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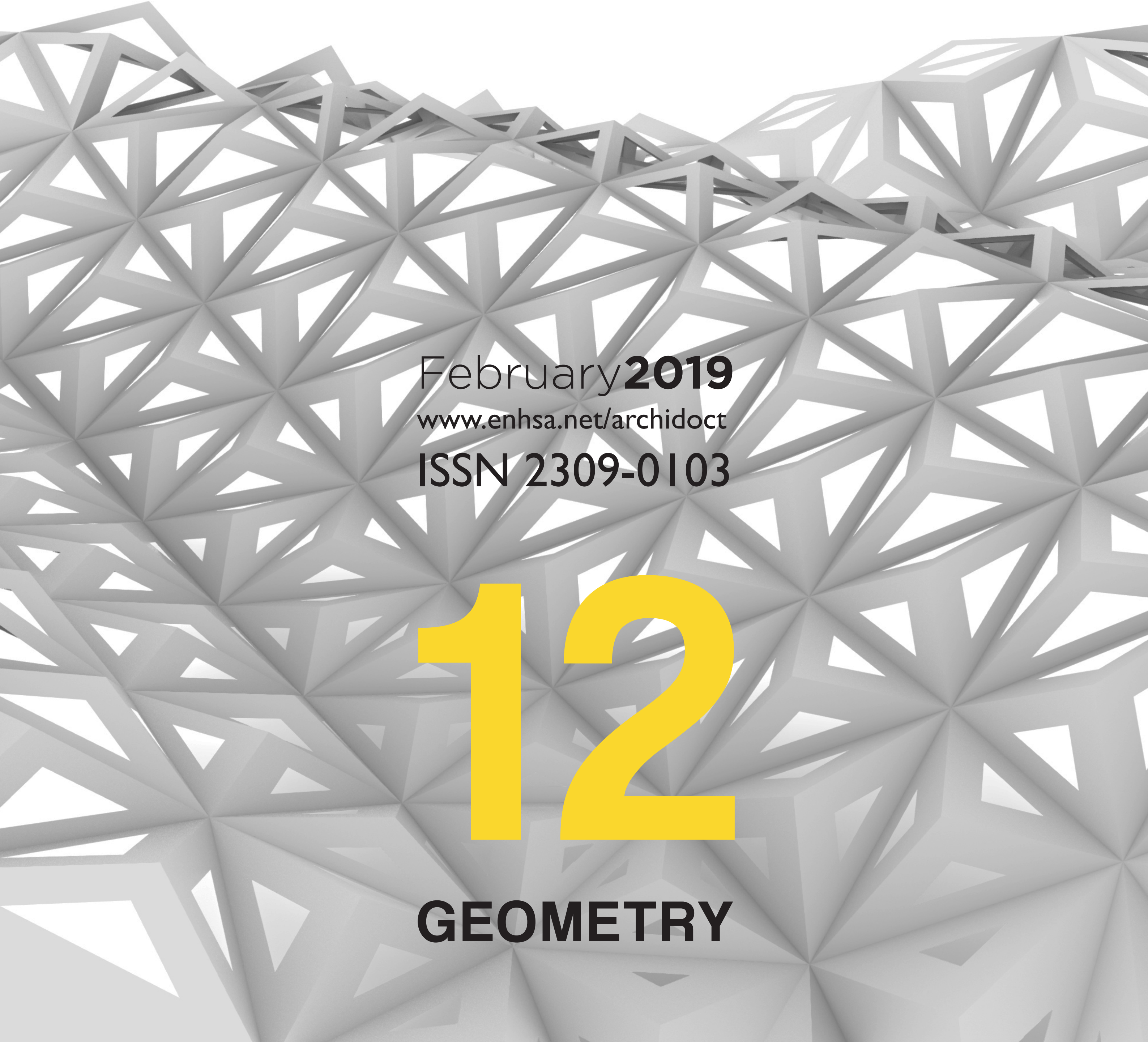

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GEOMETRY

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Geometries

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Abstract

Architecture is about values. Values are the driving forces of inspiration, the energy of the creative act, its primary material, its intellectual motivation, its main objective. Values or 'arches' form the immaterial realm of Architecture, its internal 'archi-tecture' to be formally manifested in space.

What is the role of Geometry as a discipline related to forms and their order, in the intellectual tectonics of Architecture? What is its contribution, its position? Does Geometry affect this 'archi-tecture' by enriching its contents with notions and meanings or, on the contrary, does it affect it by eliminating or restricting its potential formal configurations? Is this diachronic symbiosis with Architecture dynamic, inspirational, instrumental, deliberative, imposing? Does Geometry act as a framework to create an enclosure or does it constitute an escape room from the ordinary, the established, the regular, the 'out of the comfort zone', and to investigate in freedom the new normal, the innovative, the original or, at least, the different and the better? Architecture is addressed to Geometry with entirely different demands in time. We could, therefore, suggest that there are many versions of Geometry affiliated with architecture, that is to say, many Geometries.

