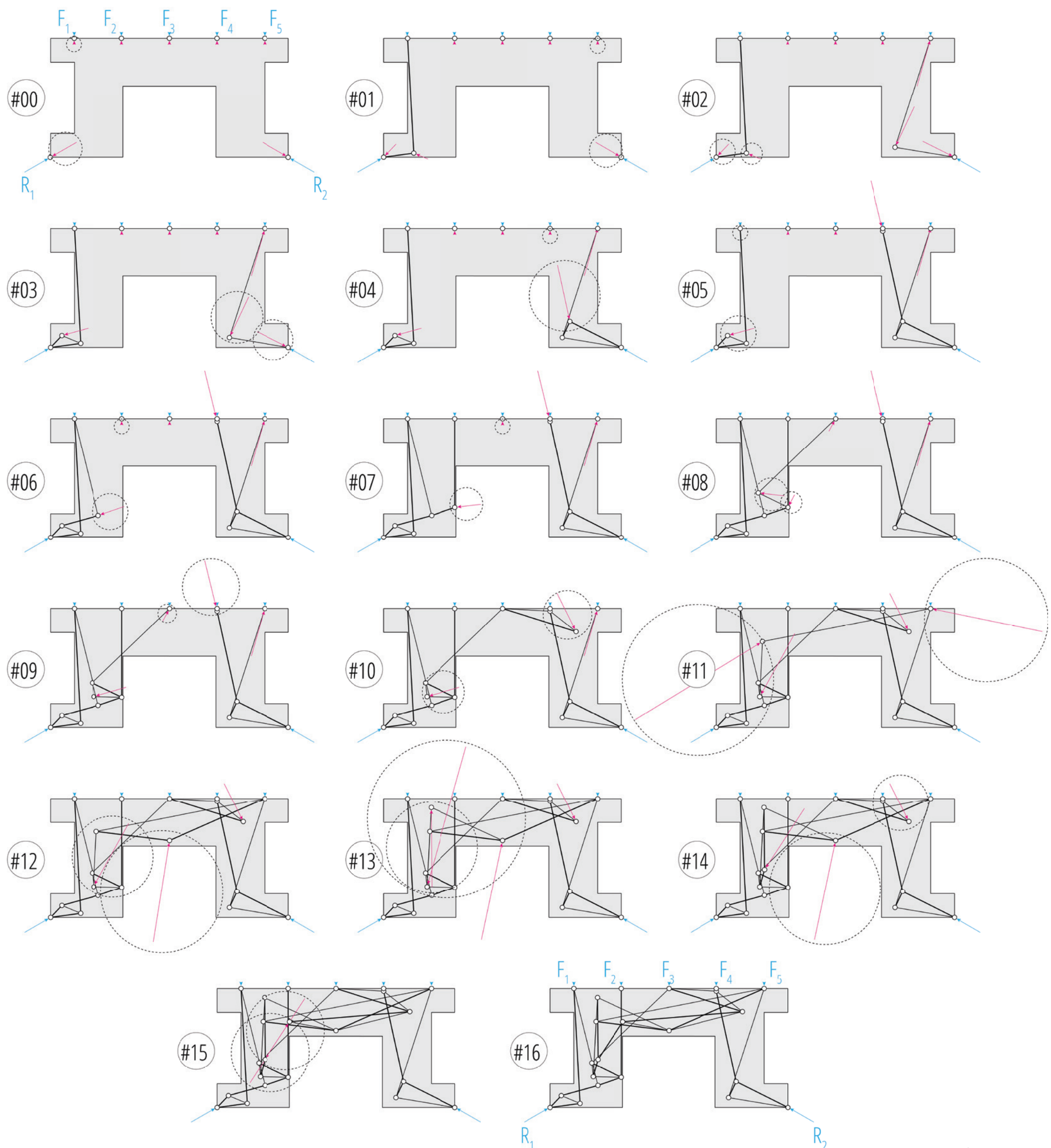

Figure 7.
The rule is incrementally applied and converges after 16 steps. Forces selected to form a force candidate object are circled. The process terminates when the pool of interim forces is empty.

1. Nature of design domain

The shape of the design domain has remarkable impact on the incremental rule application, depending on its convexity and the presence of voids. In general, added complexity increases the number of transformations required until an incomplete network converges to a complete network in global static equilibrium. The small size of the convergence entropy rate domain disqualifies prospective

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force candidates to be chosen for the rule application. Often, no force candidate can undergo convergence and the entropy rate has to get decreased. Below the impact of convexity and cavities is demonstrated.

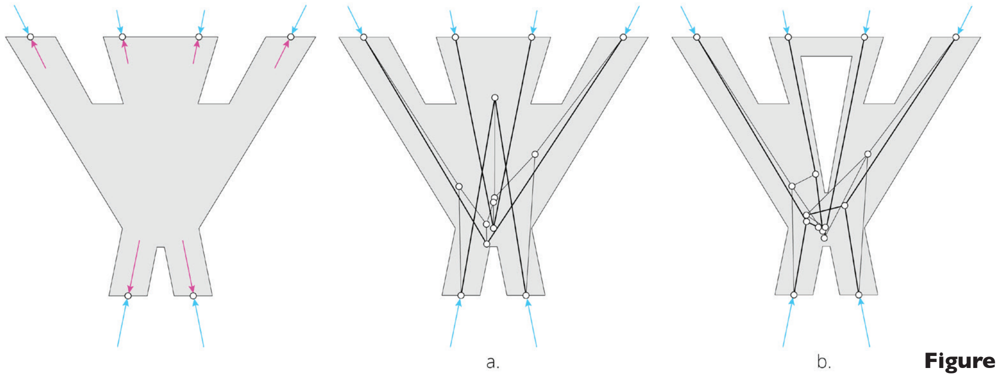

Figure 8.
Impact of design domain on rule application: (a) non-convex boundary without void: 9 steps, (b) non-convex boundary with convex void: 13 steps

2 Entropy rate sequence

This case study considers the exploration of a load-path between two equal, opposite forces (Fig. 9). Different number of initial diverging rules is considered on each row, from left to right, all subsequent applied rules are converging.

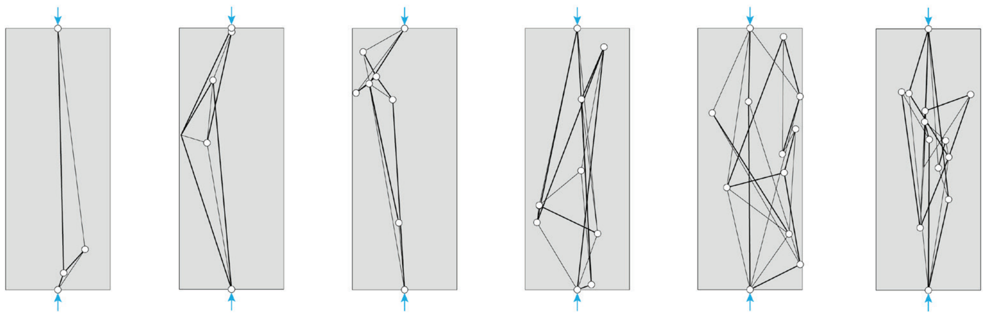

Figure 9.
From left to right the number of steps the system diverges for increases by 1. As a consequence, the number of steps required to converge increases. These additional steps introduce more bars and the structure becomes denser.

