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PREFACE

On behalf of the organizing committee and the co-chairs, we would like to welcome you to the 9th *International Conference on Computational Methods* (ICCM2018) at the Auditorium Antonianum, Rome, Italy, between August 6th and 10th, 2018. The conference aims at providing an international forum for scholars, researchers, industry practitioners, engineers and graduate and undergraduate students to promote exchange and disseminate recent findings on both contemporary and traditional subjects in computational methods, numerical modeling and simulation, and their applications in science and engineering. It accommodates presentations on a wide range of topics to facilitate interdisciplinary exchange of ideas in science, engineering and allied disciplines, and helps to foster collaborations.

Computational Modelling and Simulation are fundamental subjects in engineering and sciences. They can be applied to many of the primary engineering disciplines, including Aerospace, Bio-medical, Civil, Chemical, Mechanical, and Materials Engineering among others. Computational Modeling and Simulation covers a broad range of research areas, from conventional structural and mechanical designs, failure analysis, dynamic and vibration analysis, and fluid mechanics up to cutting-edge computational mechanics, nano-micro mechanics, multiscale mechanics, coupled multi-physics problems and novel materials. This is reflected in the variety of fields featured in the conference topics.

The genesis of the ICCM series dates back to 2004, when the first ICCM2004 conference was held in Singapore founded and chaired by Professor Gui-Rong Liu, followed by ICCM2007 in Hiroshima, Japan, ICCM2010 in Zhangjiajie, China, ICCM2012 in Gold Coast, Australia, ICCM2014 in Cambridge, UK, and ICCM2015, Auckland, New Zealand, ICCM2016, Berkeley, California, USA, ICCM2017, Guilin, Guangxi, China. The present ICCM conference in Rome, Italy encompasses about 330 oral presentations organized in 64 Mini-Symposia and general sessions, including 3 Plenary Lectures, 14 Thematic Plenary Lectures, and several Keynotes.

The ICCM conference is unique in the sense that it showcases the current developments and trends in the general topic of Computational Methods and their relationship to global priorities in science and engineering. We would like to express our gratitude for the contributions of all ICCM2018 participants and presenters at this international event. We gratefully acknowledge the contributions from the International Scientific Committee, Mini-Symposium Organizers, and expert reviewers for their efforts and assistance in the organization. Special thanks go to Dr. Nicholas Fantuzzi for his efficient assistance to the scientific organization of the Conference and his patient handling of bureaucratic issues. We thank also the volunteers and the local staff in helping out in the organizing and running this important event.

Finally, we would like to warmly thank you for the contribution of our authors and participants in making ICCM2018 in Rome a very prominent scientific event. We believe the ICCM2018 has become a special event that widens the bridge between West and East in our worldwide community for computational methods.

We are looking forward to your participation and continued engagement for the future ICCM conferences, and contribute further in the development of computational methods.

Professor Patrizia Trovalusci
Conference Chairman, ICCM2018
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The topological principles in the contemporary architectural design process

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Abstract

Continuing a chronological line of mutual influences of architecture and geometry, where geometry is perceived as an inextricable part of the syntax of architectural space, this paper focuses on the clarification of a specific position which mathematical topology takes within contemporary architectural discourse. The understanding of topology within architectural design process is based on the mathematical theoretical framework in which the term of continuous deformation of geometric shapes is specified, whose subsequent occurrence in architectural creative work is linked to the increasing use of digital tools in design process and the shift of the dominant philosophical influences in architectural theoretical research. In order to completely perceive the topological method, the theoretical framework ranges between the area of architectural theory of form and architectural design theory, firstly through the explanation of three basic design principles of topological method: *deformability*, *openness* and *continuity*, and secondly through the representation of the models through which the principles occur in the architectural design process. The first part of this work will introduce and analyse the transition of concepts of deformability, openness and continuity, from mathematical topology through philosophy to architecture emphasizing the computational shift in architectural design, while the second part of the work will explain the modalities through which the principles are applied in several architectural design practices. Generally, the paper is conducted in order to determine whether the development of the topological method, as a creative tendency, resulted in forming a unique design strategy due to transformations and adaptations through some authorial design approaches. The topological method design strategy, which involves a complete design approach, is identified as a result of an in-depth research of distinguished methods through three case studies, taking into consideration the complexity of topology within the mathematical area and a complex transition towards the area of architectural theory. The final question returns to the primarily theoretical framework, seeking to set operating platform for development and use of three strategic principles, which simultaneously indicate the possible directions of future development.

Keywords: **topology, deformation, continuity, openness, digital tools, design theory, design methodology**