This essay examines the role of Geometry in architectural thinking and practice in three major periods of architectural development. The first is the period in which the focal point of architectural thinking is the cosmic and the divine, (from the antiquity till about the 13th Century) where Geometry is that of the Master Builder. The second is the era of humanism, where the central preoccupation of Architecture is the human (from the Renaissance to the late 20th Century), and Geometry is that of visual perception. The third is the emerging era of the post-human, where the main focus of Architecture becomes 'Gaia,' the Planet as an alive ecology that emerges from the symbiosis between the natural and the artificial, and Geometry is that of data.

Keywords

Geometry; Architectural thinking; Architectural Design, Representation; Digital design tools

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1. Architecture and Geometries

Amongst the affections that Architecture experienced, throughout its history, with various other disciplines and domains of knowledge and practice, Geometry seems to be the strongest and the ever-lasting one. The liaison between Architecture and Geometry transverses centuries and continents and maps different forms of infatuation, trust, dependence or questioning. Architects have been used and are still used to talk about geometry as the language of architecture, as the rational consideration of forms and their order, as the solid ground to define or legitimize beauty, as the tool to think, investigate and create. They tend to consider the bond with geometry as stable and permanent, following a linear evolution of both domains.

However, the relationship between Architecture and Geometry is rather complex, and seems to have followed the unpredictable dynamics of non-linear [1] history. Beyond the declared strong connection between architectural thinking and practice with the discipline of Geometry, Architecture appears selective to the appropriation of concepts and statements of reasoning deriving from different aspects of geometry, not always following the state of development and advancements of the latter. This selectivity is always dictated by the dynamics of the value system that Architecture establishes in different periods of history to define its social project and to legitimize its formal preferences.

Architecture is about values. It is about the form of their manifestation in space. Values represent a particular world view and more specifically a specific conception of the human being therein. They are the driving force of inspiration, the energy of the creative act, its primary material, its intellectual motivation, its main objective. Values shape the expected 'Other,' the different, the desired, the utopic or the heterotopic, the wish, the hope but at the same time the rule, the order, the principle, the law, and often the model, the standard, the 'prototype', the image, the archetype. Geometry as the discipline related to forms and their order, is always cordially invited to support and assist the spatial manifestation of the respective values.

Values or 'arches' -archés in the Greek language- structure architecture's intellectual tectonics, its internal 'archi-tecture.' What is the role of Geometry in the intellectual tectonics of Architecture? What is its contribution, its position? Does Geometry affect this 'archi-tecture' by enriching its contents with notions and meanings or, on the contrary, by eliminating or constraining its potential formal configurations? Is this diachronic synergy with Architecture dynamic, inspirational, instrumental, deliberative, imposing? Does Geometry act as a framework to create an enclosure or does it constitute an escape room from the ordinary, the established, the regular, the out-of-the-comfort-zone? Or does geometry act as the deliberating context of investigating the new

1. We use the term non-linear history as it was defined by Manuel Delanda (1997) as part of the materialist philosophy of history in the tradition of Fernand Braudel, Gilles Deleuze, and Félix Guattari in which the unpredictability of the dynamics between material, social and natural worlds play a crucial role.

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normal, the innovative, the original or, at least, the different and the better?

In this essay, the relationship between Architecture and Geometry from Architecture's intellectual tectonics angle is investigated. The questions arising are how and why different stages of the historical development of Architecture have been associated with different Geometries to attest its social project adequately and to shape architectural paradigms introducing a way to think and create possible futures. We intend to examine the role Geometry plays in the way the immaterial and intellectual realm of Architecture is pouring over its tectonics and its materiality.

Three major steps of architectural development are studied. The first is the period in which the focal point of architectural thinking is the cosmic and the divine, (antiquity till about 13th Century). The second is the era of humanism where the central preoccupation of Architecture is the human (Renaissance to the end of 20th Century) and the third is the emerging era of the post-human where the main focus of Architecture becomes "Gaia", the Planet as an alive emerging by the symbiosis between the natural and artificial.

Architecture is addressed to Geometry with entirely different demands in time. In the Greek antiquity, Geometry was invited to assure Architecture's association with the divine cosmic order and harmony. In the Renaissance, the importance of the human as the definition of natural beauty was manifested in the created architectural form. In Modernism, Geometry was employed to technically and conceptually support the demonstration of the importance of rationality in the elaboration of architectural form, the defined relationships, and the sizing of the inhabitable enclosures. Throughout post-modernity, the manifestation of the cultural specificities of the designed spaces used Geometry as their core formal language. Finally, in the post-human era, Geometry is implicitly invited to glorify the power and the virtuality of the human-machine affective symbiosis, away from Euclidean constraints, that can yield new forms of artificiality. The very many versions of Geometry affiliated with architecture are evident, allowing us to conclude that there are as many geometries as there are architectures.

Euclidean, Projective, Analytic, Differential, Topological, Algebraic, Discrete, Geodetic, Fractal, Computational, Convex Geometry are some of the foci or biases of Geometry, criss-crossing architectural discourses and practices over time. With almost no exception, the common ground of all these geometrical subject areas is that the foundation of their theoretical construction is a specific appreciation of the primordial geometrical elements: the point, the line, the surface, and the volume.

