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CLOSING REMARKS

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The complementary between the fields of theory and scientific expertise and practical knowledge is widely reaffirmed in this fourth seminar 'Formulas in Architecture'. And it continued to gather significant information for development in all the important contributions collected.

Correlating two distinct areas of human knowledge – mathematics, an essential, sheer, scientific knowledge, and architecture, of a more practical and utilitarian nature, responsible for the creation of the human habitat – opens new advances in reasoning and points out new possibilities for the development of both and for reflecting upon the scope of the framework that enhances the dynamics of human life.

Architecture has developed throughout civilization as a matter of space understanding, responsible for space characterization and for its functional and emotional qualification. Being simultaneously a theoretical and practical discipline, and dealing with extreme complexity, it increasingly requires a multidisciplinary knowledge that congregates in an operative synthesis the technical and the tectonic, the artistic and the humanistic.

All these aspects are involved in the matters studied in this seminar, which mainly focused on three main comprehensive themes among the multiple aspects that relate mathematics and architecture:

- Conceptual thinking, both theoretical-based and practical-based;
- Graphic representation and composition, dimensioning and accuracy;
- Interpreting and conceiving built environment and territory through mathematics.

These domains base on mathematical reasoning of different nature and scope, generally translated by means of a significant graphic or geometric representation. The keynote addresses, by Nikos Salingaros, of Texas University at San Antonio, Renato Saleri, of the Ecole Nationale Supérieure d'Architecture de Lyon, and António Araújo, of Universidade Aberta – Lisbon, relate to each of these main themes.

What is the direct correlation that can be established between beauty and meaning in architecture? This central question, brought by Nikos Salingaros' presentation, frames his reading on how the perception of the environment is processed by the human brain and the biological reactions of the human body in face of different architecture atmospheres. Mathematics is an important tool for the understanding of the built environment, through sensorial perception of mathematical abstractions such as symmetry, repetition, sequences, division and hierarchical

subdivision, dimension distribution and scale factors. The automatic processing of information by our brain, basing in aspects like these, has a biological origin, according to Professor Salingaros, basing on neuroscientific studies, and a visceral sense of 'beauty' which induces sensory well-being is therefore driven by this kind of perception.

Professor Nikos Salingaros pledges a shift away from current mainstream and 'fashionable' design, incorporating new practices and promoting mechanisms for mathematical coherence in shaping buildings and space, as well as in the teaching of architecture.

Mathematics allows us to find a sense of composition in the laying of an element within a structure, by encountering a proportion that relates the parts to the entire unit, thus establishing a perception of harmony from the recognition of a natural order, foundational in the universe. *"Mathematics has historically been tied to architecture as one of its most important tools."* (Salingaros, 2019).

Understanding Beauty as a quality-related adjective, found in the coherence of the unity relation between two entities, the mathematical and the aesthetic, as aesthetic can also derive from geometry and mathematics.

"Man understands the real and the virtual, by the ability of intertwining different realities in his will of reasoning and perception; he then edifies human condition in which Art is the greatest demonstration of the ability to manipulate an abstraction that exists in multiple dimensions, and which is discovering", according to Mário Chaves, that further states that *"all Architecture is yet a form of resistance, unitary but distinctible, since all diversity is complex, although not complicated, as it differentiates"*.

Reviewing a selection of writings from the classical period – Vitruvius, Plato, Aristotle – Emanuel Ferreira studies the multiple layers in which mathematics is operative in architecture and its interconnection with the artefactual and the tectonic. From these classical texts, he develops *"a specific scrutinization on the harmonic and scalar nature of architectonic institution, not mainly defined by spatial relations, but order, symmetry and scale as determined fundamentally by 'temporal calibrations' "*.

Basing on learnings from Japanese traditional architecture, Maria João Soares reflects on different cultures of geometry and space, revealed in concepts like 'Mu' (which can be translated as *nothing* or *void*), a *denial of existence* that may also be seen, for instance, as the space that a body has previously occupied. *"Are we facing a geometric universe that deviates from absolute rigor to reveal the ineffable? Or are we faced with a culture of strictness that opens the way to improvisation, as a key to privilege aesthetic emotion?"* An insight to the cinematography of Yasujiro Ozu triggers a reflection by Maria João Soares on the issues of geometry and space in the distinct Western and Japanese perceptions. An analysis of architecture in its plastic and sensorial quality, resulting from a geometry that through its presentation as scenario that through cinematography communicates space and time.

On a broader dimension, the implementation of this type of correlation systems is confirmed by a number of papers presented during the seminar focusing on order and proportion in architecture. It is the case of the study on the geometric background of one of the major works of Portuguese Architect Manuel

Tainha, the Oliveira do Hospital National Inn, designed from 1954 to 1960, and finished in 1970, where was employed “*in the modulation of some openings and in the size definition of some spaces*” a proportion system “*developed by Le Corbusier (1887-1965) in the Modulor*” as noted Teresa Belo Rodeia and João Miguel Couto Duarte, while reflecting on the design in its meaningful engagement of sensitive communication and the binding of the construction to the local environment.