Transition of topology from mathematics to architecture

In current theoretical studies of architecture, there are numerous references to a branch of mathematics i.e. notably higher geometry, which is called topology, but it is difficult to detect more precise and detailed elaboration of the analysed in-depth and somewhat hidden properties of geometrical objects that topology is generated for. The analysis of the term topology points out the problem of ambiguity, which occurs due to imprecise and frequently loose interpretations of terms which belong to the field of the exact science disciplines. In the widest sense of the word, one can say that mathematical topology does not make distinction between two shapes or two spaces, if it is possible to shift from one to another under continuous deformation. When it comes to these spaces, size and shape are irrelevant if they can be changed by, for instance, stretching. The difference between two spaces is primarily related to those components which remain unchanged when deformation occurs. The relevant literature in the field of mathematical topology explains that, generally speaking, topology studies the properties of geometrical objects which remain preserved under continuous deformations, such as connectedness or compactness. Geometrical objects that topology studies are usually manifold, but set theory enabled the studying of both general and abstract objects, the so-called topological spaces. Some of the typical examples of topological spaces are Möbius strip, Klein bottle, tori, different knots, etc. In the outline of the history of mathematics, Morris Kline indicates that the first ideas about topology can be found in the works by Gottfried Wilhelm Leibniz, in his book *"Characteristica geometrica"* from 1679, in which Leibniz introduced the concept of *Analysis situs* (Analysis of position) to counter size and form, highlighting the lack of adequate language when talking about form [1]. Also, in a letter addressed to Christiaan Huygens, Leibniz accentuated that we need "another, strictly geometrical analysis which can directly express *situm* /position/ in the way algebra expresses the Latin *magnitude* /magnitude/" [2]. The first precise setting of topological spaces was conducted by Leonard Euler in the period around 1736. In an attempt to solve the problem of *The Seven Bridges of Köninsberg*[1] he made the first topological diagram. What is essential for understanding the problem which Euler reduced to the diagram is the cognition that, regardless of the quantitative characteristics of the diagram, the shown topological structures, as well as a solution to the problem given remains the same. By changing the approach Euler has predominantly pointed out to the nature of the problem, placing it in the field of autonomous, qualitative properties of geometric shape, ones that remain unchanged under certain conditions. Euler explains this as follows: "The branch of geometry that deals with magnitudes has been zealously studied throughout the past, but there is another branch that has been almost unknown up to now; Leibniz spoke of it first, calling it the "geometry of position" *(geometria situs)*. This branch of geometry deals with relations dependent on position alone, and investigates the properties of position; it does not take magnitudes into consideration, nor does it involve calculation with quantities" [3]. Sergei Petrovich Novikov underlined that it was even intuitively clear that the cognition of geometric properties of shapes was not exhausted by data on their metrical characteristics, such as length, height, angles etc, i.e. "there is something more beyond the limits of the old geometry" [4]. Regardless of length, a line can be open, closed, knotted, several lines can be linked in different manners, shapes can contain holes etc. The characteristic of these and similar properties of geometric shapes, as well as of different mathematical objects that do not have geometric realisations, is that they do not change upon continuous deformations. The invention of precise calculus i.e. the part of mathematics with its exact terms, methods and formulas describing topological properties lasted for a long time. Throughout the 19th century, it was developed, among others, by Karl Friedrich Gauss and Bernhard Riemann, but it is deemed that topology, as an autonomous branch of mathematics, was established at the end of the 19th century by Henri Poincaré. During the following decades, its internal tasks were being resolved and only in the 1970's did the topological methods more intensively infiltrate into the apparatuses of contemporary physics and chemistry and they were more generally interpreted through discourses of social sciences and humanities, particularly through philosophy and therefrom spreading the influence to different branches of art.

By analysing the transition of topology from mathematics to architecture, one can detect certain influences which result in its more intense presence in architectural discourse around 1990's. There are two streams of influence, the first one being streamlined through philosophical discourse in specific methods and through work of certain authors, and the other

[1] Königsberg is the name of a former city in Prussia, now Kaliningrad in Russia.

stream being reflected in the change of tools used in the process of architectural design induced by emergence of digital tools and intensive development of software for drawing and modelling. One of the most significant influences on adoption of mathematical terms and concepts, notably those in the field of topology, was realized in the 20th century through philosophical theory of Gilles Deleuze. Taking distance from the predominant thought of the period, where language became the fundamental problem of philosophy, Deleuze insisted on philosophical creativity which enables the formulation of new concepts instead of exclusively describing the existing appearances and states. Basing his philosophical theory on creation of concepts through experimental thinking, Deleuze stressed that there were no simple concepts but instead that they were complex, multi-layer structures, figures, metaphors, individual elements etc. [5]. His overall approach to philosophy defines him as a more progressive materialist, who based his materialism on science and its discoveries and does not observe matter exclusively as essence but also addresses its genesis and the genesis of its form. Matter does not have an inert but rather an active character, and its form is shaped primarily by generic processes, which results in concepts that merge scientific knowledge with philosophy. The link of philosophy with scientific knowledge, primarily with that of mathematics and mathematical topology, gave a fundamentally spatial character to Deleuze's numerous philosophical concepts, and thus he defines the differences between continuity and discontinuity, smoothness and folding, topological and metrical, large and small, stable and nomadic etc. Through his philosophical materialism which relied on mathematical terms and their interpretation, Deleuze made topological concepts accessible to public. But Deleuze's contribution to topology was somewhat greater than mere interpretation of mathematical discoveries. He applied topological discourse to his philosophical concepts falling within the domain of philosophy, such as the issues of ontology and the nature of being, metaphysics etc, and thus he gave additional meaning to classical philosophical terms, attributing them the properties such as continuity, deformability, curvature, smoothness, folding, bending etc. The impact of his work thus became important for theoretical discourses apart from philosophy, notably for architecture, since he used dominant spatial characteristics to interpret the issues of individuals, societies, relations within social groups.

One can observe that the methodology of applying mathematical concepts to wider scope of knowledge frequently relies on specific knowledge that define different areas, which are defined by Arkady Plotnitsky by reciprocity of mutual influence of mathematics and philosophy known as "quasi-mathematics" [6]. Although he does not question philosophical influence of mathematics on the development of civilization, he claims that quasi-mathematics enables the spreading of certain mathematical terms and principles which are not defined exclusively by mathematical tools, although deriving therefrom, and therefore they become feasible and applicable beyond its disciplinary margins. Through term quasi-mathematics, Plotnitsky explains the difference in interpreting algebra, geometry and topology in general. He interprets algebra as an ultimate concept of formalisation, whether formalising a system in sciences, conceptual systems like those in logic or philosophy, or language system existing in linguistics. In this manner, "algebra" means a set of certain formal elements and their relations. On the other hand, "geometry" and "topology" have different mathematical backgrounds although they both deal with the issues of space. "Geometry" deals with space measuring as *geo-metry*, whereas "topology" disregards sizes and deals exclusively with the structure of space *(topos)* and the essence of a shape. Putting them in a philosophical discourse, Plotnitsky explains the difference between these two theoretical aspects with Derrida's "algebra", which referred to writing, characters, and form dislocated in negation, and Deleuze's "topology", through which he insists on the continuity of folding.