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2. The Geometry of the Master Builder

The fine or even blurred line of demarcation between Geometry Construction dates back to the third millennium BC, a period when stone progressively replaced sun-dried or baked brick and wood as the primary building material. This replacement was one of the most important revolutions in the history of construction (Kostof, 1977, p. 4). It introduced a new relationship between building and time, built strong(er) bridges between tectonics and Fine Arts, affected the scale of constructions and generated the need for new skills and specialized techniques for which geometry was the most appropriate background. The attachment between Geometry and Architecture was essential for the further development of both domains.

The beginnings of Geometry, as knowledge and expertise, are dimmed back to the period when the Agricultural Revolution was already established together with the commitment for the Homo Sapiens to domesticate plants and animals for his survival. The very first indices of geometrical knowledge and experience are traced in Egypt and the Mesopotamia. This coincides with the development of crowded agglomerations, the establishment of big-ordered empires and the formulation of the relevant myths providing the necessary legitimization[2] of the established power structures and the mechanisms controlling the existing social stratification.

The myths and the cosmic references originated from astrology and religion, offered a set of numbers to define proportions and relationships amongst parts. Geometry was invited to sustain the appropriate manifestation of these proportions and relationships either on earth or on constructions and their components by dividing measured lengths into parts to locate the different building elements.

Taxes were the very first imperative for the development of Geometry (Mlodinow, 2001, pp. 5-6). Egyptian landowners had to pay taxes calculated by the height of the flood of River Nile and the surface of the holdings. As the river overflow fertilized the earth and was, therefore, considered to be a divine gift, the Pharaohs, who presented themselves as the divine mediators, imposed unbearable taxes as a compensation for their mediation. This mythological construction legitimized the need to define ways, not only to calculate the surfaces to be taxed but also to determine the division of the fertile land stably before or after the flood. In ancient Egypt, the implementation of geometric measurements was an official and primarily ritual process, always related to power and religion. The calculation of land surface had to be delivered officially and with accuracy as it had direct financial repercussions.

The very first geometric tool for the measurement of land and buildings was a rope with knots at predetermined distances. It had to

2. For a study on the role and the importance of the myth in the foundation of power structures and the control of the production means in precapitalistic societies, see Godelier (1978).

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be stretched, not to sag, having the knobs as vertices of triangles with given lengths and consequently with angles with precise measures. Its use crosses Egyptian, Greek and Roman building tradition. The person who performed these measurements was an officer, the harpedonopta, translated as the rope stretcher, while all the foundation measurements on the site of the new constructions followed formal religious rituals. The stretched rope defined points and lines through which ancient Egyptians could form and measure surfaces [3]. Other used geometrical instruments were the triangle, the square, and the compass.

The rope offered an empirical definition of the line as the distance between two points and of the surface as the area defined by three points, as described more abstractly by Euclidean Geometry, a few centuries later. In this conception, a point is either the beginning or the end of the measurement, or the mark of a division following proportions derived from the cosmic and religious interpretations of order [4]. It is interesting to note that, even nowadays, the compass bears the alternative name of the divider.

The emergence of the 'polis' in classical Greece, transformed the contents and the meanings of Geometry radically. The 'polis' as a conception of social condition and as the outcome of a rationalized understanding of cosmos, marginalizes the myth dedicated to the descriptions of the 'origin' by endorsing the strength and by glorifying the powerful. The logos, the discourse, is now excluding the supernatural, and reason wants to be associated directly to the human mind. Humans, nature, and gods become the object of a systematic investigation, history (ιστορία, historía) the outcome of which is a comprehensive view, the theory (θεωρία, theāríā). According to Vernant (1982, pp. 100-107), it is no longer the beginning that illuminates and transfigures the everyday, but, on the contrary, "it is the everyday that made the beginning intelligible." By referring to nature, the philosopher wishes to repeat what the theologist described by referring to as the divine power. Polis and philosophy, with their reciprocal social and mental structures, are closely linked phenomena.

Geometry undertakes a crucial role in this intellectual project. As now the center of the Greek thought is the relation between humans, geometry is invited to assist the philosophical thinking in constructing its rationality. As Vernant suggests (1978, p.132), this thinking keeps its distance from physical reality as it considers that nature belongs to the realm of the "approximate to which neither exact calculation nor rigorous reasoning could be applied." On the contrary, it elaborates its concepts to prove that the social world can be the subject of number and measure. Geometry is progressively detached from its practicalities related to the 'measurement of the earth' as its etymological origin dictates -geometría γεω-μετρία in the Greek language- to delve into the abstract thinking of relations, laws, and axioms ready to be projected

3. According to Mlodinow (2001: 7) the Egyptians did not form lines but geodetic triangles and curves along the surface of the earth. He detects in this primitive geometrical method the beginnings of what we call today Differential Geometry.

4. Kostof (1978, pp 8-10) presenting the different phases of the construction process in Egypt, describes the geometric system as structured by simple figures. These figures are the square, the sacred triangle of Osiris having a relation 4 to 3 between the height and the base, the isosceles triangles with the height either equal to the basis or twice the base or height to base to have a ratio 5 to 8. The construction followed different combinations of these figures.

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onto social reality.

