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GEOMETRIC MODELING AND COMPLEXITY - A CONCEPTUAL APPROACH IN ARCHITECTURAL DESIGN AND EDUCATION

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By encompassing abstraction and patterned information, the new fields of geometry and mathematical models of complex dynamic spatial systems provide a new method for spatial modeling. Different approaches to the application of spatial modeling in architectural design are possible, taking into consideration on the one hand the theoretical background and knowledge of geometry, and on the other, advanced computational techniques. The generative principles of complex dynamic spatial formation allow parallels between the differentiated representations and directions of approach to spatial organization. The integration of conceptual, theoretical and practical methods into complex dynamic geometric models in the preliminary phase of design could support the development of cognitive capabilities, internal representations and understanding of complex dynamic formative processes. The development of nonlinear, dynamic, complex spatial imaginative thinking corresponds with trends in contemporary computational design. The application of complex geometric modeling, including sophisticated mechanisms of human perception, intelligence and creativity, provides a synthesis of artificial and human potential.

***Key words*: architectural design, complexity theory, geometry, modeling.**

INTRODUCTION

Architectural design process deals with spatial determination and creation, in the context of a complex natural and artificial environment, and thus goes beyond the principles of rational linear logic that are not capable of encompassing the extremely complex intertwining of multiple parameters that shape the design space. The complex character of design means that adequate representation is difficult, and that it is not possible to apply a simple analytical approach, or to find optimal solutions by logical operations (Simon, 1962).

Through the process of graphical representation and modeling, it is possible to analyze a design, anticipate solutions and evaluate different variants, synthesizing multi-leveled abstract and concrete spatial information in proper representations. Graphical representation of an architectural design relies on geometric spatial modeling, from classical Euclidean and projective geometry to contemporary dynamic geometric structures and computational models. The expansion of new fields of geometry that are supported by computing technology, as mathematical models of complex dynamic systems, could provide a new approach to spatial modeling that should be investigated and applied in architectural design. Different approaches are possible, considering on one hand the theoretical background and knowledge of geometry, and the other advanced computational modeling techniques. The role of geometry in architecture and architectural education will be analyzed and explored in this research through consideration of the application of complex dynamic geometric modeling in the conceptual phase of architectural design.

DESIGN COMPLEXITY AND GEOMETRIC MODELING

The development of architectural spatial concepts and the structural framework of spatial plans are determined by spatial geometry. Based on the abstraction of spatial elements and their relationships, geometry deals with the universal properties of spatial structures, as the union of empirical experience and logical deduction, which can be applied in physical science and engineering. Geometric modeling is a rational and intuitive process that involves the perceptual, cognitive and logical structures of the

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human mind in a single stream of incessant activity. Classic geometry fixed by conventional means of representation is now changing, expanding towards greater complexity and a more dynamic form. Information technology opens new constructive possibilities in a new medium, raising some fundamental questions related to the modeling of space, enveloping non-linearity, self-organization and complexity.

Complex nonlinear dynamic systems

The theory of complex systems has been developing since the second half of the 20th century, generating new concepts in science and technology. Complex systems are composed of numerous different components, connected in a nonlinear way, forming a whole dynamic spatiotemporal pattern that cannot be described as the sum of its parts. The science of complexity envelops the diversity and heterogeneity of many natural and physical systems. Numerous design and engineering problems could be better approached with a basic understanding of the dynamics and properties of complex systems. By transcending linear ways of thinking, new spatial concepts are established, based on complex systems theory and its models. Various kinds of complex systems at the abstract level exhibit common properties (Mitchell, 2009). Different natural, physical and artificial human-designed systems can be studied based on similar principles of their complex dynamics and organization.

The elements of complex systems are characterized by diversity, differentiation, a leveled hierarchical structure and complex dynamics (Simon, 1962). The stability within those complex systems results from a dynamic balance, with more equilibrium states, which maintain the system to be stable but not static. The structural hierarchy of complex systems is neither homogeneous nor linear. The identity of complex systems emerges from their dynamic organization, in which their boundaries and hierarchies are simultaneously maintained and transformed (Cilliers, 2001).