Referring to the previously given elaborations, one can conclude that topology was difficult, incomprehensible and entirely abstract for architecture, and that it emphasised certain differences in mathematical and architectural perception of space. On the one hand, mathematics brings abstraction to its extreme, which exceeds architectural perception of spatial relations. On the other hand, the methodology used in mathematics for solving its internal tasks is exceptionally precise and exact, which is not characteristic for the process of architectural design. It appeared that philosophical texts, which were already highly positioned in the theory of architecture, managed to overcome this discrepancy between architecture and mathematics by interpreting certain mathematical terms using language that was much comprehensible for architectural discourse.

Simultaneously with the change of philosophical influences, the presence of topology in architectural discourse was also registered in the change of working tools used in the process of architectural design. Digital tools and the development of modelling software changed the position of classical drawing where space was displayed through projections during the design process. Even greater influence is resulting from the knowledge of software and their intensive upgrading, which introduces algorithm logic for design problem solving into architectural discourse. Computer software had an option to generate geometry of topological characteristics, not only by means of equation, but also through parametric functions that provided numerous variants for continuous curves. Already in mid-90's, the computers with software for modelling the desired curves became affordable because their price was drastically decreasing. However, in the context of this paper, there is a more important thesis that states that digitalisation in architecture implies a more drastic progress towards a new architectural paradigm i.e. a new way of thinking where use of digital technology does not only imply the use of digital tool, but also the theory of algorithm as the main creative postulate, way of thinking, special thought and creative form. In early 1990's, Peter Eisenman introduced a new term: "During the fifty years since the Second World War, a paradigm shift has taken place that should have profoundly affected architecture: this is the shift from the mechanical paradigm to the electronic one" [7]. During the nineties, theoretical papers in the field of architecture and the related discussions began to see the positions that digital principles started to transform the paradigmatic framework and that they were growing from technological fascination into the way of thinking. Word has it that algorithmically-generated space indicated fundamental, ontological change of basic elements of architecture and that the appearance of digital tools and the specific logic for their use in architectural theory and practice became a reality. The Deleuze's philosophy in the theory of architecture definitely appeared at the moment when digital technology was already well developed. At the same time, this is a basis for debating whether Deleuze's philosophical platform found a tool for its realisation in digital means i.e. whether it would have such an impact on architecture if there were no technological prerequisites for its visualisation. Anyhow, the presented comparative analysis of the impact of philosophical thought on the one side and the development of computer tools for modelling on the other, proves that the connection between Deleuze's philosophical theory and digital tools in architectural discourse is undeniable. By joint action – that of Deleuze through philosophical terms based on mathematical topology and that of digital technologies that enabled the manifestation of certain abstract mathematical concepts expressed exclusively by calculus – the idea of topological tendencies in architecture is actualized.

In the context of in-depth elaboration of different modes of use of topological principles, one can understand why certain historical overviews contain the term "topological architecture". The clarity of visual expression, which was present at the very beginning of use of topological principles, led to the denial of claim that certain fields of art must first decide how to present their final product in relation to the process of its generation. It appeared that quite the opposite was in the case of architecture – the form of final product was known, with increasingly clear picture of the possibilities for its realisation through faster development of technological means and applied materials, but once the manifestation became clear its actual meaning came into question.

Three topological methodology principles

The discussion on positions of different scientific disciplines in architectural discourse tells us that certain parallels can also be made with topology, primarily in the context of relation between architecture and sciences. When it comes to methodologies of architectural design, it is clear they can be different, but they usually do not imply the exactness and fixed language for solution of individual problems such as other scientific disciplines. Therefore, for the sake of more efficient link between contemplation and creation leading to ultimate result – the work of architecture, architecture freely adapts specific methodologies of other disciplines. As regards topology, it is clear that in architectural discourse it cannot be formally considered as mathematical topology. Adjustment of knowledge in topology for the purpose of forming topological principles in architecture is explained by philosopher and architectural theorist Manuel De Landa through term "topological thinking", based on the idea of research of system potentials and the manner in which the potentials may generate certain forms, whereas he treats form as a system of elements with capacity to influence other system elements [8]. Relying on De Landa's positions, in the upcoming text we will use three topological principles - continuity, openness and deformability - to explain transition and transformation of topological properties, from mathematical definitions to segments of individual project methodologies, and to explain their potential for creation of a wider design platform.

Principle of continuity

Generally speaking, the main idea that defines and specifies mathematical topology is the idea of continuity, which in topology primarily refers to continuity of mapping. Continuous mapping can be explained by the idea that "close" points of one set are transferred to the "close" points of the other set. Intuitive explanation of continuity implies that, upon mapping of figure A into figure B there are no sudden rises, hence upon "slight" changes of the original its picture is also "slightly" changed. The term homoeomorphic mapping that can be found in architectural theory texts comes as a more precise definition of mathematical topology, and it can be perceived as mapping of one set of elements into another, without tearing or subsequent gluing together. If we presume that it is possible for figures A and B to be stretched and bent so that we bring figure A to translate to figure B, we can generally say that they are homoeomorphic. For instance, the perimeter of triangle is homoeomorphic to a circle, the surface of sphere is homoeomorphic to the surface of cube or cylinder and it is not homoeomorphic to torus etc. Also, line segment can not only be stretched and shrunk, but also bent and straightened.