This shift redefines its basics. A point is no longer conceived as the beginning but as the center, and this abstract center expresses or represents Hestia or the Omphalos, the social space. The points of the circular periphery reconstruct with the center the line of the equal distance, the equality (ισότις), the egalitarian concepts forming the deep structure of democracy. The same way, symmetry which presented in the past the divine instructions for order now becomes the rational expression of the principle or arche of the balance of power (ισονομία) as the appropriate foundation of the social order. The geometric grids on the space of the polis implemented by Hippodamus in Miletus did not represent any distribution of the surface of the earth but an "effort to order and rationalize the human world" (Vernant, 1982, p. 125).

From Thales and Pythagoras to Euclides and Archimedes, Geometry became a necessary part of philosophical thinking. Plato declared that no man destitute of geometry could enter his doors (Vernant, 1982, p.129) (Ceccato, 2010, p. 9). Could a master builder be welcome in Plato's place? In other words, did the master builders (the Architects in the Greek language etymology) followed this shift in the meaning and the contents of geometry? Was Architecture directly affected by these changes? There is no clear evidence of that.

On the contrary, we know (Kostof, 1978, pp. 21-22) that the education of the Architect was not related to the school of the philosopher and that the skills they obtained were ensured either from their work alongside a master as an apprenticeship, or from their experience gained by practicing other relative to the construction arts or crafts. There is marginal information about the master builders Architects such as Iktinos, Callicrates, Theodoros, Rhoikos, Skopas, Polykleitos to name a few. Even though the profession was considered noble and well paid, Architects were not considered to be intellectuals.

Architecture's evolution in Classical Greek antiquity offered magnificent works of the highest level of perfection and aesthetic quality, but it seems that this was primarily the outcome more of the development of the available means, techniques, and experiences based upon traditional applications of the Geometry than the systematic pursuit of its further and parallel progress as a distinctive part of the philosophical contemplation. The mathematical number of the golden ratio and its geometrical version as the golden section was one of the fascinating issues of Geometry, and mathematics in all centuries of the Greek antiquity. However, recent researches present clear evidence for golden-ratio application in constructions of ancient Greece: They proved that "the golden ration was absent from Greek architecture of the classical fifth century BC, and only very rarely employed in the third and the second centuries BC" (Foutakis, 2014, p. 86). It is also characteristic that in Roman times as master builders were defined the engineers emphasizing, this way, more the construction and technical aspect of the profession and less the conceptual and the creative one.

3. The Geometries of Humanism

If the stone introduced a new era in Architectural thinking and practice, lasting from antiquity to the Medieval times, the rise of humanism in the Renaissance is accompanied by a new radical turn in Architecture. Stone offered the proper means to manifest enclosure adequately, both in terms of scale and form, a worldview focused on the godly origin of the cosmos and dominated by the desire, or the duty, to glorify the supremacy of the divine as a condition to survive. The intellectual tectonics of the human-centered Architecture replaces the divine from the center of its mental

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preoccupations and positions the human instead. Architecture and its materiality, in turn, undertake to manifest the power of the human spirit and culture. To observe the tangible reality, to appreciate it, to experiment with it and to ensure the survival of the human by acting on this reality, is the ultimate aim of the Renaissance. The eye becomes the most vital human organ to serve the request for truth (Savignat, 1981) as knowledge does no longer belong to the religious order, but becomes the outcome of human intellect revealing the requested truth.

One of the most critical consequences of this shifted worldview is the emergence of the polymath human-observer, whose intellect is mastering a broad spectrum of skills and knowledge crossing art, technique, ethics, and logos. The Architect is coined with this profile by mid 15th Century, as can be traced in Alberti's 'Ten Books of Architecture' which Choay (1980) defines as the inaugurating discourse of the new Architecture.

This new Architecture takes a distance from the manual part of the building construction. The intellectual part of the creation of space is separated from the manual [5] (Voyatzaki, 2018, p. 7). This division of labor in the domain of building construction removes the conceptual and creative duties from the Master builder to allocate them to the Architect redefining his professional identity. The work of the Architect is no longer to build buildings but to elaborate ideas about (the form of) the buildings which builders will construct.

This detachment of the elaboration of the form from the construction site separates and divides the maker from the thinker. The former works on the real material and physical realm while the latter works on an abstract transcription of the reality on the surface of its representation. The former negotiates with the materiality, acts on it, teases it, fights with it, reconciles and attunes with it (Voyatzaki, 2018, p. 9) to extract the expected form. The latter negotiates with the ideal, the imaginative, the virtual and the possibilities to become real. The one manipulates the details of the parts to assure a not-as-yet precisely conceived total, following a bottom-up process. The other elaborates a well-detailed total to be achieved through components by the construction, in a top-down process starting from the idea and ending up with the matter to bring it to life. In the former case, the authorship is attributed to the one who leads the techniques and the material aspect of the building, while in the latter, authorship is assigned to the one who generates the idea and the formal qualities and meanings of the outcome.

The new task of the architect is to create detailed geometrical drawings of the building to be materialized with the least possible compromise from design to building. The accurate depiction of form and enclosure prior to construction is a recent experience in architecture that marks its development till present times. If what has to be built must be drawn in advance, then what can be built must be possible to be drawn.