3 Ranking policy and selected force candidate

In this case, the situation of two symmetrical supports and a uniformly distributed force on a plane is examined (Fig. 10). Two different ranking policies to select the forces candidates are studied: random selection (Fig. 10a); selection of the two forces whose intersection is closest, which naturally leads to an arch (Fig. 10b). In both cases convergence is chosen.

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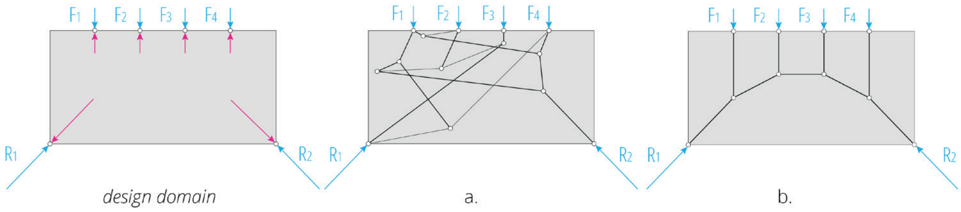

Figure 10.
In the middle (a), the force candidates are selected randomly. This influences the candidate's ability to convergence. On the right (b), choosing the ranking policy intelligently on every step, leads to the generation of a rational structure.

Conclusions

The proposed methodology has proven its capability of generating versatile reticulated structures in static equilibrium. Currently the location of the new node is randomly chosen within the feasibility domain, whose generation is the main concern, and thus final structures look neither rational nor functional. In cases that optimization for specific objectives is not part of the design process, the creation of a feasibility domain allows the designer to understand the variability range. His/her decision making will influence the size of the feasibility domain at the following step and, in combination with the intended entropy rate, shrink or expand the variability range.

Contrary to precedents, static equilibrium at every intermediate step is not achieved through triangulation but through the structural awareness that is embedded into the grammar rule syntax. This way, the design space can be explored thoroughly. Regardless of the number of completed steps and the size of the existing structure, i.e. number nodes and bars, in every iteration, the selected force candidate acts as a sub-system in interim equilibrium. Consequently, the algorithmic complexity does not increase along with the number of steps. Specifically, it is polynomial, as the application of the grammar rule only requires solving a simple matrix. After the rule application, this sub-system gets integrated into the existing structure.

Very few methods allow the designer to choose the number of steps which the process will converge, stagnate or diverge for. The user has direct control over the convergence (or divergence) on demand. Additionally, the fact that interim static equilibrium is ensured at all intermediate steps of the process, allows backtracking on previous design variants and favors exploration of the design space.

Last but not least, the model transformations (convergence, stagnation, divergence) are part of the same, universal rule, i.e. the same matrix is used to solve the rule application. Contrary to previous approaches, this rule is independent of specific structural typologies and is unaware of the designer's intentions. This disconnection allows designers to escape from catalogs of structural systems and frames a new, broader, domain, where new structural forms are to be discovered.

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Affonso Eduardo Reidy and the Aterro Do Flamengo Pavilions. Structural Concrete Shells During Modern Revisionism

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Abstract

This article focuses on the research of the last three works built by Affonso Eduardo Reidy, designed in 1962 for the urban project of Aterro do Flamengo, in Rio de Janeiro.

The conception of the Coreto and the Morro da Viuva and Flamengo Pavilions is based in the logic of concrete shells and folded plates. This structural system, despite being used since the end of the XIXth century by engineers, was ignored by Modern Architects until the second half of XXth century. The reason for that can probably be found in its formal and expressive connotations, and their assimilation in the Modern Movement occurred only after some conceptual changes produced within the revisionist context of the 50s and 60s. While the combination of forms can be infinite, most of the architects intended to optimize the structure in terms of material saving, logical construction or easier calculation. In order to do so, they studied natural shapes to find the most efficient variables.

Through these three modest buildings designed by Reidy, this article will try to analyze not only the key points of this assimilation, but also the intrinsic qualities of the structural system, based on the variations and the flexibility of the same geometric principle.

Keywords

concrete shells; folded plates; structural system; Reidy

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1. The ambivalent nature of concrete shells and folded plates: structure and envelope.

The music stand (also called "Coreto") and the two pavilions built for the Aterro do Flamengo Park by Affonso Eduardo Reidy, in Rio de Janeiro, are three small buildings that remain imperceptible within the architect's rich architectural legacy. However, its chronological position at the end of his professional career makes them specially interesting. Not only for synthesizing some important features of Reidy´s work, but also for showing new strategies that, even appearing in previous works, can be better seen in these three buildings. Reidy's premature death in 1964 didn´t allow the possibility of continuing this research, remaining halted in the pavilions.

The construction of geometric concrete forms to increase the structural stability is a common strategy used in all three works. Their shapes are defined by the principles of this system, resulting in a prominent variety of solutions. Even though they belong to the same structural family, the differences are also remarkable: continuous folds of concrete plates define the Coreto and the Morro da Viuva Pavilion. However, while the Coreto (fig. 1) shows a delicate and open composition, based on an umbrella structural typology, the external appearance of Morro da Viuva Pavilion (fig. 2) is circular and hermetic, an abstract volume based on the radial deformation of the same folded unit. The Flamengo Pavilion Playground (fig. 3) can be considered a different variation of the system: geometries are based in curves and not in folds. Specifically, all components are curved in just one direction. In addition, the building is composed by different units resting one on each other and not as a continuous concrete element.

Figure 1.
Coreto Music Stand

Figure 2.
Morro da Viuva Playground Pavilion

The complex geometry of the pavilions reveals Reidy's intention to experiment with different solutions and reach a variety of architectural forms. This strategy is also related with other concepts that were highly valued by Reidy, like economy, prefabrication and structural expressivity. However, comparing to the structural concept, other parameters look secondary or not considered. This fact can be easily seen in several inconsistencies in the architectural solution in relation with the program required.

The mushroom typology is a well-known approach in 1962 and a widespread typology used by Modern architects. It normally works by addition, as a combination of several units to compose a bigger structure. This propriety to be combined, applied in most of the projects composed by umbrellas, contrasts with an isolated unit in the Aterro Park. This fact, together with the ambiguous resolution of the program, highlights somehow the intention of the architect to experiment with a structural prototype, rather than designing a correct music stand: the central column remove

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visibility and make difficult the distribution of the band components. The roof, with four segments oriented to four opposite sides, doesn´t seem to be the best solution for an acoustic shell. At the same time, from a structural point of view, the use of folded plates shows a variation that totally differs from other similar structures. Candela´s hypars, probably the most known mushrooms, are based in the membrane theory: the roof works as a thin and continues surface with no hierarchies. Comparing to Candela, Baronni´s umbrellas are based in linear structural ribs to support the roof. From this point of view, the Coreto's approach is closer to an umbrella, with the particularity of implementing the triangular folded logic to establish the structural hierarchy.

The Morro da Viuva pavilion is also based in triangular folded elements, but the logic of the structure is comparable with a dome. The regular external appearance doesn´t show the extreme deformation of each segment in the roof. The reason for that is the oval shape of the top compressive ring. Starting with the same shape in the perimeter, each segment deforms differently to adapt to the geometry of the ring, getting a wide range of variations from a single element. The opaque configuration of the folded shell creates a difficult relation with the environment and makes again wondering if this was the best structural strategy to solve the required playground program.