The principle of smooth continuous stretching contains deep spatial references and, interpreted by the continuity of architectural space, it demonstrates a necessary degree of flexibility of spatial framework. It can be interpreted through continuous circulations, implying that the architectural structure has continuous trace of movement and continuous flows of different information. With regard to the type of the observed trajectory, it is possible to treat continuity as a spatial characteristic that includes and spreads within an architectural structure, or more narrowly observed as a continuous planar communication visible at the architectural plan. Continuity of architectural structure reflected through superficial continuous movements is conditioned by predominantly organisational solutions, whereas spatial continuous movements can be achieved by the continuous void within architectural

structure. The principle of continuity of spatial voids is closely linked with interpretation of and linkage with the principle of free plan, since both of them rely on acceptance of basic architectural postulates, as defined back in the modernism.
The analysis of this specific principle tells us that it comprises of two terms that need to be elaborated: *continuity*, which is closely linked with the mentioned principle of modernism and which can be partly interpreted through forms of movement within space, and *void*, the manipulation whereof can be used to define the structure of the work of architecture. Specific continuity of inner space in terms of volume relates to a more general perception of continuous flows including, beside movement of users, visual, information and other spatial circulations. However, the issue of spatial articulation, empty space within certain form, represents one of the key issues of architecture that can be interpreted both as a relation and as mutual action of internal and external space. The origin of these contemplations dates back in the 19th century, when space i.e. void had a sort of metaphysical significance, but the overall methodological basis was developed by Raumplan concept at the beginning of the 20th century through a complex system of interior development by Adolf Loos. Although connected with the development of open plan principle, Raumplan builds on Loos' design methodology based on the idea of designing space instead of plan. The basic idea of interior space segmentation is achieved by dividing different floors in to the several levels, so that continuous space spreads within a building. Although this system is close to Le Corbusier's methodology "from the inside out", Loos' perception of space incites a volume-based modality of creative thinking, relying on enclosing skin as a structural element. Charles Jencks indicated the existence of another approach to modern space, based on the tradition of rational Chicago school, and Le Corbusier further developed it through structural skeleton of Maison Domino, where all future principles of modern architecture can be observed [9]. Space is here perceived as being homogenous in every direction, but segmented as skeleton at right angle to the façade plane. Although such interior space is characterised by vast and open structures, it is nevertheless limited by edges, the enclosing skin is clear, ultimately rational and feasible.
It was only with contemporary definitions that the terms of *continuity* and *void* were brought into clear connection for the purpose of explaining topological properties of architectural works. Methodological postulates of architectural theorists such as Greg Lynn, Lars Spuybroek et al. clearly rely on previous researches, they underline the significance of Raumplan concept and take a distance from Le Corbusier's open plan, whilst topological continuity of space is described by emphasising the potential towards more flexible connection between internal elements. The logic of fluidity supports the thesis on intensive mobility, which implies vast and easy deformability because the interior structure is such that small forces lead to large deformation. The issue of continuous interior discussed herein is maybe most relevantly referring to the logic of continuity elaborated by Spuybroek in his book *The Architecture of continuity*. In the first place, he writes that buildings are made of elements does not mean that architecture should be based on elementarism; we should rather strive for an architecture of continuity that fuses tectonics with experience, abstraction with empathy and matter with expressivity [10]. Spuybroek recalls the logic of continuity that is philosophically developed by Charles Sanders Pierce on basis of topology explanation [11]. Elaborating Pierce's notion "structure of vagueness", Spuybroek explains that the relation between elements is always vague since they are at the same time elements and parts of a whole. Vagueness does not represent the absence of logic, on the contrary, the logic of vagueness is what constitutes the relations. In this manner, using Pierce's conclusions, Spuybroek establishes equivalence between continuity and relations, strictly opposing the idea that architectural space can be classified as space and void. He thus concludes that void needs to be interpreted as a spatial structure and not as air between the walls. Thus observed,

an architectural work implies that emptiness has a temporal aspect as well, since it can change iterations over time. The definition of this type is significant in the domain of continuity research, since it indicates that it is possible to create a specific design methodology which defines space through manipulation of the absence of space. As it is completely unnatural in built structures to conduct construction and subsequently take out its parts, the design methodology building on emptiness implies that the most significant spaces within buildings are created either by elimination or omission in the phase of architectural concept design. Strategically, such design methodology treats void as an integral part of spatial complex and builds upon it in the design process.

In her experimental work, Dagmar Richter used the model of Le Corbusier's Maison Domino as a subject of research and a mechanism for verifying her own hypothesis that topological principle of continuity can be largely defined through changed attitude to *surface*, which becomes the ultimate structural concept [12]. Richter tests her explicitly topological position starting from a paradigmatic definition of five architectural principles, where the connections between reinforced concrete column and beam bear the ceilings on six offset points and represent the only load-bearing elements of architectural assembly. The research process implies that the structure of Maison Domino is analysed by layers, where the first layer in the structural hierarchy – slab – is treated as a series of fields with local characteristics in points of bearing, which breaks up the primary form of universal form skeleton. During the first phase of research, the skeleton evolves, during the second phase it develops spatially under the influence of spatial connectivity principle, non-hierarchal spatial relations and adaptability, all for the purpose of controlling the variable nature of the newly-designed prototype. By application of animation technique, Richter's research team developed several simulations of the process, creating a collection of possible prototypes which typologically still refer to housing. After the second phase, the change of the structural skeleton is visible, as it is now constructed from a single continuous plane, the mass whereof becomes an important factor for construction of the new model of topological structure (Figure 1).