5. For a detailed presentation of the transition from the Gothic to the Renaissance see Savignat, (1981, pp 34-56). See also Carpo (2011, pp 53-68).(accessed 1.11.18).

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(Savignat 1981, p. 25, Carpo, 2011, pp.31, 75). That means that the drawing with its techniques, tools, and means defines the context in which the architect is restricted to think and conceive the form of his or her creations.

Even though there is evidence of the existence of architectural drawings in Ancient Egypt and Greece, revealing a capacity to represent form and space (Kostof, 1978, pp 40-4. Ackerman, 2001, p.28), there is no clear evidence of whether these drawings were done before and not after the construction and by whom. On the other hand, these drawings, in most of the cases, presented parts of the building or building elements leaving unclear if they were produced before or during the construction process to facilitate the clarification of technical issues or to guide the builders in particular phases of the construction process. According to Savignat (1981, pp 8-10), the gothic cathedrals were not built following pre-drawn plans, but by implementing in situ formal and construction patterns, proportions, and techniques repeated and tested for centuries.

All these changes mentioned above establish a new relationship between Architecture and Geometry. As the Architect is now working on virtual space, needs to bring an abstract version of the reality onto the drawing board or desktop. This transfer requires new skills and knowledge, and new tools, techniques, and means to be used. Geometry is invited to play a brand-new and decisive role in this new condition. The Geometry used in the past originated from measurements and concerned real space. In the human-centered logic of the Renaissance, representation has to bring on the drawing board an abstraction of the seen and perceived reality. The drawing board represents the perceived space, the visual space exposed to the experience of human observation.

The perspective drawing is an illustration of this new use of Geometry. To construct a perspective image is necessary to have an eye located in the space. The line of the horizon indicates the distance of this eye from the earth, and the 'point of view' its distance from the observed object. A perspective drawing presents what an eye can see from the selected position. As geometric construction, the perspective drawing is a unique creation of the Renaissance mindset marking the history of Art, Architecture and Geometry.

Even though drawing as the new conditional mediation of architectural creation represents the human experience, its consistency is based on the infinite, which is not immediately apparent to the senses.

Euclidian Geometry defines a straight line as drawn between two definite points. It states as an abstract and hypothetical possibility its unlimited extension, as this is not detectable by the human senses. However, in the Renaissance, inspired by Euclidean Geometry, a line is conceived as an entity extended to the infinite, given as a whole, on which we can define parts with points. The presence of the infinite in the Geometrical thinking of this period is important, as in the Christianity the infinite refers to the divine. According to Whitehead (1911, 119), "the spire of a Gothic cathedral and the importance of the unbounded straight line in modern Geometry are both emblematic of the transformation of the modern world." The Architecture of the Renaissance takes the infinite from the sky (or from the end of the Gothic spire) and iconoclastically locates it into the perspective drawing as the vanishing point. Panofsky (1991), revealed the importance of this profoundly symbolic gesture to place the infinite in the center of the drawing board as a glorious manifestation of the liberation from the theocentric world view.

The Perspective could offer a reliable view of the building before its existence, but it was not equally

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efficient to assure measurability in the construction process. For this, architects had to do their drawings in projection so that measurements could be taken from them (Ackerman, 2001, p.29). The coexistence of these two ways to represent space indicates the need or the wish to combine, in the new profile of the architect, the artistic with the technical and to expose the creative work to aesthetic and rational judgments.

Architects practised projection drawings from the 15th to the 17th century. When, by the end of the 18th Century, Gaspar Monge invented and founded Descriptive Geometry following the spirit of the Enlightenment and the Cartesian amalgamation of Geometry with numeric references, Architecture soon embraced this new domain of Geometry in its drawing practices. Architect Jean-Nicolas-Louis Durand, Professor at École Polytechnique in Paris, a prestigious institution founded by Monge just after the French Revolution, embedded principles of Descriptive Geometry into his architectural teaching (Savignat, 1981).

As we move from the Perspective and Projective to the Descriptive Geometry as the context for architectural drawings and the background of architectural creation, the geometric beam of parallel lines replaces the Euclidian visual cone. This shift is fundamental for architectural thinking for many reasons. Architecture is no longer conceived as the outcome of what the human can see and experience but as a purely abstract construction, which re-arranges rationally the relationships between its main elements guided by the rationality of the representation medium. We shift from the polymath human of the Renaissance to the Kantian human of the Enlightenment; from a subject observing the infinite to a subject located in the infinite; from the priority to perceive to the priority to arrange; from the superiority of the visual to the supremacy of the functional. Architecture and Geometry re-establish a new solid relationship.

Architecture remains attached to the principles of Euclidian and Descriptive Geometry until the end of the 20th Century. Modernism glorifies this relationship by attributing to this specific Geometry the merit, not only to express exactitude, clarity, rationality and the ruling of forms but also to express the intellect of the human itself as presented in Le Corbusier's 'Le Poème de l' Angle Droit.' (Le Corbusier, 2006). Even though Post Modernity focused on the social and cultural agents of the individual's intellect, the same Geometry is invited to direct the manifestation of this intellect in space. It is interesting that the education of the architect traditionally offered, and to a certain extent continues to offer nowadays, courses on Perspective and Descriptive Geometry even though many other domains of Geometry were invented and enriched this subject area since the 18th Century.