Figure 3.
Flamengo Playground Pavilion

Even having exactly the same program as Morro da Viuva, the Flamengo Pavilion seems to be the opposite: an open and centrifugal configuration, visually connected with the Park. The structure, based on a beam mounted on two supports is composed by prefab elements that work as almost independent units in a perfect balance. The fact of being fragmented instead of continuous surfaces, reveals the intrinsic variability and the open results provided by the combination of the same ele-

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ments. As the concept of repetition of the umbrellas, this feature is related with other movements appearing in the 60´s against Rationalism. The dynamism and flexibility of Structuralism, based on combinations of the same elements that may compound different results, emphasize the importance of the relation between components. This quality draws the attention to the roof of the Pavilion, showing the archetypical vaults of Modernity upside down, an intentional manifest that changes dramatically the perception of the building and put forward the fact that these elements are not vaults anymore, but beams.

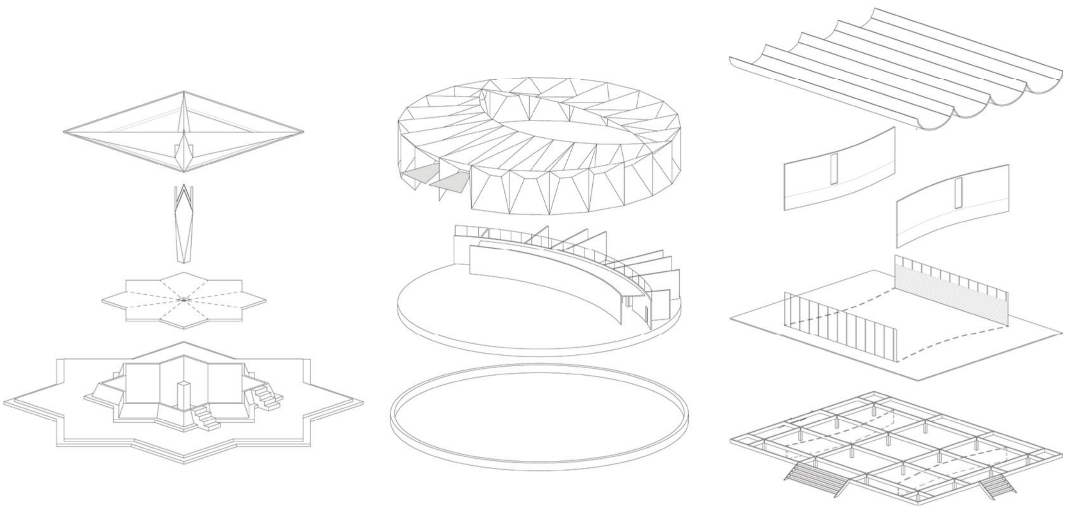

Figure 4.
Axonometric view of the pavilions.

The construction of self-supporting concrete shells has been used in architecture since its origins[1]. Shapes were defined by their structural behavior and the properties of opus caementicium (assuming mainly compressive stresses). These limitations would be solved after the technological development of reinforced concrete in the 20th century, making it possible to obtain other types of shapes with more complex geometries due to the combination of steel and concrete, and thus being able to withstand compressive axial forces combined with meaningful bending moments with thinner cross-sections.

The studies of biological theories around the idea of form and natural evolution in 19th century established the necessary links to influence the structural studies and calculation methods in 20th century. Carmen Jordá (2015) highlights D'Arcy Thompson, and the book On growth and form, as one of the most important texts. The author established consistent rules for biological forms and relations between mathematics and nature, defending the variability of the same shapes in all biological forms based on the same logarithmical spiral.

1 Mass concrete domes, vaults, arches or slurry walls already used these principles in Roman times. The Pantheon in Rome, built around 125 A.D., is the biggest non-reinforced concrete dome in history (Croci 2006).

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These principles, applied to the structural behavior of concrete shell elements, became an infinite source of variations. Even so, the most common forms due to the easier calculation and construction process are grouped in two: folded forms, based on flat surfaces, or curved forms based on ruled surfaces (fig. 4). Among curved forms, Gaussian surfaces, due to its simplicity and geometric logic represent the majority of the forms developed: domes, cones, hyperboloids and hyperbolic paraboloids. Most engineers also applied the principles of catenary on these surfaces, meaning that the form responds mainly to axial stresses (membrane theory), achieving a combination of simplicity of both calculation and construction process. Folded plates work as a combination of different flat concrete surfaces that becomes a bigger element, taking advantage of the spatiality of the form and differing from curved shells in the fact that they don´t benefit from the curvature properties and the membrane behavior, resulting in a more complex calculation.

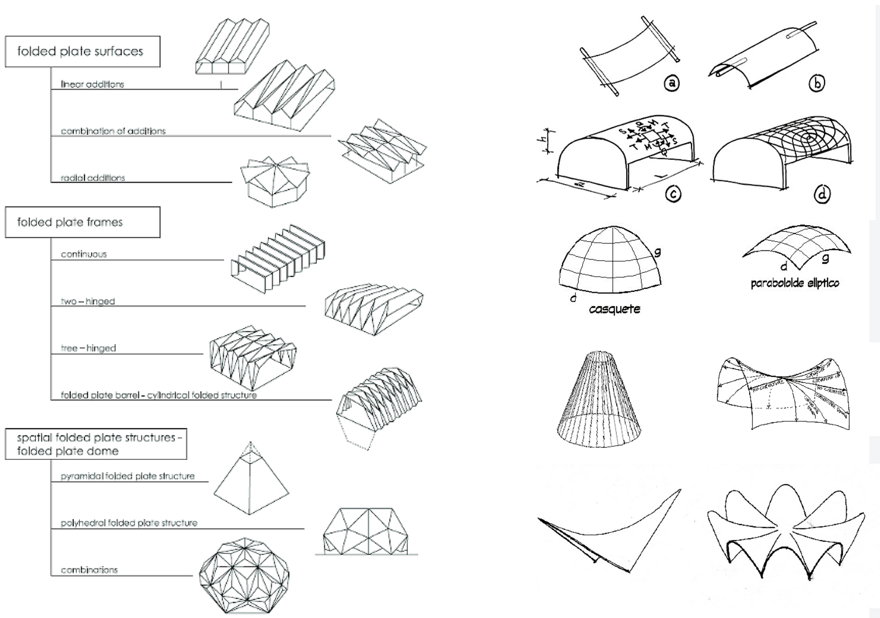

Figure 5.
Examples of reinforced concrete shells classified in folded forms and curved forms

The 1930s mark the beginning of the most remarkable concrete shells structures, establishing their acme between the 50s and 70s (García 2013). Mainly used for infrastructures, engineers like Eugène Freyssinet, Pier Luigi Nervi or Eduardo Torroja, among many others, designed all kind of buildings based on the geometric form as the principle of the structural optimization. Most of the works were public, in many cases covering large areas for specific programs. To do so, they developed calculation methods which made possible big spans using shells that may have a thickness of just 5 cm. Freyssinet's hangars in Orly in 1923 (fig. 6), Torroja´s Fronton of Recoletos in 1935 (fig. 7), Candela´s structural hyperbolic paraboloids (fig. 8) or the UNESCO Auditorium (fig. 9) by Pier Luigi Nervi between 1953 and 1958, are revolutionary structures built with this technology which covered huge areas with reduced material.