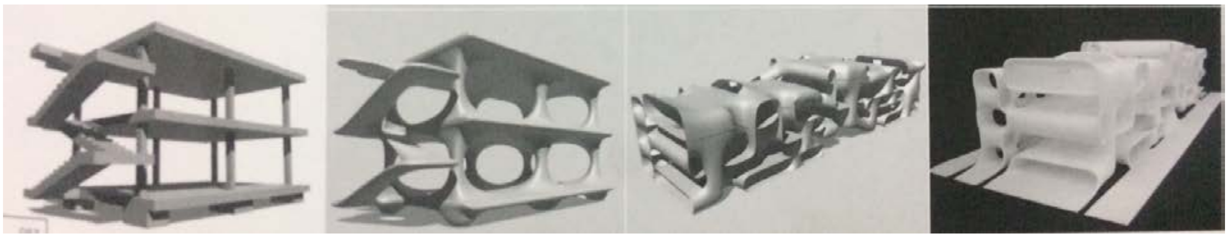

Figure 1. Dagmar Richter, new structural role of surface - transformation of Le Corbusier's Maison Domino model

The aspect of deconstruction of façade shell, which drastically differs from Le Corbusier's free façade, can be interpreted as a prototype of essential intertwining of interior and exterior space of the house. An important conclusion of Dagmar Richter's research is that topological deconstruction of an architectural work can only be achieved by changing the structural system i.e. its major transformation relative to the existing assemblies. Throughout the project research, she demonstrates how this can be realised, proving her own assumption that the treatment of space, relying on topological principles during the design of architectural works, is founded on the new structural role of *surface.*

The establishment of the role of topological principles in the design and research done by Dagmar Richter can be monitored through all phases of architectural work design. In addition to structural system deformation and creation of a new type of topological architectural structure, Richter directly refers to topological principles in her theoretical essays, as well as to mathematical discipline. Broadly observed, the entire research process, which starts from the paradigm of modernism, additionally refers to post-modernistic references, where a new structure can never be clear and original in a classical sense, but it is always an interpretation. Thus perceived, the design methodology is defined as a strategy for adapting previous systems to new conditions i.e. rather as a process of reinterpretation than that of creation. The design methodology of Dagmar Richter directly relies on chronological references to the notion of space continuity, including the questions of what was before and what would follow, as a constant historical postulate, that the science has been striving to overturn since the beginning of the 20th century. Cyclical history, fundamentally different as compared with the evolutionistic, is a history of one multi-dimensional space where texts and writing overlap, making a single network of "diversity" of events. Each text has a reading history because different societies re-write the text by reading it and unconsciously attribute it with different meanings. No one can read a text without making an image of the context in which it was made and what it actual aim is.

The principle of openness

Generally speaking, the notion of limits of space is related to the notion of distance between two elements, which in mathematical sense implies that elements can be attributed real number and declare it distance between them. Metrical space reflects natural ideas about the notion of distance, relying on understanding of spatial relations where i.e. distance between two points is always positive – distance between x_1 and x_2 is always equal with the distance between x_2 and x_1 etc., which simultaneously most corresponds to the perception of Euclidean space. The notion of openness becomes very important for the topology induced by metrical space, because mathematical definition of surface relies on understanding of the surrounding of points that it comprises of, so that surfaces with and without boundaries are being distinguished. Surfaces with boundaries are, for instance, circle or sphere where several openings have been cut out, while surfaces without boundaries are generally classified according to the number of holes they contain.

Contemplation on the notion of boundary in architectural discourse can be extremely broad, but in the context of the postulate of topological principle of openness, it primarily implies the research of properties of space at the limits of structure, where topological character is displayed in its imprecision. As originally explained in topology, the focus on *surroundings* of a point can be perceived as a small shift in the surroundings so that it is never even abandoned, which complicates the relation inside-out and the question of defining the limits and bordering areas relating to the observed point surroundings. Openness thus starts to refer to the property of architectural work which relativizes the treatment of exterior and interior of architectural structure and is manifested through the weakened attitude to the object limits. The characteristic of this type implies the research of classical spatial duality interior/exterior, by methodologies where architectural work is designed by intertwining structure with imminent surroundings. Research can be done from two aspects, by analysing façade plane and ground floor of the architectural work, in order to clarify possible approaches relative to the shell and to the ground. Transition of openness term from mathematics towards architecture is largely founded on Deleuze's interpretations, both through specific spatial indications and through more direct elaborations of philosophical postulates. Architectural discourse of the 1990's recognised the importance of interpretations of Deleuze's positions stating that exterior is not a fixed limitation but rather a mobile matter, animated by movement, folds and bending, which defines the interior: it is nothing else but exterior, or more precisely the interior of the exterior [13]. Research of the architectural work boundaries demonstrates that folding goes from outside to the inside and vice versa, through different scales and regardless of distances, where nothing is fixed but rather in constant change.