4. The Geometries of the Post-Human

The role of Geometry in the immaterial realm of Architecture over the two previous periods examined in this essay, was to build a bridge between the main poles dominating the mindset of each period: God, the Human, and Nature. Geometry was invited to transverse these polarities and to transcribe essential characteristics of each pole, creating a solid ground, capable of stimulating and directing architectural creation.

The intellect of god-centered cultures was structured upon these three main poles: The God, the Human and Nature. According to Picon (2011, p.30), Geometry translated the demiurgic divine power of creation into proportions. The Architect, as human, developed skills to use this geometric interpretation to surrogate God and to manifest his glory on the secret buildings offering to society

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the possibility to negotiate its protection from the powers of nature.

In the human-centered period, the rational humans dispensed God to stay in a perpetual competition with nature. In this case, Geometry abstracts from the human body its proportions and establishes them as a natural definition of beauty that architecture has to implement on the designed buildings. Geometry is the mediator of human supremacy over the natural world. From the Vitruvian man to the Modulor, Geometry was used to ground architecture theoretically, to invent new formal orders and to control their realization through the developed drawing and construction skills (Picon, 2011, p. 31). In both periods, Geometry acts as a foundational reference and as a tool to create space.

Post-human contemplation shifts the human away from the center of intellectual preoccupations and replaces it with Gaia (planet Earth) understood as a living organism. The concept of Gaia reconciles old polarities founded in anthropocentrism, like life versus matter, given versus constructed, mind versus body, human versus nature, immaterial versus material, humanities versus sciences. Gaia is understood as the declaration of the existence of permanent and necessary symbioses between these polarities, which due to these symbioses blur their lines and refute their established identities. The human is no longer conceived as the dominant agent and controller of natural elements and artefacts. It is now located within the natural and artificial ecologies it created, not recognized as the unique agent who can safely form and transform them (Voyatzaki, 2018, p.12).

In this new intellectual construct, Architecture is released from its previous anthropocentric concerns about the finitude of the human (mind and body) according to which the building was conceived as a reliable image of human beauty or rationality. The building is now redefined as a living artifact. The elimination of the above-mentioned polarities had a direct impact on its relationship with Geometry. The harmony of the human body or the human rationality and intelligence are no longer the subject to be schematized through Euclidean or Descriptive Geometry.

The new Architectural intellect emerging from this philosophical context can be understood as the outcome of the symbioses of three critical parameters: The information-based epistemological understanding of the world, the role of computation in this understanding, and the role of Mathematics (Algebra and Geometry) in scripting the real world into numeric codes.

The establishment of the information as a unifying notion across sciences and humanities is one of the most critical aspects of the posthuman logos and praxis. In epistemological terms, information plays the same role in the construction of the contemporary intellect played by the notion of systems in the positivist epistemology of the '50s and '60s and the notion of structure in the structuralism(s) of the '70s and the '80s. By introducing the binary form one/zero, information can cross all the above polarities and establish a common mental environment, able to transcribe and describe all the crucial agents that form and transform the earth, organic life, materialities, and abiotic actors.

In this understanding, the building is no longer a technical artifact, the formal elaboration and appearance of which is undertaken by Geometry. It is now conceived as the outcome of a morphogenetic process which, through information processing, attributes to its materiality capacities of self-organization and self-adaptation to multiple and dynamic environments. The building is now 'intelligent' or 'smart', an alive artifact. Its design is not directly regulated by Geometry but by information scripting that delivers its own generative code, its DNA, from which its form emerges.

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The importance of information in the understanding of the world, is supported by the relevant technology. Information technology and computation is omnipresent at all levels of the social, cultural and economic globalization in the posthuman era. The introduction of computation in architectural practice has already a half-century history. Computers were initially used in the '60s and '70s to assist the architect on the rational decision making related to functional arrangements. After the '80s, digital tools focused primarily on drawing and presentation techniques, enhancing the drawing speed, accuracy, quality, and information. In all these cases, computers assisted the design process without challenging either the geometries traditionally used by architects or the established values of the time. In this collaborative scheme, between human and machine, it was clear who was enacting and who was representing.

In the posthuman understanding, however, there is a radical shift in the role of computation in architectural design. Intelligent machines, such as the machines that can respond and adapt to a spectrum of external stimuli and learn how to handle them, are no longer conceived as the assistant of architectural practice. They can act as the collaborator or a kind of subcontractor, who grants a particular set of skills to be performed and carries out part of the creative process. Architects can convey part of their work to the machine, introducing this way an informal division of labor in the creative process.

Due to their specific structure as hardware and software, intelligent machines can develop formal interpretations of data, based upon different types of abstractions they can perform, that the human intellect could not define and elaborate. In this scheme, architect and machine form a symbiotic assemblage dominated by the embodiment of two main agents, each one with different intelligence and skills [6]. As Braidoti states (Braidoti, 2013, p.26), this new form of vitality, human and machinic, dominant in the posthuman contemplations, wants to avoid any scripted determinism or inbuilt purpose or finality. It wants to eliminate the predefined standards of previous forms of computation and to remain open to random and unpredictable stimuli, providing (design) responses as a creative ground on which new ideas and patterns could be tested and implemented.