The geometric model of a complex dynamic space envelops a continuity of varying degrees of complexity, forming a hierarchical multiplication of scale sizes and dimensions. The generator for the development of a complex system could be a geometric structure with different degrees of complexity. Forms of complexity have a changeable shape that is only a phase state at a certain level of development dynamics. One form includes a variety of spatial and temporal levels, and passes through various stages and degrees of formation. The principle rule of the spatial order is transmitted through different levels and directions, different scale sizes and dimensions. The visual representation of complex dynamic forms expresses multiple-scale order and often visually "irregular" shapes as a result of iterated transformation processes on different scales (Figure 1).

Modeling and geometry of complex design space

From the ancient systems of proportions, Renaissance projective space and modernist geometric modularity, to the digital morphogenesis and computational design of the late 20th century, architects have been trying to determine rules and patterns for the suitable spatial modeling of architectural forms. The rules of geometry have often been intertwined with rules of composition, aiming to achieve unity for all parts of a designed object, recursively applying rules at different levels of details, mostly in a top-down structure: from abstract definitions to specific instances (Mitchell, 1990).

The development of CAD/CAM technologies, dealing at first mainly with the application of computer graphics in the representation of an architectural design, highlighted the need to further explore the possibilities for geometric modeling based on more complex geometry. Both geometry, understood as a decontextualized system imposed from above, and geometric form, seen as a perfect solution to spatial problems, are in conflict with architectural endeavors emerging in the real space of an extremely complex context.

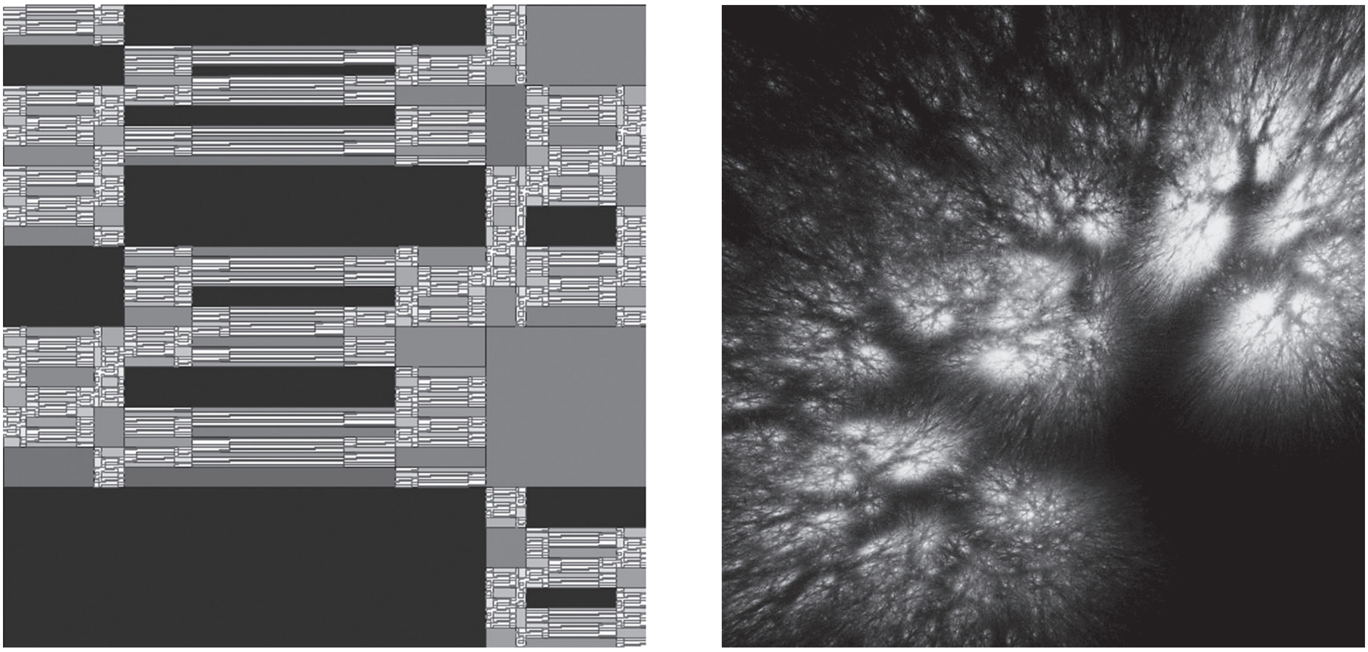

Figure 1. Representation of complex geometric structures: Examples of fractal geometric patterns as iterated multiple-scale ordered systems. (Source: authors using Fractal Subdivision applet and Apophysis software)

The geometrization of space in modernism based on universal abstract shapes is superseded by the universality of complexity and transformability of an evolutionary form (Čahtarević, 2008).