Architectural treatment of façade through theoretical assumptions of the 20th century, formed within the two previously noted and somewhat opposed architectural principles: the principle of structure and the principle of membrane. Design methodologies of architects such as Walter Gropius and Le Corbusier affirm the idea of structural façade plane which is based on the plan of structural columns (*pilotis*) by means of which façade can be treated apart from the spatial assembly of objects, which is fully described by Le Corbusier's fifth postulate of architecture. The structure principle enables the façade plane to exist irrelevant of the interior space organisation, which provides it with certain autonomy in display of exterior/interior relation, so that the limit can be treated both as open and closed, depending on different external parameters. On the other hand, Bernard Cache explains that, as opposed to the principle of structure the principle of membrane is being developed, which is particularly affirmed in theoretical platform of Adolf Loos where façade is an element conditioned by internal space organisation and the membrane indicates the differences between internal spaces. This gradual movement toward interior can also be understood as an attempt to create an extrovert architectural work. Although the principle of membrane in Loos's realised works is displayed through organisation of façade openings, a significant deviation in façade treatment is represented by the attempt of its deconstruction, which leads to the nearing of interior and exterior of architectural object. Italian architectural theorist Alicia Imperiale explains that modernistic design methodologies generated in the first half of the 20th century strived to present a tension between deep interior space and façade surface, using glass or similar transparent façade planes, which actually indicated a dialectic difference between interior and exterior [14]. Certain contemporary approaches use different techniques for processing façade plane in order to allude to this principle by means of delayering the surface with specific materials or patterns with different transparency. However, Imperiale deems that the openness principle can only be achieved by substantial merging of the interior and exterior, inseparably from the continuity principle, and that the relation between these two dualities can only be significantly changed by continuous plane treatment. If the weakening of limit in the façade plane is not restricted exclusively to the impacts that the membrane receives from the inside and/or outside along its surface, but it is rather interpreted through more intensive inside-outside relation, the perception of membrane surpasses the plane structure and the limit along which the membrane extends becomes a zone on the inside-outside crossing. Blending of interior and exterior is in this case slowly shifting, according to Loos' attitude to structural shell, which in its final form can become the entire structure. In theoretical postulates where façade is comprehended as a certain area, where width and position of the area fluctuate to the outside or to the inside, one can record significant use of topological surfaces such as Möbius strip, Klein bottle etc. Möbius strip is a surface with one side and only one boundary, but its direction covers both the inside and the outside through orientation reversal. Although it is clear that the system of Möbius strip and notably that of Klein bottle do not have three-dimensional realisations, they cannot be directly applied, in the context of architectural design the non-orientability of surface indicates membrane treatment where certain bending can provide for continuity of interior and exterior. If the notion of non-orientability in architectural discourse starts to refer to Deleuze's notion of fold, it can also be interpreted as a process of continuous and homogenous transformation that manages to preserve integrity, continuity and uniformity of parts. Intuitively, this process can be perceived as bending of surface, smoothly and without pulling, whereas after several variations the limit between the outside and the inside and between full or empty would disappear. Therefore, topological property of openness can be estimated on basis of recognition of the open façade interspace which displays the causative relation that affects its deformation. The weakening of opposites outside/inside does not imply the vanishing of architectural structure, but it requires theoretical analysis of elements affecting the limit behaviour. Through such postulates, the space between interior and exterior is treated as space between, as defined by Andrew Benjamin when he says that the space of difference is not just "between" but the interspace of the boundary becomes a third segment that cannot be predefined and it is directly comprised of the inside and outside elements that generate it [15]. Direct application of openness principle can be analysed on the design for Eyebeam museum, the award-winning work of the architecture studio Diller Scofidio + Renfro at the international competition realised in 2002 by Eyebeam foundation, which is an art organisation oriented towards research of technology impact on the development of different art practices. The call and programme definition of the competition required a facility that combined the purposes of museum, theatre, education and production, wherefore the museum part was intended for exhibition of modern art works generated under the influence of new media, in form of performance, video works, 2D and 3D digital imaging, sound installation etc. The second part implied laboratory for art production, as a requirement of contemporary art institutions, for the purpose of displaying the works of art whilst transparently presenting the process of their generation.

The conceptual presentation of Diller Scofidio + Renfro is based on the use of pliable strip the disposition of which separates two museum segments: presentation and production. The strip starts to bend from the ground floor level, it extends along the entire building width so as to form a continuous plane of the floor, wall and ceiling. Each bending and change of direction opens either presentation or production zone, which additionally combines the movements of visitors and staff. Activities within the space can best be seen at the section that displays strip bending and intertwining of interior and exterior space, which is entirely transposed to the façade plane. The approach where exterior of a building is conditioned by the internal organisation, which is displayed on the façade, represents a significant departure from the traditionally closed facades of museum buildings. Spatial relations are becoming even more complex in the parts where the strip splits towards upper and lower level, which leads to additional overlapping of presentation and production spaces and announces additional thematic dualism. One can say that the concept of pliable strip permanently indicates the existence of different binary pairs within the designed space, but with the aim of their essential overlapping instead of distancing. Duality is particularly emphasised by the two-ply treatment of the very strip, which comprises of a smooth concrete ply with precast service jacks or "smart pores" line exhibition levels and a second ply of lightweight removable panels of non–conductive composite material line production/education levels. The interstitial space is an installation base running through the interior and exterior of the building so that the open structure of the strip enables subsequent additions to the necessary installations, which was described by Diller Scofidio + Renfro as the building's "nervous system" [16]. The building orientability in terms of outside/inside relation is additionally complicated by double-layer treatment of plane, where specific colours underline the change of position (Figure 2).

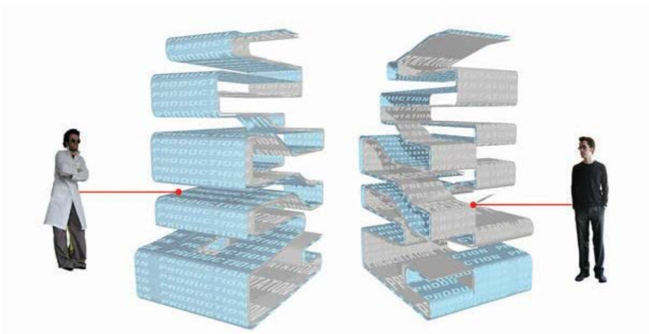

Figure 2. Diller Scofidio + Renfro, double-layered folding plane for Eyebeam museum

The presented building, generated by bending of surface that twists freely under different angles, is now indicated as paradigmatic example of architectural theoretical standpoints based on Deleuze's theory of folding. Although Diller Scofidio + Renfro do not elaborate the design in this context, other segments of their work, particularly the initial period, indicate direct influence of French post-structuralism philosophers. Direct application of topology in their work is confirmed along with the position of Deleuze's philosophical platform, so that different topological properties can be observed in the continuous and smooth deformation of plane. Generally speaking, openness that relates to the weakening of limits is reflected in specific vertical plane deformation, which results in weakening of boundaries at the positions opposite to bending.