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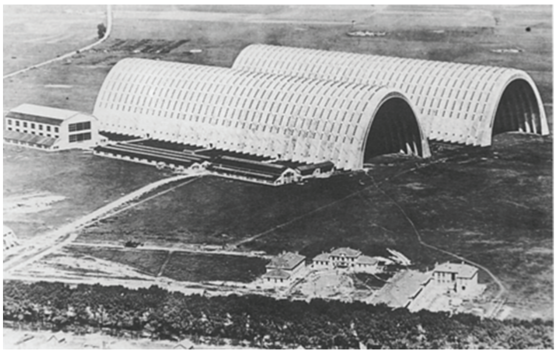

Figure 6.
Hangars in Orly by Eugéne Freyssinet

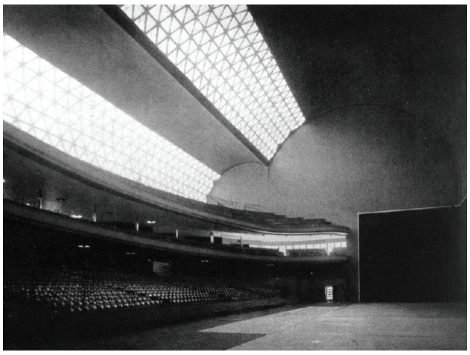

Figure 7.
Fronton of Recoletos by Eduardo Torroja

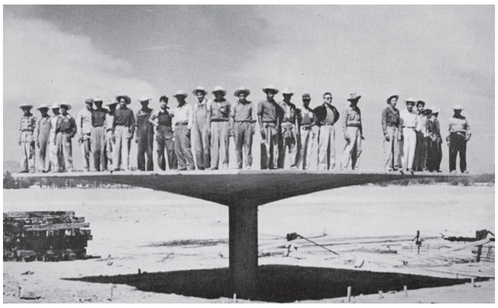

Figure 8.
Hyperbolic paraboloid by Felix Candela

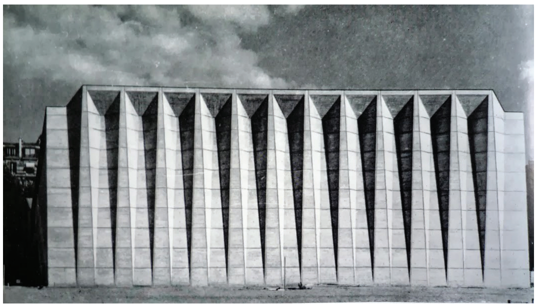

Figure 9.
UNESCO Auditorium by Pier Luigi Nervi

In an international context, in 1962 -year of the Aterro´s construction- the use of folded or curved elements was widespread. Therefore, Aterro Pavilions are not rare and isolated components in their context, but the consequence of contemporary and globalized approaches to new architecture strategies. In Brazil, concrete shells like vaults were common and used as structural element among many of Modern Architects since the 30s. Actually, Reidy projected several vaulted slabs in previous projects. However, all of them were configured only as roof elements, or just as complementary elements within a larger volumetric composition. Somehow, the potential of the system remained still unexplored until the Aterro Pavilions.

Probably, within all parameters that defined Reidy's architectural approach, the building techniques are the ones he put more emphasis on, as they allowed him to explore the potential of the structural form and its expressivity in the volumetric composition.

As Roberto Conduru abridges:

> In summary, Reidy's architecture is a research of the dialectic between the load bearing element and the building enclosure in their formal configuration. Starting from pure volumes in which the structure is embedded in the enclosure, the architect first differentiated the structural elements, then broke with the volumetric purity, after this brought the structural elements to the perimeter of the volumes and, finally, he returned to pure volumes, although preserving the distinction between structural components and enclosure. (Conduru, 2005).

In his last three works, this relationship seems to reach its limit, achieving a more extreme stage. In the Aterro there is a total fusion between volume and structure in a single element, so there is no distinction between structure and envelope. In addition, Reidy seems to bring to a more advanced stage different aspects previously experienced in other projects: the structure gets more sophisticated and complex than other concrete shells in the past. Also, there is a clear interest in optimizing the structural resources, designing elements as slender and thin as possible, in some cases 4 cm

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thick. Finally, even if Reidy used exposed concrete in the past, this time it is used as a global material, solving not only structure, but floor, walls and roof. Reidy took the role of the structure to the limit, conditioning the whole compositional and expressive aspects (Conduru 2005).

2. Conceptualization of the structure as an autonomous component. A necessary step for concrete shells

Which are the intrinsic peculiarities of concrete shells structures?

Generally speaking, there are three features that define them versus other structural systems:

- Structure and envelope as the same element,
- Formal expressivity generated by the combination of geometric forms.
- In case of concrete being exposed, the structure also defines the expressivity of the architectural surface.

The use of self-structural concrete shells and folded plates is strongly related with the idea of the structure becoming the generator of the architectural form, acquiring its expressivity through the logic of the structural geometry. Concrete shells changed the Modern paradigm of form when the architects leave the result of the architectural volume to this principle, loosening its control or putting in a second place other variables for the sake of structural optimization. This new parameter, shielded on scientific principles, let Modern Architects to break free with the static International Style standards in order to introduce, for the first time, a formal variable not controlled by composition.

Putting aside the concrete vaults previously named, during the first stage of Modern Movement it was unconceivable, except in rare circumstances, the use of such expressive elements. This fact highlights an obvious aspect to understand the way concrete shells were introduced: their conceptualization can only become part of Modernity after some changes that validate the intrinsic qualities of the system. The narrative, experiences, and contexts that let this particular type of structure to be validated are not simple and would need a different article. It is even based on certain aspects that in many cases would be contradictory with the International Style, needing a gradual process of assimilation.

As Iñaki Ábalos explains:

> Despite the radicalism in the postulates of Modern Movement and the abstraction of its architecture in relation to the context, there are formulations that could not be correctly stated by their contradiction with the bases of the movement. Some of the most representative architects, such as Le Corbusier, Bruno Taut or Mies Van der Rohe, among others, established links between the picturesque aesthetics and Modern ideology that escaped from the postulates that they established (2005, p.115).

Ábalos unmasks the "picturesque" elements in Le Corbusier's work. The author explains how, while many of them were "latent" from his early theoretical postulates, gradually and "almost secretly" they took over his way of designing to conquer all the scales of architecture in its final stage. Among

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the most representative elements of the picturesque elements are three major questions that would be characteristic of Le Corbusier's latest work: the importance of the context, or *Genius Locci,* the *Promenade Architectural* and the use of exposed concrete. Moreover, Ábalos shows two different stages in the architect's postulates: a first, positivist stage, with a total fulfillment in the social and technological development on the basis of a scientific nature, against a late stage, after World War II, where nature becomes related with subjective perceptions. Le Corbusier would free himself from the rationality of his first stage and evolve to a period characterized by a sensitivity towards to scale, monumentality, architectural perception, structural expression and materiality. This transformation, established in these two stages, helps to understand how concrete shells could eventually be assimilated at the end of Modernism.

Even if Le Corbusier's work is not representative of concrete shells architecture (he developed several of them, but they are more related with formal and expressive shapes than efficient structural elements), changes introduced in his architecture helped indirectly to the assimilation this alternative way of projecting. Le Corbusier personal relation with A. E. Reidy and the influence in Reidy´s works can help to establish a parallelism between changes that Le Corbusier's architecture produced into Modern architectural and the way these changes ended in the Pavilion's concept. In a strategic and simplified way, we can highlight in Le Corbusier's works the steps that allow the assimilation of expressionist parameters compatible with concrete shells.

