Origins of Computational Design in Architecture

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Origins of Computational Design in Architecture

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ABSTRACT

The changes that the computer is bringing to architecture are one part of a revolutionary social upheaval. Tools not only change individual patterns and behaviour, but also cause transformations in institutions. Just as other tools have in the past, the computer is in the process of conditioning our understanding of the world and our perception of our place in it. The application of computers to architecture is more than a new sophisticated tool that can be manipulated like a pencil or pen. It is rather, “the culmination of the objectifying mentality of modernity and it is, therefore, inherently perspectival. The tyranny of computer-aided design and its graphic systems can be awesome: because its rigorous mathematical base is unshakable, it rigidly establishes a homogeneous space and is inherently unable to combine different structure of reference.” Digital space is quantified by a programmer, who enacts a simplification of reality through a process of abstraction in which empirical that does not fit the chosen conceptual framework is discarded.

The aim of this paper is to investigate and track the origins of the core concepts of geometries in the history of architecture and to designate its basic conceptual applications that could be probably using the same concepts and processing steps that are used today with computers. The gained benefits of this investigation could help in boosting new methodologies in architectural design regarding form generation. Comparative analysis shall be the methodology used to reach these theoretical origins, and, the royal palace of the Alhambra will be the main case study together with related styles from Islamic architecture.

1. INTRODUCTION

Geometry lies in the core of the architectural design process. It is omnipresent, from initial form-finding stages to actual construction. It also underlies the main communication: namely, graphical representations obtained by precise geometric rules. Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real geometry revolution. In the genesis of the work of art, shaping principles is named “the structural theme” of the work, and sees it as working in conjunction with a cosmos form building force called the “anabolic tendency”. The structure theme “must be conceived of dynamically, as a pattern of forces, not an arrangement of static shapes” (Figure-1). Modern architecture takes advantage of the greatly increasing design possibilities, and geometric computing is a broad area with many branches. An interdisciplinary field such as architecture benefits from such variety [8].
Figure 1: Development of geometry shaping process.

**Shaping Principles, Cellular Automation and Genetic Algorithms**

Cellular automata are a special class of poly automata which lend interesting insights into how complex behaviour can emerge from simple rules. They are disarmingly simple devices for demonstrating the behaviour of rule-based systems. A cellular automaton consists of a regular array of cells in one, two, three or more dimensions. Each cell is said to have neighbours which are cells with some specified spatial relationship. In the simplest two-dimensional grid of squares, a cell might in having four edge neighbours, or eight, including those of the diagonal. In three dimensions, a cube cell might be considered to have six-face neighbours, or up to twenty-six if those adjacent to the edges and vertices are also counted. The behaviour of the cellular automation is controlled by transition rules which determine the state of each cell at each moment in time in relation to the previous state of the cell and of the whole of an automation at one instant and by the operation of transition rules which usually affect every cell in the same way, synchronously (the system responds to some form of “clock” pulse).

The rules of the individual cells are referred to as local and the overall behaviour as global. Successive changes are often referred to as “generations” and “neighbours”, affecting behaviour may be referred to as “parents” and “grandparents”. Complex behaviour can result from simple local rules. While the rules control the overall behaviour of the emergent “pattern”, the precise nature of an actual configuration may be significantly affected by the “seed”. A variety of behavioural pattern can emerge (Figure 2).

This forms the basis of a mathematical formalism which defines a set of structures appropriate to the field of interest using all possible combinations of elements (chromosomes). An environment is then defined for the system undergoing adaptation: this is an adaptive plan which determines successive structural modifications in response to the environment and measures the performance of different structures in the environment. This treatment is then developed into generalized reproductive plan and genetic operations.

The technique of genetic algorithms was developed primarily for problem-solving and optimization in situations where it was possible to state clearly both the problem and the criteria to be fulfilled for their successful solution.

Genetic algorithms are a class of highly parallel, evolutionary, adaptive search procedures. They are characterized by a string like structure equivalent to the chromosomes of nature. These represent a coded form of parameters which control the problem being investigated.

Algorithm is derived from the Persian/Arabic mathematician Al-Khwarizmi and originally referred exclusively to the arithmetic rules for manipulating Arabic numbers. Nowadays, algorithm means somehow: a definite procedure for solving problems or performing tasks. An algorithm consists of instructions how to do a task by splitting it into subtasks and sub-operations describing their order in a process. In most programming (or instructing) of computers it is necessary to be rigidly precise and complete. Algorithms are rules and techniques (definite procedures) for writing such instructions or code. Algorithmic thinking shares with number systems and logics the fundamental ideas of precision and determinedness. Algorithms and mathematical functions abide so to say to the “ideology” of determining a unique element or step for any input or previous step (related to the notion of abstract Turing machines.