The principle of deformability

Although the previous presentation of topology might lead to the conclusion that in the essence of homoeomorphic translation contains the deformability of a certain figure in order for it to translate to another figure, the introduction of deformation notion in topology primarily implies the deformability of the translation itself. More precisely, the term deformation is used in order to describe the relation between two continuous functions and not between two figures. Off the record, the function parameter can only be perceived as *time,* whereas the notion of time in this case does not imply any of the precise mathematical definitions, but it underlines that the process of deformation primarily displays over a certain interval and the display of change happening within such interval. It appears that the relation to form change temporality in architectural works can be built and displayed by application of the same principles. On the other hand, in architectural design methodology deformability usually implies the analysis of potentials of spatial structure for deformation, but not as a property which explicitly regulates formal rules for architectural buildings. Deformability implies that an architectural work was created by application of design methodologies where elements build structure by examination of internal relations instead of according to pre-defined order principles. Generally speaking, deformability property is preserved through a specific space building logic and it can be analysed on basis of two key issues: *what* has the potential for transformation of the main form, which is known and metrically defined, and *how* the change occurs. The first issue indicates the object of deformation i.e. specific characteristics of architectural work and it pertains to the research of deformable potentials of the existing elements. The second issue focuses on the display of the change of form of architectural structure i.e. the process that deforms it. Accordingly, the deformability of architectural structure speaks about the potential for topological logic of construction to be manifested in the ultimate form of architectural work.

Anas Alfaris deems that the form is a set of elements and their structure, where elements represent parts of a whole, and structure regulates formal relations between such elements [17] Referring to this definition, it is possible through the history of architecture to follow the development of the principle of architectural form creation *from general to individual,* which is rooted way back in the architecture of ancient Greeks and Romans, where the system of proportions was based on the golden ration, symmetry and examination of ideal relations between parts and the whole. The first examples of use of *individual to general* system in form development can be found way back in the Islam architecture, where mathematical formulas were used for repetition of geometric figures to obtain a complex pattern surface. Generally speaking, both systems of form development – from general to individual and from individual to general – rely on the idealised perception of the world. Geometrical systems of proportion, perspective, typology, geometrization of tiles is Islam architecture etc. are *a priori* based on ideal principles which either multiply elements or separate the whole, but the internal principles of the given system remain unchanged. Considering that both parts and the whole are displayed as fixed, unchangeable geometric forms, they cannot be combined so as to make any impact on or to modify one another. The presented systems of composition of structural assemblies neglect the character of relation between elements and such relation remains quite simplified, even in the treatment of structure as developed by Metabolists or members of Archigram group. Against these two systems, Farshid Moussavi's book *The function of form* suggests a different system for construction of architectural functionally-formal assembles which she called *transversal system* [18]. The system implied that the main constructive element is not geometrically pre-defined but that it comprises of multiple causatively-complex systems. The principle of element combination arises from their specific nature, which causes form to be generated from proto-geometrical characteristics that are physically and geometrically specific but are not necessarily specified. The elaboration of proto-geometrical characteristics of basic constructive elements is close to definition of topological invariants, and, as explained by Moussavi, these are the characteristics with capacity to be the constants in any form they generate. Topological character of deformable spatial assembly essentially implies the same as in mathematical discourse i.e. that architectural work is accessed at the moment of generation as to a system subject to free deformation, the formal display whereof can be freely changed if the elements, which are close in the initial disposition, remain close after the deformation. On the other hand, the limits of deformation and constant provision of architectural part are conditioned by external restrictions and they are never the result of a universal internal rule.

The principle of deformability in creation of an architectural work, including a temporal component in the process, implies the display of all phases of deformation and not only the original figures. The idea of direct display of deformation process is based on the display of change in architectural work in certain time intervals, while the transposition from one form to another is done by small deviations from the previous spatial determination. Visual research can rely on the perception of time continuum through strip element, which also represents a change graphic. This type of display implies that it is possible to read movement or motion through such formed conceptual aspect, whereas this type of minor departure in time definition is only defined when there are no fixed reference points or suggested identity, but only when relations based on uncertainty and certain differences are established, instead of those based on traditional attempts of order and its repetition. During the project procedure, what mattered was transformation of previous step into the following through current state, and in order for each deformation step to remain within the limits of topological method, the elements must not be subject to tearing and subsequent connection. Ultimately, the use of deformation principle can be tested on architectural works by application of standard architectural techniques, such as architectural drawing or three-dimensional picture, since the displayed time interval provided the projected methodologies and it refers exclusively to the design process. Elaborating the kinetic form, Kostas Terzidis added that movement was an act or process which changes position or place over time, hence the movement includes temporal component which actually represents a unit of change [19]. Referring to similar definitions, Greg Lynn indicates a need for systematic inclusion of time and movement upon form definition, identifying cinematic model when movement indication in architecture is concerned [20]. Cinematic model implies the multiplication of static film sequences that simulate movement, and the displayed frames create a memory of form which is spatially and temporally simultaneous. In fact, it generates an idea of architecture that creates temporal component through memory of time. It is based on animation, morphing and similar techniques based on the display of several isolated pictures over a defined time period. In the context of creation of architectural works, Kostas Terzidis explains that morphing is a term used to describe a process where an object changes form to obtain another shape. Although this is a gradual transition, it can result in significant change of appearance, character, state or

function. Morphing is a significant formal means and it refers to one of the most significant matters of architectural objects: possibility to express and identify itself through own form.
The interior design of Miran Galerie by architectural studio dECOi is explained by Mark Goulthorpe as a process of membrane generation and the beginning of research of architectural surfaces by Rhinoceros computer programme, for the purpose of creating the impression of morphed three-dimensional shell within a static architectural building. Homogeneity of continuous curved surface that fills the existing spatial frame by unique treatment of floors, walls and ceiling, had been preserved by bending and folding of plane within the spatial limits. A series of analytic diagrams displays how dECOi follow the change of main form through deformation of longitudinal axis, which can be interpreted according to mathematical definition as translation deforming the displayed structure in the interval starting from initial to the final position (Figure 3).