3. First condition: the structure as an external formal element.

With the conceptualization of the Dom-Ino System (1914-17) the Swiss architect synthesizes an architectural approach strongly discussed during the XIXth century, setting a new relation between the two main elements of architecture: the structure and the building's enclosure. This new concept established the mechanism for the structural rationalization as an independent element.

> One of the greatest achievements of the modern construction technique is the free structure, that means, independent of the walls of the building. The free structure allows the standardization of structural elements and flexibility in terms of the use of spaces, so that in any time its internal divisions can be modified without prejudice to the good conditions of stability and appearance of the building (Reidy 1935).

Once conceptualized, the enclosure-structure disaggregation initiated with the Dom-Ino System will give way to a more important role of the structure as a generator of the architectural form, mainly in those projects where the program needed open spaces and bigger spans.

The turning point in this evolution is the Soviets Palace in 1931 (fig. 10). This project was composed of two large auditoriums that required a structural resolution never done before. Given the size of the structure and the impossibility of keeping the beams inside, they are moved outside to avoid internal constrains. The result is a set of volumes composed by radial structures with a strong expressivity, becoming the first significant exoskeleton projected by the Swiss architect.

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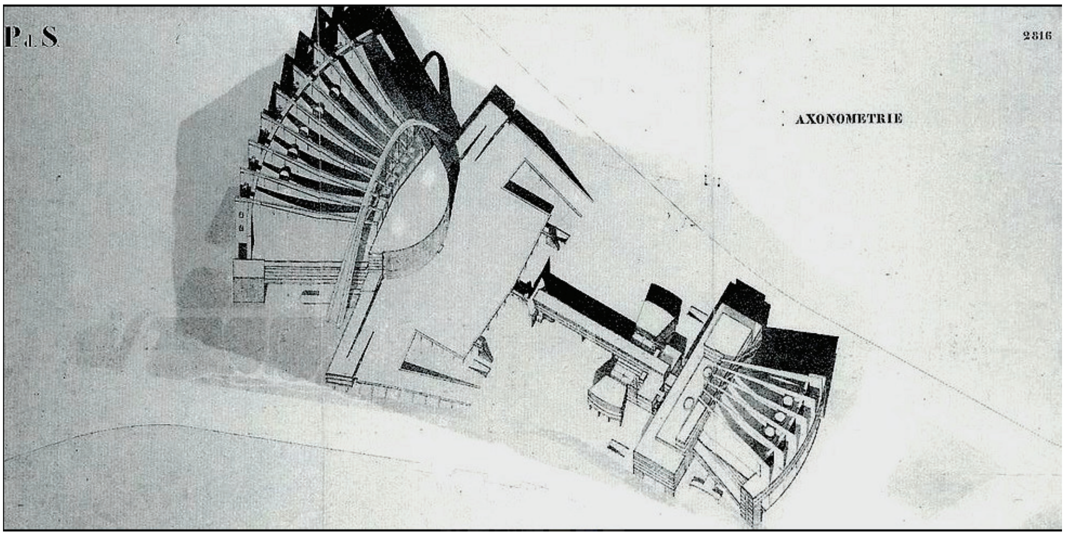

Figure 10.
Axonometric view of the Soviet Palace by Le Corbusier

As Julio Collares highlights:

> This primitive exoskeleton demonstrates the implicit potential of the transparency contained in these structures that collaborate in the porosity of the composition. In this way, a vocabulary of great significance is added in the Modern semantics (2003, p.51).

In the project developed for the University of Brazil in 1936 (fig. 11), Le Corbusier strengthens the structural strategy adopted in Moscow. This building leaves an important lesson among the members of the Brazilian team, composed of Lucio Costa, A.E.Redy, Oscar Niemeyer, F. Saldanha, J. M. Moreira, A. Bruhns and P. R. Fragoso.

Figure 11.
University of Brazil view

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> The Auditorium with its acoustic ceiling suspended in the exposed structure, expressive, almost dramatic as the old cathedrals (Costa 1995, p.183).

This exchange, really significant in Brazilian modernity, establishes the germ of the semantic tools that will be used in large part of modern Brazilian projects.

> The new technique demands the revision of traditional formal values. What characterizes and, in a way, directs the radical transformation of all the old construction processes is the independent skeleton (Costa 1995, p.112).

As an inaugural milestone, the church of San Francisco de Asís in Pampulha, built from 1941 to 1943 by Niemeyer (fig.12), opens an architectural stage for the Brazilian architecture. It is the first project developed as a concrete shell. Another simultaneous project, the Municipal Theater of Belo Horizonte in 1941, also by Niemeyer (fig. 13), already establishes a totally exposed structural language, with constructive approaches of clear correspondence with the auditorium of Le Corbusier. However, in terms of not built projects, Reidy anticipates Niemeyer when he plans his first exoskeleton and concrete shell building in 1939, the Headquarters of the General Department of Transportation and offices of Rio de Janeiro (fig. 14), where he uses vaulted structural roofs for the office body, while projects external concrete frames to hold the garage roof.

The exoskeleton buildings, where the concrete shells are integrated, will lay down the guidelines of the tectonic tendency of Brazilian Modernity after these projects.

Figure 12.
Church of San Francisco de Asís in Pampulha by Oscar Niemeyer

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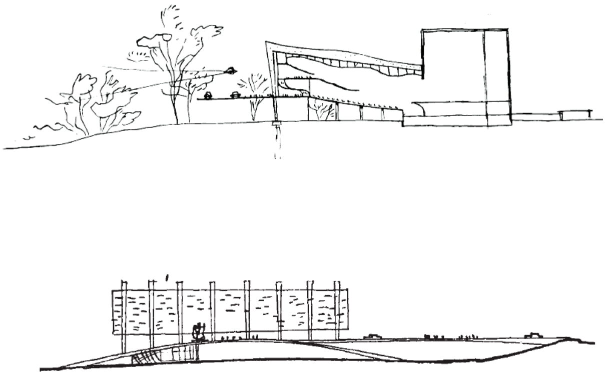

Figure 13.
Drawings of the Municipal Theater of Belo Department of Horizonte by Oscar Niemeyer

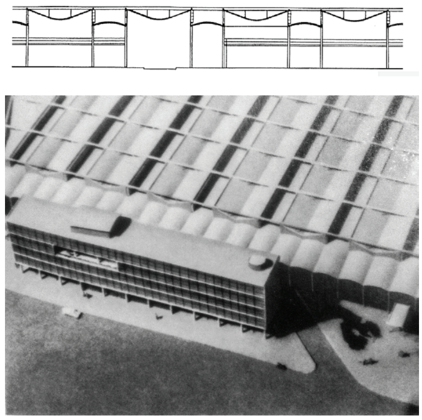

Figure 13.
Headquarters of the General ransportation and offices in Rio de Janeiro by Reidy

4. Second condition: exposed concrete as matter for expressivity

The expressivity of concrete as exposed material will come through the influence of another project by Le Corbusier: the Unité d´Habitation (1947) in Marseille. Although Le Corbusier doesn´t have all the merit for the general use of exposed concrete in modern buildings, it can be said that at least he was its major disseminator, as a consequence of his influence throughout Modern Movement.