The case of muqarnas formation is a direct application of the technique of the genetic algorithm which was developed primarily for problem-solving and optimization and a class of highly parallel, evolutionary, adaptive search procedures. They are characterized by a string-like structure equivalent to the chromosomes of nature. These represent a coded form of parameters which control the problem being investigated. They are described as highly parallel because they search using populations of potential solutions rather than searching randomly for adjusting a single potential solution.
Complex behaviour can emerge from simple rules.
Figure 2: Behaviour of rule-based systems in traditional 2D/3D Islamic patterns.

Since optimum solutions are obtained by small, gradual changes within the population over several generations, they are defined as adaptive. Selection from the population occurs according to a measure of fitness criteria.

The behaviour of the muqarnas invented and applied widely in Islamic architecture since 9th century, applied a rule-based system that was applied manually by builders who were perfectly trained on geometrics and mathematics. They followed a clear mental model i.e. a powerful relational operations for a rigid implications of solid modelling with a set of powerful relational operators to encourage the builder to specify logical relationships between elements rather than specific geometric coordinates. This process required the syntax and grammar of a particular formal language to be specified in advance (Figure-3).

It is within the subjective space of the aesthetic experience that the things seen (the architectural forms) and the things known (the epigraphic content) truly articulate themselves, in fact giving birth to diversified semantic connections. Among these connections, imaging associations take place that govern the determination of metaphors, namely the mutation of a certain potentially virtual image into defined metaphors. Under the dual effect of visual suggestion and scriptural imagery, all those faculties related to the imaginative (the cognitive, the informative, the re-collective and so on) are excited and build various combinations, associations and correspondences, through which the material field fills with epigraphic sense and identifies its perceptible form with iconological elements [6].

It is clear from the comparative analysis in figure 3, that the iconic elements used in Islamic architecture compared to any architectural style in the history of architecture, has the ability of developments through an up to date form generation process (digital process). The pediment used in Greek architecture is used as it is after 25 centuries on a top of an office building by Philip Johnson, where nobody could recognize it [7]. The Doric column was re used as a whole building! On the contrary, traditional Islamic patterns based on in stored mathematical data were developed, regenerated and re used in a completely different function and also in a homogenies compatible sense of cognition [4]. Here we could insist that pure cognition is compromised by digital re-creation derived from stored data, which is derived externally. The Platonic dream, of a crystal clear vision of reality seen through a mental rather than physical eye, is replaced by an existential construct, a reality reconstituted from information, constrained by binary choice [9].

Now the geometric models used in traditional art have nothing to do with a rational, or even a rationalistic, system-artization of art; the derive from a geometry which is a priori non-quantitative and which is itself creative because it is linked to data inhering directly in the mind. At the basis of this geometry there lies the circle which is an image of an infinite whole [2].

At the Alhambra palace in Spain from the Nasrid period, and especially at the Comares Hall, the metaphorical language resolves in the practice of art the difficult question of how to represent the unrepresentable, and by extension, how to represent without representation. The specific type of the imaging metaphor supplies a mode of virtual representation, a means of visualising the invisible and that the Comares Hall exploits with a high degree of rhetoric [6].

Geometrics, Aesthetics and the concept of Space

Returning to the Comares dome, by virtue of aesthetic relevance of the limits, the half stars at the margins of the supporting square strengthen the virtual continuity/infinity of the design beyond it, in an endless expansion which confers on the artefact the aesthetic character of a space in dilation, of an open field. Such a property makes the ceiling morphology oppose the enclosure shape Qur'anic heavenly bodies, due to their strict numerical limitation. No transitional elements mediate the meeting between the square and circular morphologies; an observable fact meaning that aesthetically the do not meet each other, but are outdistanced occurrences.
STATIC FORMS
European Architectural Heritage

- The Parthenon, Athens: 437 BC
- Greek Architecture

- 3D Muqarnas are regenerated using AI techniques

GENERATIVE FORMS
Islamic Architectural Heritage

- Alhambra, Granada: 13th century
- Islamic Tiling

Algorithms are rules and techniques (define procedures) for writing such instructions or code.

Congruence transformations, like translations and rotations, are the basic instruments for generating tiling.

Classical geometry of webs are employed in a geometry processing context.

Discrete-Freeform Structure
Figure 3: Evolution of geometric models used in traditional art.

The concrete result of this disposition is radical change that operates between two absolute distinct and parallel spaces: one condensed and circumscribed by four walls, firmly limited in their upper part by the cornice; the other spreading infinitely beyond like a fragment of sky seen from an open air patio. Naturally such a conception for the ceiling cannot have come about by chance, must have resulted from a deliberate aesthetic intention – the desire to generate the visual sensation of endless space [6]. Seen in the phenomenological terms of anthropo-cosmology, this endless space could be equivalent to the infinite and unfathomable celestial realm. The boundless space of the Comares dome is a “pattern of intention”, of expressing by resonance the dual metaphysical concept of immensity and infinity. In a broader perspective, the dome forms the pattern of the absolute space, to be included under the universal cosmic theorem of the imagination of the celestial world that can be defined as: all that has the round morphology of a canopy vault refers to the vast firmament (Figure 4).