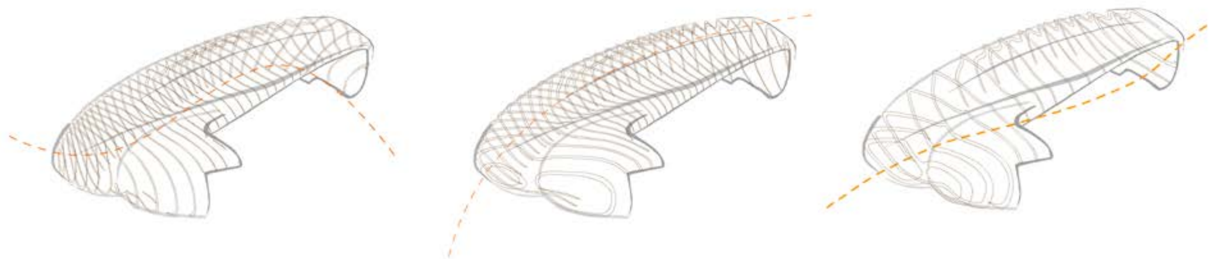

Figure 3. dECOi, series of analytic diagrams showing the process of deformation

The designers' intention to implement deformation process through a series of cross-sections implied that dECOi had to develop a sophisticated technique of computer modelling – in order to present a three-dimension form as a collection of two-dimension elements, to obtain structurally stable frames and to develop encrypted tools generating sections on the desired positions. During the elaboration phase, the problem with main figures in generation of hybrid form was detected. Their manipulation uses two curves of *nurbs* type, where one controls the angle of cutting and the other controls the assumed density of crossing, hence the final figures can be harmonised with the primary volume. An important part of the developed methodology relates to the development of diagram approach to the control of these two lines – where definition of the assisting cross-section and line for density regulation, located outside the building, can be used for testing of variations of temporal axis. The displayed methodology implies changes in the manner of element production, along with the development of special computer programme with clear optimisation parameters. The recognition of use of topological principles in the development and realisation of the internal membrane of Miran Galerie is reflected in the clear intention to present the process of deformation by specific cross-section system. The design methodology, based on the development of programmed tools used to control the complex geometry of the designed membrane, takes into account the change in curvature of the local plane parts. The significance of Goulthorpe's opus is reflected in the intensified use of certain topological principles in project development phase by using certain topological methods to resolve explicit problems in realisation and use of specific materials. As the focus from its initial work was shifted towards the research of new materialisation models and creation of theoretical platform relying on specific computer logic for resolution of architectural details, Goulthorpe retains priority in the realised works as well.

Conclusions

Based on the presented topological principles, illustrated by examples of architectural works where they can be observed, it becomes clear that contemporary architectural paradigm has, by registering key principles of topological method in design process, acknowledged the presence of topology as an integral part of a wider design strategy. During the review of statement that geometry conditions a part of relations within architectural space but it needs to be integrated in a much more comprehensive theory so that her proper place and significance would be assigned, it becomes clear that topology, as a creative tendency, contains design principles based on which it builds its own framework and which ensure its position in contemporary architectural paradigm. Although the first part of the paper indicated a more complex theoretical position of topology in architectural discourse, it followed on to observe three topological properties and principles of architectural structures, demonstrating that recognising the use of topological principles in designing architectural works can be done on basis of basic architectural postulates. These principles are not new, but in previous design methodologies they were not observed in this manner i.e. so that openness is reflected in a weakened relation to façade shell, continuity in internally empty and full spaces, and deformability is interpreted by the specific principle of building an architectural structure and as a process causing deformation. The presented principles indicated a wider context of application previously elaborated through the idea that architecture and sciences contribute to creation of a specific system of world perception, while it is insisted on flexibility of structure susceptible to easy changes dictated by a moment. If we assume the most general position that architecture, as well as sciences, speaks about the creation of the world which is inhabited by subjects and objects, whereas the “manner” is always historically determined, we can understand the position of Antoine Picon who refers to relation between a subject and its environment, while architecture and sciences are the fields which define this relation, primarily in the domain of the created environment. It can be noted that certain historical processes hold this relation to be more significant and productive, and Picon relates it to the periods when architecture and sciences contribute to creation of a specific system of world perception [21]. The manner of perception and image of the environment refers primarily to the environment as a cultural category.

This paper is an attempt to clearly outline the causative link between digital technologies and complex geometry reflected in topology, but also to emphasise the additional problem arising from the approach of topological treatment of form which refers to the absence of aesthetic valorisation of the deformed amorphous architectural forms. A part of problem also stems from the absence of clearly defined system of evaluation of aesthetic characteristics of new forms, and another part is in the process of their generation which is underlined by question of what is it in the process of form transformation that determines when the form would end. Similar observations are made by Michael Meredith who states that the results of use of topological principles during the 1990’s are reflected in isolated physical and aesthetic models that have no wider impact but instead remain within their own limits [22]. In this context, we can contemplate whether literal application of topological principles in architectural design favours the formal-shaped aspect of architectural work, which transfers the matter of use of topological principles from the domain of architectural theory of form closer to the architectural design theory. The three suggested strategic principles of application of topology: principle of continuity, openness and deformability represent certain characteristics of architectural works and indicate methodological processes rather than precise designing recommendations, which makes the defined platform for use of topological principles less determined and looser for interpretation.

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