Studies of the properties of complex dynamic processes and their morphogenetic manifestations and patterns, with the help of theoretical models of complex systems on one hand, and enhanced with computing technology on the other, contribute to a better understanding and application of equivalent principles in the design of architectural form. The design process includes indeterminate, unstable and complex situational contexts. In the conceptual stage of design, a specific kind of thinking is required that has a complex character. It includes the multiplicity of different parameters, which may be conflicting, complementary, or have an ambiguously defined structure. The design process involves an unstable area of exploration as uncharted territory. Conceptual design thinking requires an open design space, where the resolute solution is often not the most optimal choice, but rather emerges from the synthesis of a multitude of different insights throughout the design process (Cross, 2008).

Digital and post-digital tendencies in architectural design

Architecture of the "digital age" relied on digital information technology and spatial modeling in virtual space, by rationalizing the form through computational geometric determination, which prompted computational geometric formalism. On the other hand, biomimicry and the exploration of natural generative processes have led to a new approach by means of the digital materialization of the architectural form. It integrates biology, physics and geometry with engineering, towards design based on the interconnection of form, structure and material (Menges, 2007). New insights into the notion of material, shape and form, can be gained through a new approach to geometric reasoning and modeling based on more complex and dynamic conceptions of geometry. By entering a new domain of information technology and computation, algorithmic processing of information and pattern-oriented design, geometric modeling introduces non-linearity, self-organization and complex relationships into architectural design, as well as parametric design and digital fabrications (Legendre, 2011).

The "digital turn" brings into focus the integration of modeling, graphic imagery, and geometry (Ammon, 2017). The application of 3D modeling software in architectural design rarely demands a deeper knowledge of computational logic and the utilization of computing techniques in architecture is often reduced to mastering the commercial software and its graphic user interface. In fact, digital tools reveal that full spatial control is not possible and is limited by the user interface properties, demanding that the designer enters the depths of programming and computational logic. "Computational design" is mainly focused on the logic of the design process, the formal quality of the design methodology based on computational power and information processes, structural design and performance. The language of the formal logic of the computer and the algorithmic design rules aim to define the model of the object being designed as a computational process (Aish and Bradella, 2017).

What characterizes the "post-digital" approach in architecture, on the one hand, is how to get behind the limits of the user interface, and on the other hand how to get out of the standard representation models that computer graphics relied on in the early "digital age". The restriction of user interfaces could now be overcome by programming and coding, but at the expense of the simplicity of design description, making it mostly unreadable and incomprehensible, and lacking coherent correlation with natural linguistic, visual or cognitive human capacities, or with intuitive processes of human creative performance.

After the breakthrough of the digital and computational paradigm into the engineering and design domains, a new approach is arising in reaction to the overall impact of digital technology on human society. Human-computer interaction has become a new paradigm, focusing on the human role in contemporary technology. Computational systems established in formal languages cannot capture the intentionality, judgment, and insight necessary for a creative approach to design problems. Computational systems, as symbolic systems that are enclosed in structural rules, limit open interpretations that lead to an understanding of new, unrepeatable situations, in the context of existing representations and their necessary modifications (Winograd, 1991).

INTEGRATING INTERNAL IMAGINATION WITH GEOMETRIC MODELING AND REPRESENTATION

Following architectural thought, from modern and postmodern "form follows ..." to the architectural "digital age", the classical education of architects and the application of geometric modeling of space was focused mainly on functional design and technical external visualizations of architectural design solutions. Eastman (2001) emphasizes the importance of the designer's internal mental imagination and representation of the current design context as the main concerns in design education. Mental imagery, used for cognitive processing and reasoning, could be internalized from the learned external representations. Thus, the ability to learn new representations has become crucial in forming mental constructs and the contextual definition of complex designs (Eastman, 2001).

The emphasis in the first digital phase was on the externalization of mental processes through computational tools, treating computers as an extension of the mind (Picon, 2004). The digital became hybridized with the physical; the material world became enhanced and even produced digitally. But the reverse process is possible: to internalize computational principles as enhanced mental imagination. It is necessary to put internal and external representations in a proper balance, avoiding too much emphasis on external representations powered by computer technology.