To ensure a reliable translation of the reality into a computer programming language and algorithms, mathematics that include geometry are necessary. In recent times, new branches of Geometry are used to enrich, through computation, the architect's digital and formal palette. It is, however, interesting to note that most of these branches of Geometry which, through different software, are invited today to collaborate with architects, have been formulated as specific subject areas three centuries ago. Throughout this period, they did not seem attractive to Architecture, and they have never threatened the

6. Cf. D. Coole and S. Frost (2010) p.8

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dominant role of the Euclidian and Descriptive Geometry in the architectural intellect. The reason for this belatedness is that the representation tools that Architects had at their disposal at that time, could not cope with the complex manipulations needed to translate the abstract statements of these Geometries into formal expressions.

To better appreciate this discrepancy, we need to examine the origin of the Geometries used by the contemporary machines and the underlined logics that formulated their contents and directed their development.

Architectural drawing tools were built to represent Euclidean space. Till the end of the 18th century, Geometry and arithmetics were two different subject areas, by and large with clear boundaries. Both, as knowledge and tools, offered their input to architectural intuition and the understanding of space, inspiring, controlling or standardizing the creative process and its outcomes. Drawing tools were tailored to elaborate this input. Descartes's idea of coordinates opened in 17th Century the window to the association of Geometry with Algebra by defining a point with a numeric reference and the connection between two points, the line, by a mathematical equation. The Cartesian method was able not only to transcribe Euclidean Geometry in algebraic terms, but also to offer the ground for the invention of other branches of Geometry.

Based upon the Cartesian method, Newton and Leibniz introduced Calculus to study continuous changes in natural phenomena and Gauss and Bolyai founded non-Euclidian Geometry. Picon (1911, p. 12) argues that the appearance of calculus marks the starting point for the estrangement of Geometry from Architecture. Calculus was the background of the development of Differential Geometry initiated by Euler, providing techniques to study geometric structures on differentiable manifolds. From Differential Geometry and Euler's studies, Poincare formulated Topology, which studied the properties of space that are preserved under continuous deformations, such as stretching, twisting, crumbling and bending (Mlodinow, 2001).

The development of these branches of Geometry, generated by the end of the 19th Century new ones like Convex and Discrete Geometry which study convexity, polyhedra and tessellations, Algebraic Geometry which examines multivariate polynomials, and more recently Fractal Geometry and Computational Geometry. The first studies the 'mathematical shapes that display a cascade of never-ending, self-similar, meandering detail as one observes them more closely' (Bovill, 1996, p.3), and the second transcribes in algorithmic terms the outcomes of all the above branches.

All these new Geometries were attached to a new worldview, introduced by the Enlightenment, and a set of new priorities and foci. Renaissance thinking was grounded upon the Aristotelian definition of immobility as the natural condition of the empirical world (Savignat 1981). Galileo and Keppler proved that this assumption was not valid since movement is the physical condition of the permanently rotating planet. The Cartesian method and the Calculus, upon which all other new branches of Geometry were developed, reflect this new worldview. Movement is the change of the location of a point according to the modification of its coordinates determined by the relevant equation. The geometrical point is no longer stable but moves, and guided by the equation. The line, on the other hand, is not the link between two points becoming the trace of a point's movement.

Change and movement introduced the notion of time that played a significant role in the development of sciences after 17th Century. As Picon (2011, p. 33) states, calculus, at its profound structures, has to do primarily 'with the consideration of time, instead of dealing with purely spatial

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dimensions'. Architecture always conceived the building as static and not dynamic, a conception that rendered calculous rather incompatible with the architectural intellectual construct and the established drawing tools.

The emerging new geometrical and mathematical thinking removed from its vocabulary the notion of harmony, which was for centuries the center of architectural narratives. As calculus and the new mathematics dealt with dynamic phenomena, they appeared to architects more appropriate for the study of the strength of materials or the hydraulics and flows, but not for the study of static idealized proportions and standardized formal relationships.

The fact that Architecture was alienated from the development of all the branches of Geometry over the last three centuries, does not mean that the new worldview established by the Enlightenment did not affect Architecture. On the contrary, the main concepts structuring the value system introduced by this worldview were approached through other disciplines with which architecture was associated over this period.

History, for example, was used to elaborate the concepts of change and time and to make them operational in design thinking and formal elaboration. Gottfried Semper used history to reveal the condition of becoming and to scrutinize the tension between continuity and innovation as Mari Hvattum explains in her book (Hvattum, 2004). The question of harmony was transcribed in Semper's historical discourses as a question of style. In a similar way, history becomes the medium to elaborate and to establish the development of the technological subject in the case of the restoration studies of Viollet-Le-Duc (Bressani, 2014).

Similarly, we can recall the strong affection that Architecture had for other disciplines like systems theory in the '50s and the '60s, the social and political sciences and anthropology in the '70s, the semiotics in the '80s, the philosophy and biology in the '90s. All these disciplines nourished architects' inspiration and directed their practices. It was clear that in this period a distance was taken from mathematics and more specifically from the areas of Geometry developed after the Enlightenment. Even though Le Corbusier glorified Geometry as the unique source of the sense of order (Le Corbusier, 1987, pp 65-86), he makes reference only to classical geometry and to the Platonic solids (Schumacher, 2018, pp.3-4) and not to the more recent Geometries.