In an interview in 1962, Le Corbusier recognizes the personal way of using exposed concrete in the Unité and its subsequent works: "I take advantage of these resources (of concrete), why not? I have fun, it interests me" (Charensol, Mallet cited in Sbriglio 2013). The expression "I have fun, it interests me" reflects the subjective nature of exposed concrete in Le Corbusier's work. It reveals a sensibility that approaches the artistic side of the architect. The expressiveness of his concrete wants to transmit sensations that have nothing to do with its structural function. Therefore, his main motivation would be the exploration of the material as an artistic element, providing the building with a new plastic component previously limited by its own postulates. With the Unité, Le Corbusier definitely leaves the positivist parameters, moving away from the lightness and abstraction of his previous stage to focus in the expressivity of the structural components (Frampton 1985).

> The crucial innovation of the Unité was not the heroic state, nor in its originalities in sectional organization, nor its sociological pretensions. It was, more than anything else, the fact that Le Corbusier abandoned the pre-war fiction stating that reinforced concrete was the precise "machine-age" material (Banham 1967, p.16).

The impact caused by the Unité among modern Brazilian architects is evidenced, again, in the words of their intellectual leader, Lucio Costa:

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That was an impact. I was unarmed, I didn´t know what to say. We were thinking and demanding to the engineers to reduce the diameter of the columns and suddenly these huge piloti came with all that mass [...] When they were making the Jaoul houses [...] I was shocked, I said it was absurd, using concrete as mass, a prehistoric thing, such a primitive way, when in reality reinforced concrete subtends an intellectual speculation, taking advantage of the structure, the possibilities of the structure, the economy, and never using concrete as mass [...] We weren't prepared for that […] (1995, p.150).

5. Conclusion

Concrete shells and folded plates constitute a way of understanding architecture based on the observation of geometric and natural shapes. The variability of the system shows a strong flexibility and provides with infinite possible solutions. However, only some of the variations can be considered the most efficient under parameters of structural optimization, material waste or construction strategy. These combinations can only be defined through mathematical relations linking architectural form with biological structural behaviours. This new method gave the tools to Modern Architects to explore new architectural solutions, breaking the standards of International Style.

The path defined from the understanding of the structure as an internal element to its total prominence out of the building's enclosure was a necessary intellectual process for the proliferation of concrete shells and folded plates. Through this process Modern Architects assimilated the formal possibilities of the structure, first moving it to the exterior, then exploiting its expressivity through the study of different variations on the same principle. Concrete shells and folded plates, perhaps the last of the structural tools used by the Modern Architects, are also those which allow going further in the strategy of joining structure and enclosure, being at the same time the best expression of concrete qualities as a continuous, superficial, structural element.

The last three works of Affonso Eduardo Reidy constitute a meaningful shift in the role that structure had played in previous projects. In the Aterro´s Pavilions the structure became the building itself. The result is a variety of solutions highly efficient in terms of structural behavior, but shows a lack of balance between structure and other architectural parameters that highlights the fact of being projected as prototypes where Reidy had the opportunity to implement different thoughts on variability and flexibility of the structural system.

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Alternatives to artificial lighting: Varying patterns of bio-light in architecture

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Abstract

The notion of variability is identical to the phenomenon of light. The present paper examines characteristics that shape this variability, in all forms of light, both natural and artificial, as well as light that is experimentally produced in a laboratory environment, through genetic modification of plants, in line with current trend of architectural fluidity.
At a time when architecture is interacting with emerging technologies by creating parametrically changing shells and environments, that are evolving as biological models and organisms, lighting is becoming a tool for highlighting forms while ensuring the functionality of spaces.
It is up to the designer to manage these variables of light in an inspired way, in order to create an elegant, sustainable and environmentally friendly environment for all beings.

> *People are designed to seek for change and the visual system reacts primarily to contrast and changes. It is vital to vary the light*
> *(Karlsson, 2015).*

Keywords

bio-light; variability; parametric design; emerging technologies; bioluminescence

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Introduction

Every time a person opens his eyes, a new unique image of the environment emerges in front of him, which activates his visual perception of the world (Yot, 2010). The variety of this scenography is highlighted by the variability of light, depending on its attributes. Especially in an ever-changing natural and artificial lit environment, the designer looks like a magician holding a magic wand. By modifying the variables, he "shapes" the quality of the light, which, although not easily quantified is perceived through the created atmosphere by the forms of lighting, resulting to a sense of well-being.

The effects of depriving the environment of the variability of natural light

The widespread predominance of artificial lighting around the world has radically changed the picture of the periodic variability of light in the environment. The "dark" night image of the daylight cycle has completely changed, with the relative brightness of the starry night sky often disappearing, especially in the urban areas of the earth.

The resulting nocturnal pollution is associated with the genesis of many environmental impacts, the main ones being:

- the difficulty of performing astronomical observations and measurements (Hunter, 2017)
- the disturbance of the biological clock of all organisms, affecting their health and well-being (Atari, 1982), (Brenninkmeijer, 2008)
- the disorientation of migratory birds, which are attracted to artificial light sources and consequently disappear (Zielinska-Dabkowska, 2013)
- the inability of many nocturnal animals (terrestrial or marine) to find food, protect themselves from their enemies, or unite with their mate
- the disturbance of plant growth due to altered photosynthetic function (Biswas, 2013)
- the destructive for health of beings blue spectrum emitted by many light sources (Gudkov, 2017), (Gelder Van, 2004)
- the extensive disposal of destructive materials and substances for the environment, from light sources components (Ippolito, 2017)

Three versions of the variability of light in architecture

The self-evident importance of variability in human evolution is briefly demonstrated in Swami Vivekananda's excerpt from his lecture at Floral Home in Colombo, late 19th century: «Variation must exist; without variation life must cease» (Vivekananda, 1897).

As new trends in architecture and urban design are mainly based on the search for new dynamic and evolutionary forms, corresponding to the fluidity of modern urban life, lighting has become a dominant tool for highlighting and functioning these forms.

It is an indisputable fact that humans perceive the concept of variability of the natural environment through the alternations of light and darkness, which are determined due to natural phenomena. Then, after sunset, through the management of artificial lighting variables, variability is succeeded by producing a wide variety of lighting forms, both to expand daily activities and to increase the sense of security, while at the same time highlighting the structured environment.

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The variability of light, depending both on the functionality of the space and aesthetic requirements, dictates a different approach from the point of view of architectural design. The factors that shape the requirements for differentiating lighting in an architectural environment are:

- The environmental zone
- The specific climatic conditions
- The brightness of the adjacent environment
- The type of building
- The functional requirements of the spaces
- The lighting standards in accordance with applicable law

The characteristics that shape the variability of light, whether it comes from nature or is produced by man, as well as the variables that affect its form, are analyzed below:

I. Natural light

The variability of natural light follows the periodicity of the daily cycle, achieving the following:

- Helps living beings perceive the changes of the seasons and the daily periodicity
- Programs the circadian system (biological clock) of all beings, the main factor for maintaining their health and life
- Enhances the developmental functions of organisms
- Creates visual changes that outline the "scenography" of the environment and enriches it with unsurpassed aesthetic quality

The variability of daylight is determined by variables, most of which are imposed "from above", i.e. they are "unavoidable":

First variable is the source of origin. The main source is the sun, from which light is directly emitted. If the sky is covered by clouds, then the light penetrates through them and reaches the earth as diffused. But also, light is emitted reflected from all surfaces, on which sun ray's incident.