Computer-aided design brings almost infinite possibilities of variations and generation of forms. Picon warns that "While form can vary endlessly, choices have to be made; decisions have to be enforced in order to break with the theoretically reversible nature of digital manipulation"

(Picon, 2004). Stolterman emphasizes the importance of design judgment, which must be equally valued as rational decision-making within "design as an informed process of intention" (Stolterman, 2003). Design judgment is based on accumulated experience and designer choices in complex and unique situations based on "knowledge inseparable from the knower" (Stolterman, 2003). The qualitative and quantitative aspects of a particular situation are too complex to be oversimplified and analyzed by simple, or single, rational models, so the analytic approach often dissolves in an endless chain of data and divergent information structures. Too much emphasis on computational generalization and rationalization causes a loss of particular and real insight into the specific situation, making some aspects invisible by rational framing, potentially causing unforeseen consequences by reducing the real-world complexity. It is necessary to enhance capabilities for design judgment as a convergent process that provides focus and "brings form and meaning" into complex, real-world situations (Stolterman, 2003).

Thus, the educational goal dealing with complexity in the architectural design should not be just to learn an advanced technique of digital and parametric modeling or force a theory as a direction to follow by executing rational algorithmic rules, but rather to enhance human cognitive capabilities and insight into the multi-leveled and interactive aspects of complex real situations. No computational model can fully subsume environmental complexity, so the recognition of behavioral tendencies and patterns is considered as the main objective of computational morphogenesis, according to Menges (2007).

Modeling process becomes the most important aspect in design, which takes place on multiple levels and in parallel. According to Ammon "design models play an important role as instruments of cognition" (Ammon, 2017). It is necessary to instigate a basic knowledge of new spatial models into architectural education, based on a more complex and dynamic approach, introducing architectural students to the geometry of complex systems and their modeling. Internal mental imagination and reasoning can be enhanced, not just by imposing formal computational determination and digital expression by computer-generated external representations, but based on the integration of complex dynamic geometric modeling and representation with intuitive insight in the preliminary conceptual phase of design. The results of such an approach used at the Faculty of Architecture at the University of Sarajevo are presented here as an example of possible teaching methodology.

Conceptual approach to complex form and geometry in architectural education - case study at the Faculty of Architecture, University of Sarajevo

At the Faculty of Architecture, University of Sarajevo, within the framework of elected subjects and modules, students were introduced to the theoretical background of the theory of complex systems, as well as new fields of geometry such as fractal geometry, dynamic computational models such as cellular automata, and examples of various software applications that allow visualization of complex geometric structures. However, specific software was not immediately used in the further process (reasoning, planning and design). The aim of the study was for students to apply the theoretical research and project design in their master's theses, supported by an understanding of dynamic formative geometric concepts and complex spatial patterns, with the aim of achieving the complex dynamic morphological genesis of spatial organization in preliminary architectural design. The geometry in this approach should not be considered just as a frame of descriptive external representation, allowing graphic visualization of the shapes conformed into the geometric figures and bodies, but as a generator of internalized mental structuring of information, allowing different interpretations coordinated within material, physical and environmental constraints. By structuring spatial information, geometric spatial modeling becomes a generator of the creative formative process, supporting intuition, and directing it into intelligent, qualitative, innovative thinking.

Students were introduced to a new kind of abstraction, based on compressed information instead of generalizations, and which can uncover unique principles that govern the dynamics of complex systems, revealing their generative structure hidden in mostly disordered visual shapes. Students worked at different levels of abstractions, allowing parallels between the top-down and bottom-up approaches. The form of the architectural object is viewed as a whole, but also as part of a larger entity, in a spatial, temporal, material and immaterial sense, interacting with a complex environment as a multi-layered integrative system of subsystems. In complex geometric modeling, the form cannot be reduced to the sum of its elemental parts. Form emerges from a multi-layered network of reciprocal relationships that overlap across different levels and scales of magnitude. The students were instructed to recognize and abstract the patterns of different architectural spatial forms (from natural to artificial, from urban to structural or material). The importance of the particular situation and context was emphasized, returning geometry to concrete patterns that contain historical, temporal and material layers (Figure 2).