Speaking about absolute space Lefebvre’s ontology may be useful as he notes that the word “space” was usually associated with Euclidean geometry, or was considered to be infinite, empty ether. He sought to bridge between the mental concept of space then being described by philosophers and epistemologist and the real physical implications of its social equivalent. Lefebvre settles on Hegel’s “concrete universal” as a starting point in his search for a generative mechanism to replace the prevailing philosophical view of space as a static mental construct. He calls this mechanism “production”, which, intentionally or not has connotations of manufacture goes far beyond discourse to provide a code that brings “the various kinds of space and the modality of their genesis together within a single theory” [9].

It was the aim of Islamic philosophers, as it was of the Christian medieval philosophers, to make a cosmos – a coherent whole- of their own experience or the experience of mankind. In other words to find truths about one’s perceived environment. When we look at the solar system, from either the mechanical or the perceptual point of view, we see a series of concentric rhythms: from the point of view of the sun these rhythms, i.e. the path of the planets around the sun are in fact elliptical. From the point of view of the Earth, the planets travel in other kinds of rhythms, that is to say they appear to make orbital loops in the sky: this is due to the fact that we observe these orbits of the sun from our, i.e. the planet Earth’s position within this system [1]. Similarly to Burckhardt the arabesque (Islamic art) “represents a perfect transcription of the laws of rhythm into visual terms. Like geometrical interlacement, it is “an extremely direct expression of the idea of Divine Unity underlying the inexhaustible variety of the world [3]. Islamic art is predominantly a balance between pure geometric form and what can be called fundamental bio-morphic form: a polarization that has associative values. The Islamic art of geometric form can be considered the crystallization stage, both of the intelligence inherent in manifest form and as a moment of suspended animation of the effusion of content through form [1].

The New Model of Architecture

There is so far no general developed science of morphology, although the generation of form is fundamental to the creation of all natural and all designed artefacts. Science is still searching for a theory of explanation, architecture for a theory of generation – and it is possible that the later will be advanced before the former. In other words, form- generating models developed for architectural design. As a general rule, any type of aesthetic morphology is defined by the nature and content of this matter within space, namely the position of its limits, its horizon. Thus, the affirmation or on the contrary, the negation of the edges of this morphology constitutes a determining element for its ontological status, relative to the aesthetic dialectic between finitude and infinitude involved in the phenomenology of created visual spaces, above all in the phenomenology of pure geometric space [6].
No transitional elements mediate the meeting between the square and circular morphologies; an observable fact meaning that aesthetically they do not meet each other, but are outdistanced occurrences.
Figure 4: Comares dome, the Alhambra-Granada, Spain 1370.

The idea behind digital design is comparable to the geometrical science of the Alhambra that comes from a highly sophisticated aesthetic conceptualisation where the geometrical constitution resulting from the pure mathematics of spatio-temporal shapes. They, in general, form the primary character of the generic concept of geometry and confer on geometrical arts the particular perceptual property of abstraction, as opposed to the property of figuration. Following the common acceptance of both aesthetic notions, in art, abstraction basically consists of an elimination process of references to the matter towards thought, ideality, and ideas, whereas figuration, on the contrary, consists of a combination of references to matter in order to represent recognisable existing things and beings.

Conclusion

The process described before shows how we can use tools to generate a new model for the generative form process. The term tool does not imply that we regard these techniques in the dismissive sense implied by the phrase “a computer is just a tool” - as a means of reinforcing current practice rather than challenging it. This paper proved that architectural design process using CAD is fundamentally unsatisfactory in any known form, as soon as it will only reflect traditional non-CAD methodology. Instead, they should be tailored to make them acceptable to the designer’s sensibility and concerned with creative morphology.

At the Alhambra, the palatine complex does not simply constitute a geometrical object or the material projection of an exercise of intelligence drawn into the shape of an architectural construction through complicated axioms and tabulations. If this were so, geometry would supply both the means and the end of the work of art, according to a single and univocal aesthetic principle. But on the contrary, the geometry in the Alhambra fulfils a plural function as it transforms spaces, volumes and planes into different visual creations concealing different significations by means of a great diversity of aesthetic systems and through the elaborate use of the principle of variation. This means that, instead of a unified geometry, there is a conjunction of geometries in the Alhambra, or several geometrical propositions differing in content.

The regenerating of some of the classical geometry of webs used in Islamic patterns that were employed in a geometry processing using digital context proved that the approach used in this paper has yet more potential and applications, in modern architecture. It has become apparent that methods from Geometric Computing bear a great potential to advance the field of freeform architecture derived from a geometry which is a priori non-quantitative and which is itself creative because it is linked to data inhering directly in the mind. This fact has created the new research area architectural geometry, which draws from various branches of geometry and which is motivated by problems originating in architectural design and engineering.

The Islamic heritage is an important link in the chain of man’s progress. Their significant contributions in the fields of science have been recognized, but in its achievement in the field of design have been greatly under-estimated.

References