The presentation by Professor Susana Nápoles of a film about the geometry of forms and their use in architecture provided other examples of work by masters such as the Catalan architect Antóni Gaudí, the Valencian architect Santiago Calatrava or the Brazilian architect Oscar Niemeyer. Geometric forms generated from mathematical formulas and examples of the application of ruled surfaces that mimic natural structures are some of the examples shown in this Gulbenkian Foundation funded film.

Founder and President of International Association of Mathematics and Art – Italy (IAMAI) Giampiero Mele presented a study on an 18th century work in Ferrara/Italy, the Teatro Comunale, in which there were “*several renovations that have affected the decorative apparatus by Migliari, technological systems and structures. However, the plan has never been strongly altered, and has come almost intact to this day*”. In this study is stressed the importance of the dimensioning accuracy in graphic representation: “*The result, obtained through the indirect survey carried out by laser distance meter 3D, was very helpful. By this instrument, the profile that faces in the audience, at the first order of boxes, where the oval had to have the intact measures - net of the mouldings - has been detected*”. The debate on the ‘operativity of a geometry’ – in this particular case on the utilization of the curve in the shaping of the living space – is complemented by the study by Miguel Brito on the use of composition patterns on façades in standard and author architecture. Notions of symmetry, grouping, repetition and sense of rhythm are aspects that, in combination with the typologies, are used by the authors to communicate in more or less complex, organized, or intentional ways, and interpreted by users according to their own assimilated reading codes, in a two-way relationship from which can be inferred the potential fluidity or difficulty of interpretation.

Clara Germana Gonçalves presented the evolution throughout history of the concepts of ‘symmetry’ and ‘proportion’, highlighting the genesis of the terms and the distinct interpretations they had in different periods and cultures: “*If the concept of symmetry continues to be transdisciplinary, despite the different approaches taken by different disciplines, it may still be a connection and an important factor in a new holistic vision of humanity and the universe*”.

From Joaquim Marcelino’s standpoint the scope of mathematical and geometric work and its realization is more an accurate description than a metaphor, as he states that “*This problem seems to be particularly critical when we approach architecture. We know and we are able to identify proportion systems in architecture as well as forms and shapes given by algorithms. And this fact means that we have strongly crashed into the mathematical realm. Thus, how can we accept an eidetic reduction in which geometrico-mathematization does not play a major role? The case seems to be serious because algorithms and similar approaches have become so attractive*

that we can never find an eidetic reduction substantive if at the act of perception, we have not found some intuitive way of dealing with the way to mathematical formulae."

Mathematics applied to the visual representation of shaped space is a further area of application of utmost importance in two acquainted moments of the process of creation of the built environment, the registry of the idea that precedes the design and construction – the experience of space by the body and the mind – and the communication as such for the process of building, with the necessary mathematical exactitude and rigor. Other domains can also be referred, like the interpretative representation of space *a posteriori*, an open field in constant progress with the development of new technologies like laser scanning and drone survey, and also the creation of virtual spaces and constructions, again using new technologies, media of communication and register. Computer geometric applications have undergone a strong evolution with a wide applicability in architecture.

On these new developments, Professor Renato Saleri points out that *"over the past twenty years, the considerable growth of digital tools has enabled the emergence of technologies capable of imitating and reproducing human behavior in an increasingly autonomous way"* and therefore *"we are now seeing the emergence of many tools capable of accompanying conceptual exploration"*. Saleri concludes that regarding the reproduction or imitation of human behavior in creating built environment by emergent technologies, *"besides the impossibility to solve with a single formalism the exhaustive shaping of existing architectural forms across history and cultures, we believe that an artificial creative process cannot be separated – so far -- from conscious intentionality to get it out of the trap of 'disparate uniformity' "*. The creation of different and many times interesting virtual alternative environments in the digital world still needs therefore the understanding of multiple processes that occur simultaneously in the real world and, at least for now, of the creativity of the human mind.

The development, outside of the digital world, of new methods for the precise representation of space and buildings was an interesting subject addressed by Professor António Araújo, presenting tools he has developed in his research, such as spherical perspective and immersive visualizations. *"The theoretical innovation consists in the possibility of drawing the whole perspective manually and systematically"* he emphasized, although *"these projections and visualizations can be made by computer with relative ease. There is software that allows to make and display 360 degrees photographs"* but *"unlike photography, which captures everything indifferently, drawing is the expression of the expert thoughts, his selections, reasoning, interpretations and conclusions. If this is true for classical perspective drawing, it will also be true for drawing in an immersive perspective"*, he argued, corroborating with sketches produced in his parallel activity as illustrator. The tools perfected by António Araújo open a field of direct relation in the parameterization of space for its communication and graphic recording, representing reality in a virtual process: *"Spherical perspectives (...) have a particular interest in the present precisely because they establish a connection between free ('analog') drawing and digital visualization, they keep us aware of the illusionism of visualization and awake to the multiple possibilities of visualization and its significations"*.