The non-Euclidian Geometries emerged in the architectural scene when computation could calculate the complex mathematic relationships scripted by the software, but primarily when computers offered the possibility to visualize their outcome graphically via graphic user interfaces. This way, Geometry could enhance the creativity of the architect in elaborating ideas about buildings in the virtual space of representation.

The new tools expanded the formal vocabulary of Euclidean Geometry by introducing the curve as a new expressive component of form. The elaboration of the curve was ensured by the calculus-based Topology and its more recent developments that the Bézier Curve used in automobile industry. The splines and Non-Uniform Rational Splines (NURBS) labeled as 'folding', influenced a large number of architectural creations and experimentations. (Schumacher, 2018, pp.8-10). Folding was not only a formal achievement offering the possibility to shift from the established angularity to a promising curvilinearity by smooth curves. It also ensured continuity between parts and components, canceling their borders and limits. It was also a formal expression of the profound philosophical foundations of the post-human era. It introduced the continuum, and the integration

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of differences within a continuous and heterogeneous system, initially proposed by the works of Deleuze and Guattari (Carpo 2004, p. 14 and Carpo, 2013, pp 9-12). Different elements with different characteristics could be blended within a continuous field without losing their integrity (Lynn, 1993, p. 24).

In the same period and as a continuation of the use of spline and NURBS geometry in Architecture, another application of Topology is invited to extend the existing formal repertoire: The Isomorphic Surfaces or Blobs introduced by Greg Lynn (1998). This approach is dealing with surfaces or volumes of different objects that can deflect each other or fuse with each other, depending upon their relative proximity, creating complex surfaces (Schumacher, 2018, pp. 10-11). As in the case of folding, blobs map the contextualized sensitivity and adaptability of the elements of a system. In the overall system's dynamics, each one of its components is dependent upon and regulated by the others. This condition also meets the main lines of the post-human worldview, the dynamic interdependence of all kinds on the planet, organic, material, and inorganic.

The dependence of the form and the location of a system's elements from the specific and unstable characteristics of the other elements, renders the overall form and functionality of the system unpredictable. The new digital tools are promising to provide simulations of such systems and to elaborate for inspiration, forms that could not be conceived outside of these models. This is the case of swarm models that since the last decade try to simulate principles of nature and to incorporate a cross-disciplinary definition of properties and conditions of their models. By introducing parameters coming from different types of data and subject areas, these models raise the complexity of the model whilst offering a simpler understanding of the surrounding complexity. By incorporating technical aspects in the formulation of these models like construction, material, fabrication, environmental and cost parameters, these models can offer formal proposals to enhance design creativity. Schumacher (2018, p. 23) defines these parametric models as tectonic articulations.

5. What next?

Could we argue that nowadays Geometry is regaining the position of a foundational reference in the contemporary architectural intellect as it used to have in the theocentric and human-centric periods? It is rather difficult to give an affirmative answer to this question.

On the assumption that the architect, as a human, has to have the absolute control and sovereignty over the creative process and over all the artifacts used in this process, then the answer would be undoubtedly negative. The principles and the techniques of the non-Euclidean Geometries remain almost unknown in the architectural circles. These Geometries are not part of the education of the architects in the vast majority of Schools worldwide, and consequently, they cannot have any impact on architectural thinking.

Those who believe in human superiority and sovereignty would argue that nowadays machines can design what humans cannot (or do not want to) design; that humans do not need any theoretical investigation of geometrical principles, axioms, and hypotheses since human-made machines can offer humans the expected outcome; that we can control machines to do what humans want them to do for them, there is no need, then, to learn anything that machines know and can do.

For those who believe that the architect and the machine together form ecologies in a symbiotic

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action, the question who is more competent has no real meaning, and the answer could certainly be positive. Geometry is again in the heart of architectural creation as the abstract concretization of philosophical values and understandings of the world, as it has almost always been the case in both periods examined. It drives the manifestation of these values so that architectural creations are meaningful statements about life and time.

Followers of this view realise, to their frustration, that the contribution of the architect to the construction of the respective software is marginal, and that the majority of this software is designed for other creative disciplines. Scripting, as a process to develop or adapt the digital design tools in use, is not at all between the expected skills of an architect, while at the same time these skills are not embedded in the interfaces companies create.

If machines are not just the artificial extension of our body and brain but an agent that forms and transforms us, as it happens with all human artifacts, then the further efficiency of machines will not automatically imply a better architecture. Together with machines, humans will expand their sensorial domains and will gain from nonhuman creativity, towards constructing speculative scenarios for a technologically- advanced and innovative architecture to come.

The core trait of our times is not the change that calculus and topology elaborate. It is rather the speed of change that contemporary machines help us gain awareness of. It is rather difficult to predict if this generation of architecture is lucky enough to experience a new revolution in architecture similar to the ones examined in this essay. As Mario Carpo states (2011, p. IX), "it may be too soon to tell if the digital is a revolution in architecture, but it is not too soon to ask what may be upended if it is".

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