The students first detected all the elements of impact and significance to the project (characteristics of the specific location, sociological conditions, architectural program and others), then they made an abstraction of them (from concrete to abstract), establishing a scheme of interrelationships and interdependencies between the elements. This resulted in the pattern of their function that would define the form of the project. The form thus defined represented the synthesis of all spatiotemporal levels of the object, which are treated separately in the classical design approach. In the classical approach, the design process was not focused on the form of the object, but rather on the shape and function to which other components of the solution were subordinated. In the process of setting up the concept of a future object, instead of a linear process, a multi-leveled network is created. This network becomes the frame of reference for formulating the concept. In this way, the conceptual form of the object arises from the elements significant to it.

The final solution is the concretization of the abstract, making it possible to reconcile the conceptualization and operationalization: the abstract form as a constant, and the particular materialization becoming a variable determined by specific constraints. By means of a geometric conceptual model that integrates mental images and geometric structures, space is hierarchically constructed, not only describing objects like shapes, but the process of generating, mapping, transforming, combining, and forming. Its topological form, which is the general framework, is differentiated into increasingly detailed levels, introducing specific limits. Form is created as a conceptual and structural expression of modeling that can integrate discreteness and continuity, 2D and 3D representations (Figure 3).

Results and discussion

The students recognized spatial conceptualization and its geometric modeling based on complexity theory and its application as being more comprehensive than the usual design approach (including modern and postmodern design methods, which are more focused on spatial visualization). Considering the multi-leveled interdependence of individual elements as factors of importance in the project, through the complex intertwining of the analytical and synthetic procedures in the process of defining the form, students were more confident and creative in their search for final solutions.

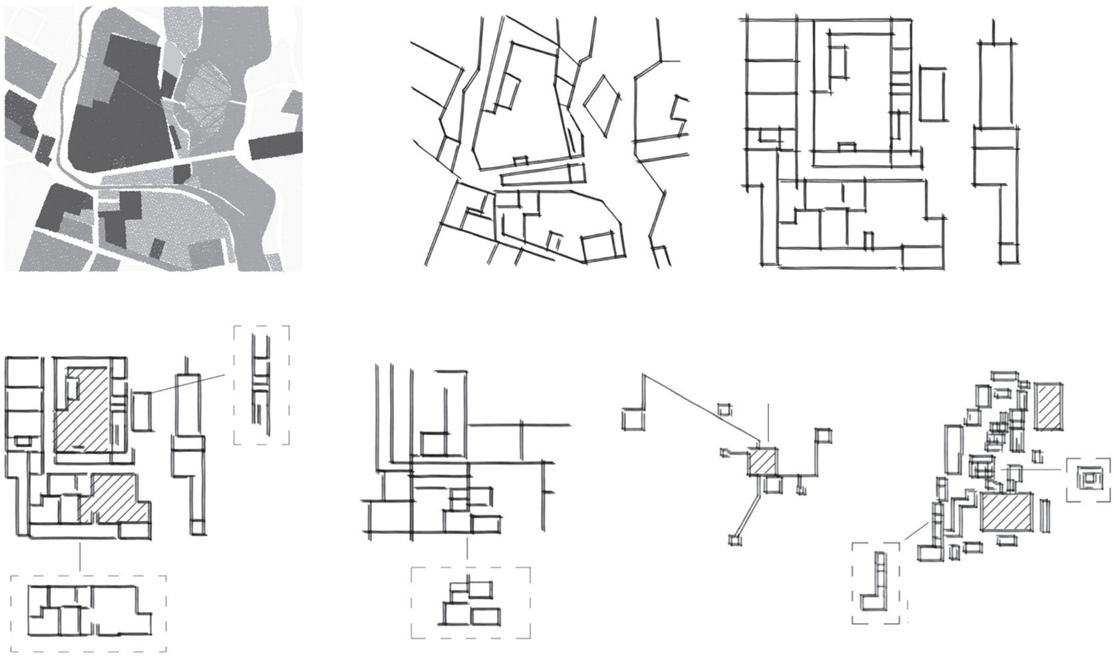

Figure 2. Abstracted patterns of urban structures, as the principles of organizing complex systems and subsystems - analytical research in student design work. (Source: MA student A. Alibegović, Master's thesis: "The complex geometry of the city as a generator of ideas for the design of the administrative facility", Faculty of Architecture Sarajevo, 2015)