Cubical perspective, an advance in the application of this immersive drawing methodology, was presented by Lucas Olivero. *"Cubical perspective is maybe the youngest alternative among the options for immersive drawing"* according to the researcher, highlighting *"the important role played by the publication and debate of e-practical theories to disseminate knowledge and creativity. The lack of communication about the importance of the use of immersive perspectives begins perhaps in the academy itself, where its teaching is virtually non-existent"*. From the explanation of the concept of anamorphosis and the presentation of multiple studies, Olivero describes his methodology, which bases on the personal analysis of space and its elements from an equirectangular panoramic photograph using the cubic format converting it into a cubemap.

Once again the subjects addressed in the seminar confirm the compelling importance of returning in this new millennium to an integrative knowledge as was sought in the Renaissance and which can today be attainable with an interdisciplinary converging cooperation, providing a more comprehensive perspective both of reality and of its adequate and conscious use and transformation.

As Sylvie Duvernoy emphasizes, the evolution we are witnessing *"stems from the changing and evolving commitment and meaning that both mathematicians and architects, each on their own side, have put into their work, and also to the intellectual approach at the base of their professional researches and challenges. In addition, the ancient relationship between mathematics and architecture was built on a common sense of a certain beauty that evolved in time, and we can wonder what kind of inheritance is left today"*.

In respect to architecture, *"order is obtained when shapes are regular. Equilateral, equiangular shapes are regular shapes, and therefore beautiful. In modern terms we would say 'simple'. The square is the paradigm of order in planar geometry"*, Duvernoy states. *"In addition, the switch to abstraction and analysis unfortunately created a sort of hierarchical relation between mathematics and architecture, where architecture became an application field of mathematics. This new kind of relationship had already started to be claimed by some mathematicians"*.

Two presentations explored the interpretation through mathematics of the dynamics of the territory.

Ramón Piedra-de-la-Cuadra presented a study based in the metropolitan area of Sevilla area addressing *"the problem of locating a rapid transit line (metro, tram, BRT) with the objective of maximize the functional diversity of the districts traversed by the alignment"*. This issue intends to counterbalance the impacts of urban sprawl and the extensive use of motorized transport modes with negative environmental impacts that it induces: *"Increasing the existing infrastructures is a decision which often induces the installation of new urban settlements that generate a new increase in the demand for transport. This vicious circle can be broken by reducing the need of transport imposed by the urban model, which is only possible bringing services closer to the citizens"*.

The Estejo Research Project presented an ongoing study that aims to perceive multiple specificities of different territories, by quantifying the level of infrastructures which can foster economic and social development. Elsa Negas

and Rui Seco presented the research on a methodology to create an *“application to quantify the level of urban infrastructure in the territory, in order to create a useful and operative system to classify its urban conditions. It is intended that this indicator may become a tool to indicate the development potential of different territories, based on the availability of basic urban infrastructure and services”*. This tool is meant as a potential contribute to a more accurate and thorough knowledge on the territory, to be applied to the Tagus estuary and eventually any other area.

The subject of natural acclimatization was interestingly addressed in a poster by Jeanne Seixas, who studied the CTT neighbourhood in Luanda, Angola, designed by architect Fernão Simões de Carvalho in the modernist period. Cooling was a main concern of the project, being developed ventilation systems and shading elements that were incorporated in the design taking into consideration the main direction of sunlight and the layout of the various buildings.

As in the previous three editions, the seminar ‘Formulas in Architecture’ was complemented with a field trip and an exhibition.

The Ajuda National Palace was the object of the field visit. Planned to be the Portuguese Royal residence after the devastation caused by the 1755 earthquake, tsunami and fire that ruined Lisbon, the Ajuda Palace construction work was never completed, the incomplete existent building being nearly one third of the initial project.

Architect João Carlos dos Santos, the author of the ongoing project to finish the Palace, made a presentation in site, explaining the history of the building and its occupation from the 18th Century, exposing the ideas and principles that conducted his design to complete it, presenting the project and leading the participants and students in a visit both through the existent building halls and to the ongoing construction site.

Back at Lusíada University, an exhibition of the architecture students’ work was held along the seminar. This work, under the guidance of Professors Mário Chaves and Rui Alves, was developed by freshmen students on the subject of a contemporary interpretation of the Temple of Solomon.

Both the exhibition and the study trip enable a better connection between the objectives of the seminar and the academic component for university students, an important element also in the relationship between the Faculty of Architecture and Arts and the Research Centre, which organize the seminar.

The fourth edition of the seminar on Architecture and Mathematics ‘Formulas in Architecture’ continued the sequence of the three previous editions, always seeking to evolve and improve, without shedding its attributes and accomplishments. In this edition, in addition to the guest keynote speakers, was opened a call for papers and carried out a peer review process in which all the articles were reviewed and further perfected, a methodology that follows the best academic practice and which is intended to be pursued in the future.

Believing in the importance of interdisciplinary debate for the progress of the diverse fields of knowledge, the organization thanks all speakers, guests, scientific committee and participants for their commitment, involvement and effort, and looks forward to welcoming them in the future.