The second variable is the daily fluctuation of solar radiation, as has been recorded in scientific data (Muneer, 2004). The third variable is the range of the angle of incidence of the sun rays at the specific location, therefore depending on: a. the geographical location (essentially the geographical components, such as latitude and longitude) and b. the season and the time of day.

Finally, the variability of light is affected by the effects of scattering due to the medium through which it reaches a particular location.

Regarding the *variety* of forms of light, they could be divided into two main categories, depending on the source of origin, as well as on the type of surfaces. In the first case light is emitted either as direct, causing hard shadow patterns, or as indirect (diffused, by smoothing out shadows), while in the second, materials, textures and translucence of surfaces affect the color of reflected light.
In the case of natural light, the lighting designer should:

A. Keep in mind to take advantage of the properties of natural light to illuminate a building or space, while dealing with the potential problems that will arise, acting as follows:

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a. By selecting the appropriate orientation of the building openings (Baker, 2002),
b. By exploiting the advantages of natural light (creation of proper size and type openings, use of shelves of augmentation or reduction incoming light) (Littlefair, 1996) and
c. By "tackling" the potential problems caused by solar radiation, such as glare and overheating during warm seasons (use of shading systems and "devices" for deflecting incoming radiation).

B. Create varieties of lighting forms through effects and patterns, by using colored filters or glasses and specific constructions, to "play" with light and shadows, or just water surfaces to create varying reflectance (Niesewand, 2000).

II. Artificial light

During evening hours, artificial light allows people to extend their activities, with some of them taking place during the night and increase the sense of security and functionality. The variation of light is achieved through wide variety of light sources, each with different specifications (variables), that produce a variety of lighting forms, suitable for individual requirements. Current technology of lighting results in dynamic light sources, emitting light variating in intensity and color, activation ignition, dimming and shut off, to meet the different needs of users both on performing tasks and creating a nice atmosphere. In the case of artificial lighting, the desired variability of light is manageable through its variables, as follows:

1. The type of light source
2. The size of the light source
3. The luminous flux
4. The intensity of the light source (through dimmer settings)
5. The direction of the light beam (adjustment through "devices" and accessories of the luminaires)
6. The angle of the light beam
7. The type of luminaire that hosts the light source
8. The distance from the illuminated surface or object
9. The texture and color of the illuminated surface
10. Aesthetic requirements for a specific space or building
11. Function and quality standards for each activity
12. Time of ignition and shutdown (programming, sensors, controllers)

The forms of produced artificial light are varied, such as: a. monochromatic or multicolor, b. fixed or variable, c. warm or cool (corelated color temperature of radiation), d. directional (harsh shadows) or diffused, e. with high or poor color rendering, f. dramatic (strong contrast with shadows, sharp angles of incident rays on the surface or object) or "mild" (small contrasts) and g. creating effects (through projections, robots, special lens, filters and disks -Gobos).

Last variable, with the emergence of digital technology through state-of-the-art devices and software, introduced the innovation of interactive lighting in the urban space. Interaction contributed to the creation of changing forms of lighting, manageable by programming from consoles and computers. Through them, the interaction of humans with the environment and buildings is achieved as information, messages and artistic interventions.

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III. Bio-light

The concept of Genetic Architecture (Chu, 2011) emerges as a kind of "virtual DNA", (Gatti, 2010) which is inherited both on a scale and in projection in an innovative structured environment, both inside the buildings and in the surrounding outdoor space. It should be mentioned, that just as with organic DNA, the corresponding synthetic one resembles a constantly modified skin, which develops according to the laws of evolution (Armstrong, 2012). Through the simulation of biological systems and the emergence of adapted technologies (Hensel, 2013), among which bio-digital architecture dominates, the relationship between the functions of buildings and the anthropogenic environment becomes parametric, occasionally changing so that it responds to lifestyle and to the needs of users.

The phenomenon of light production by organisms in nature, is a challenge for the contemporary designer for possible utilization of this light in the design, so that: a) a structured space is created, more integrated in the natural environment, b) the space's operation is self-sufficient and c) some of the energy consumed to illuminate the building shells and the urban environment is saved.

In this case, the variability of light output is combined with the constant change of organisms, as they grow, being the sources of this light (Ardavani, 2019).

In the context of Genetic Architecture, the innovation of an "organic" or "living" light serves the main concept of creation of a transformative "skin" or cell, which will be adjusted to the special needs of human beings. Through genetic modification of plants with genes extracted from bioluminescent organisms, either fireflies, algae, or bacteria, they may perform as light sources. According to a recent experimental study, it was estimated that by using transgenic luminescent plants, low-traffic roads, sidewalks, dark parks, gardens, patios, etc. can be sufficiently illuminated according to International Illumination Standards (Ardavani, 2019). These light sources will grow close to human habitats, illuminating in an always variating way, depending on the following variables:

a. The plant's suitability to be genetically modified as luminescent (i.e. the availability of genetical protocol) (Fanourakis, 2005), *b.* the size, type and foliar area, as these data have proportional influence on the intensity of produced light (Ardavani, 2019), *c.* the orientation of the plant (James, 2000), *d.* the local climatic conditions, e. wind direction, e. the magnitude fields (Talà, 2010), *f.* solar radiation intensity, as according to researches, higher absorption of energy results to higher plant growth (Yan-Hong, 2009) and *g.* the maintenance of plants, as possible diseases and pathogens affect their health, resulting to lighting output reduction.

The *variety* of forms of emitted bio-light lies in the different color of monochromatic radiation (depending on the radiation wavelength).

In the case of bio-light, the designer, taking into account the above variables, may, with the appropriate selection of transgenic plants, acting as light sources, sculpt the bright environment, so that it meets the functional and aesthetic requirements for each illuminated space. It goes without saying that selected plants, in order to be genetically modified, must be capable of thriving in the local climatic conditions and the peculiarities of the geographical area.

In addition, the stage of growth of plants, but also the configuration of their foliage, is the most decisive parameter of their luminous performance as lighting fixtures. This parameter can be considered

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as an algorithm for estimating the amount of light emitted and it is the one that essentially affects the variability of light.

By simulating their measured light flux in a software, their minimum performance can be calculated, allowing the lighting designer to shape the backdrop of the bright environment. And it is particularly interesting that especially in the case of transgenic plants in the capacity of bio-luminescence, the variability of the emitted light is enhanced by the perpetual variability of light sources, not only in terms of their luminous efficiency, but also in terms of their shape (low shrubs, tall trees, all of them continuously evolving), resulting to patterns of light, that will always change unpredictably.

This variability, both in lighting and in the natural environment, integrated into the urban space and the structured web, creates a new perspective for the transformation of contemporary architecture according to the principles of biophilia. And perhaps this is an alternative to restoring the circadian rhythm of beings from the predominance of artificial lighting. Within future urban space, the varying bio-light is expected to create a vivid atmosphere and stimulate the senses, in line with architectural fluidity.

Conclusion

Natural, artificial and "bio" light are constantly being transformed and the wide variety of light forms produced, which depend on various variables, constitute the variability of light as a single whole. But it is crucial for lighting designers to vary light levels in the same way natural light varies. The development of the idea of utilizing bioluminescence in the urban space, is offered in this direction, while at the same time ensuring the enrichment of the urban environment with vegetation is an essential sustainable approach that improves the microclimate and the quality of life of the inhabitants. The ever-changing appearance of plants, which as living organisms grow and evolve influenced by the weather, the season and the conditions of their maintenance, results in the continuous and unpredictable differentiation of light produced.