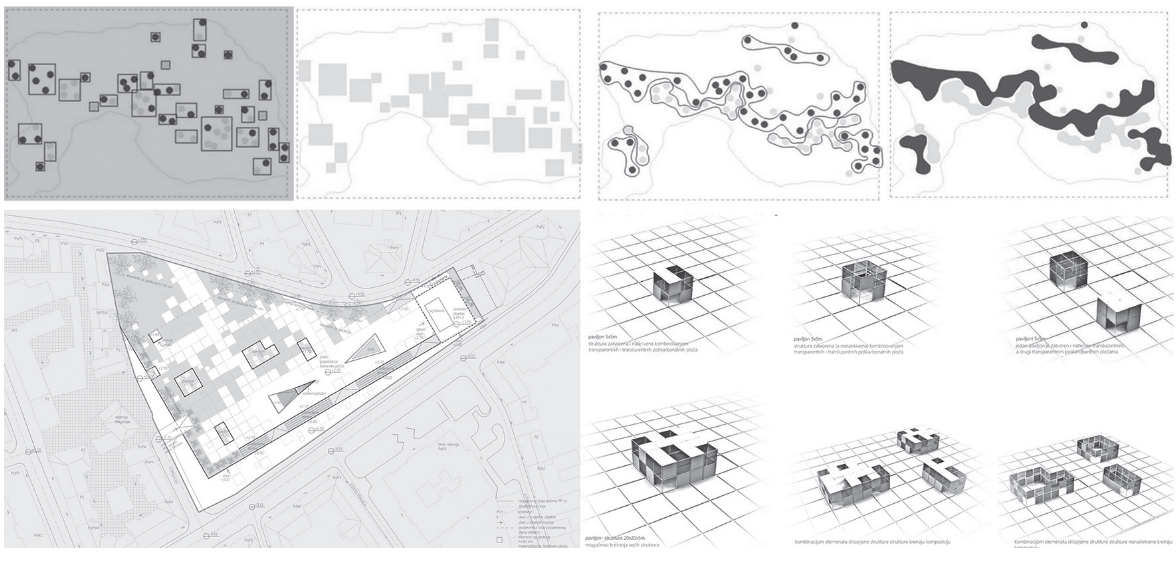

Figure 3. Conceptualization of spatial organization based on analyses of complex patterns of order and disorder of the city in war. (Source: MA Student Adna Šarac, Master's thesis: "Museum of the Sarajevo Siege 1992-96", Faculty of Architecture Sarajevo, 2015)

In the development of the design concept, the principles of functioning are defined, and empirical facts are established. A multi-leveled abstraction of facts and their connection as abstract laws and explanations are followed by concretization and a return to material practice. By abstraction, depending on the nature of the information or data being processed, different structural patterns of spatial design can be explored. In the next step, the patterns are joined: by overlapping, connecting, networking on different levels, thus forming a hierarchical structure of complex character. A multitude of different variations can be explored, through many levels and scales. The complex solution emerges from the non-linear development of the design process realized through a reciprocal use of bottom-up and top-down approaches, also integrating different intermediate levels. It is important to emphasize the importance of a complex nonlinear approach to design modeling in all phases, from ambivalent preliminary sketches to more concrete and contextual interpretations. The models must be visually and structurally legible, but open for a wider and more complex internal insight, allowing multiple variations and flexible representations.

CONCLUSION

Integrating the geometric abstraction and rational determinism of formal design methods with an intuitive, subjective experience of space can be achieved, turning away from a narrow understanding of "digitally" determined design and computational geometric formalism, towards a more complex spatial conceptualization and modeling. Modeling conceptual design space combines mental processes and geometric structures, simultaneously building and describing a space of mental and physical informational matrices. Established by dynamic relational patterns formed as a hierarchy of different connections at different levels and spatiotemporal scales, more complex design models are based on geometric abstractions integrated with the intuitive and creative processes of the human imagination and cognition. Represented through different media and different levels of complexity, geometric form becomes the generator of creative processes and new qualitative expressions. The complex character of architectural design requires on the one hand the externalization and visualization of conceptual thinking through abstract modeling, enabling the parallel setting, description and evaluation of problems and solutions, and on the other hand the internalization of representation and mental imagination, creating a design space as a complex system with more interdependent levels of abstraction and comprehension.

The focus of architectural education should be directed towards the development of more dynamic and complex spatial imaginative thinking corresponding with developing computational trends in contemporary design and more complex concepts of geometry. The application of complex geometric modeling, as the integration of the abstract and physical realms, including the sophisticated mechanisms of human perception, intelligence and creativity, provides a synthesis of artificial and human potential.

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