In the context of light pollution, designers should expand the alternations of darkness and light instead of a plenty lit environment. This means, that modern man must be re-educated to live with less light and more darkness at night, in order to mitigate the destructive effects of light pollution on the environment and to restore the magic of the incomparable variability of light.

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Constantinos Miltiadis is a transdisciplinary architect whose research focuses on virtual spatiotemporal environments as a means of expanding the scope of architecture practice and aesthetics. He is currently an arts doctorate fellow at Aalto University, Helsinki. Constantinos has studied architecture at NTU-Athens, architectural computation and philosophy the Chair for CAAD ETH Zurich, and pursued studies in computer music at the Institute of Electronic Music of KU Graz. Between 2015 and 2019 he was assistant professor at the Institute of Architecture and Media of TU Graz where he founded the "Virtual Spaces Master Studio." Constantinos' work has been presented in exhibitions, seminars, published in academic conferences and by international press, and received awards in international competitions. In addition, he has taught creative programming and experimental computation in academic contexts, as well as in conferences and festivals. He was also founder and curator of the "IAM Open Lecture Series" as well as co-founder and co-curator of the experimental electronic music event series O.

Chrissa Papasarantou is an architect (University of Thessaly, 2008), a holder of a master's degree in MSc Advanced architectural Studies at the department of Bartlett School of Graduate Studies (UCL, 2009), while she is a PhD candidate at the Department of Architecture (University of Thessaly). Her research interests focus on finding alternative ways on approaching, analysing and designing mixed environments through the notions of presence and embodiment. She has participated at international conferences and architectural competitions, while currently is participating in the research project "ACETHEODIP" with the research group of LECAD (Laboratory of Environmental, Communication, and Audiovisual Documentation). Concurrently, she is also participating, as a researcher and trainer, in STEAM related European projects (RoboScientists, WeMakers, Inbots) with the organization of EDUMOTIVA (European Lab for Educational Technology).

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Sergio García-Gasco (Madrid, Spain) is an architect graduated with honours from the Universitat Politècnica de Valencia, Spain, in 2006. Since then, he has collaborated with several international architectural practices in Spain, France, Brazil and UK, particularly Dominique Perrault architecte, Carla Juaçaba, Gru.a or Skidmore, Owings & Merrill.
Interested in theorical knowledge as a key to develop the architectural practice, he has been involved in the academic research since graduated. He is currently completing his PhD program in UPV with a research focussed in concrete shells structures. Previously, he completed his M.Arch studies in the Universidade Federal do Rio de Janeiro, Brazil, in 2015. He has taught and being involved in several research and study programs of Universitat Politècnica de Valencia (Catedra Blanca Coordinator, EnBlanco Magazine Coordinator) and Istituto Europeo di Design - IED (MA. DE.IN - methodology), in Rio de Janeiro.

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URBANITIES

Guest editors: Dr Gaetano De Francesco[1], Dr Valerio Perna[2]

1. PhD Architect | DFR Architecture Founder

2. INNOVATION_Factory Coordinator, Faculty of Architecture and Design, POLIS University, Tirana

The 16th issue of the ArchiDOCT e-journal welcomes papers that explore the theme of 'urbanities' in architecture and the built environment, considering the contemporary need to open up new discussions and critical reflections regarding the condition of the depressed spaces of our cities and the need for catalytic interventions headed towards their comprehension, reconsideration and future reactivation and mobilisation.

With the term 'urbanities' we anticipate a possible constellation of projects that symbiotically operate to define the future urban environment and to respond to multiple crises associated with intertwined issues such as climate change, flooding, land consumption, but also inequality, gender issues, production processes and geopolitics. At a smaller scale, they own their specific boundaries and peculiarities while, through a progressive blurring of lines of demarcation, at a bigger scale they act as a network of meaningful fragments that creeps into the city and composes infrastructural webs to reactivate our urban fabric.

Indeed, these 'urbanities' don't convey only a functional quality to the city, but they also carry within themselves a whole set of social, political, and human values, as well as the nonhuman presence in the form of gaia, nature and data sets that reinforce the sense of citizenship of the dwellers of these places. As a reflection of the IT era, they often inherit the multifunctionality at the core of the digital technologies that allow them to be open to phenomena of people's appropriation (Dix 2007) and re-semantization, which consequently lead to the rise of new aesthetics.
In a city similar to a motherboard, 'urbanities' are small strings of codes that, as specific plug-ins, connect to the urban environment and become meaningful narrations. They contribute to creating proper infrastructural networks of information which are incremental (it keeps growing and evolving from the original DNA) and not top-down oriented; they have the capacity to fit within the tangles of the consolidated city and re-active the forgotten and neglected areas generated by the urban sprawl phenomena; they are enriched by injection of information that could foster alternative dynamics of participation and civic engagement and can deliver new values that can give rise to a revised sense of citizenship and, indeed, bottom-up urbanity.

With these premises, the 16th issue of ArchiDOCT invites academics, researchers, and PhD students, that can relate their doctoral thesis as solo authors, with their supervisor(s) or with fellow doctoral students or doctoral holders to deliver an essay focusing on any field related to the entanglement within architecture and urban design in the contemporary city. The aim is to explore the theme of 'urbanities' in the design process through both a theoretical or practice-based approach and highlight the breadth and scope of the results

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their possible implementation can bring about. For this reason, and considering the breadth of possibilities contained in the topic itself, we are interested in contributions pervaded by a design'n'built philosophy that could directly illustrate their resonance within the real world. Independently from the scale of the 'urbanities' proposed, we invite discussion concerning tangible examples of the implications within architecture, IT, and urban reactivation, and the possible connection within theory and praxis.

Relevant subthemes include:

- 'urbanities' in the design process through a practice-based approach and highlight the breadth and scope of the results their implementation can bring about;
- Contemporary theories of urbanity;
- Bottom-up multifunctional strategies towards urban reactivation;
- Mediated urbanities developed by urban design, planning and ICT applications;
- Resilient urbanities;
- Ethics, politics, aesthetics of contemporary urbanities;
- Speculative tools and strategies within the design process.

Important dates

Submission deadline (full papers): 15 September 2020
Review period: 16 September – 15 October 2020
Revision period: 16 October – 30 November 2020
Follow-up review: 01 December – 15 December 2020
Final revision: 16 December – 31 December 2020
Publication date: 01 February 2021

Submission policy

ArchiDOCT is published twice a year, in July and January. The official language of the journal is English. Submitted manuscripts for review should not exceed 4500 words, including abstracts, references and image captions. The referring system will be the Harvard System. Text should be saved in a Microsoft Word or RTF file, while the supporting visual material (images, diagrams, sketches, tables and so on) should be sent as TIFF files with a resolution of at least 300 dpi. All visual material should be clearly indicated and numbered in the text, along with the respective image captions and credits. Additionally, all manuscripts should be submitted in A4 "camera-ready".pdf format that gives an idea of how a finalised version looks.

ArchiDOCT accepts manuscripts from PhD holders, students, postdoc students, either as co-authors or in collaboration with fellow researchers and/or with their supervisors.

Reviewing policy

The peer reviewers are all confirmed educators of architecture coming from different educational backgrounds, with different specialisations and expertise that share the common interest of their doctoral students: to encourage them to publish their work while improving their thinking processes towards academic research writings. Each submitted article is reviewed by two members of the journal's Scientific Committee anonymously.

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