A Generative Urban Grammar for Portuguese Colonial Cities, During the Sixteenth to Eighteenth Centuries

Towards a Tool for Urban Design

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Abstract: *This paper main goal is to depict the generative principles of 16th -18th century Portuguese colonial urban design described from its Pythagorean-Euclidean geometrical genesis and correspondent logical rules and operations. These origins were found in Portuguese compendiums and treaties on practical geometry, architectural and military engineering from the sixteenth through the eighteenth century. The study attempts to show that rigorous operative geometrical discourse is inseparable from social knowledge, whereby form is the operative result of abstract mental processes and logical visual reasoning associated to ideas of growth and reproduction of order.*

Keywords: *Generative systems: shape grammars; Portuguese urban design; Portuguese geometric knowledge.*

Introduction

Colonial Portuguese cities designed from 16^{th} to the 18^{th} centuries feature a remarkable resemblance concerning urban form irrespective of continent and other local attributes. This similitude had been described in previous papers by Teixeira (1996, 1999), Rossa (2002) and Paio (2007, 2008). The theoretical framework utilized to demonstrate similarities and differences between these cities is related to common historical events and cultural identity factors. Different authors concentrate their attention in topographical features of the site, external shape (circular, rectangular,..., and the existence of typical spaces or buildings) overlooking the complexity existing behind the configuration of the studied sample. In order to depict this complexity it is necessary to go beyond the visual field and to penetrate the project world, the world of abstract rules and geometrical operations performed by city builders during the process of conception and the actual construction of these cities.

Shape grammars (Stiny and Gips, 1972) allow analytical/descriptive morphological decompositions and constitute a method which can be used to unveil the syntactic order present in the cartographic representations of the Portuguese colonial urban design through the eighteenth century. Shape rules (Stiny, 1980) have potential to bridge the gap between traditional drawing techniques and modern computational methods of urban design. Its descriptive and generative structure enable the user to simultaneously interpret, manipulate and generate various geometric constructions as representations of the Portuguese urban design. The research's goal is to develop a computational tool able to generate urban configurations embedding the main geometric and urban principles of the Portuguese colonial urban design captured by the shape grammar.

This paper has three sections. The first, describes the structure of form and the operative dimension of geometry, as a cognitive instrument for urban design. The second section describes some of genetic principles of Pythagorean-Euclidean geometrical genesis obtained from the treaties and urban representations. Finally, introduces a geometric method for generating planimetric proportionate and symmetrical systems.

Research into the structural and structured urban form

Urban design involves multiple knowledge and, most of the time, the performed tasks are based on reusing past design solutions. Retrieved design knowledge plays a significant role in the pre-design and reasoning stages. Previous experiences help the understanding of new constraints and in casting older situations into new problems (Eilouti and Al-Jokhadar, 2007). A major part of pre-design stages in urban design is devoted to the study of precedents as a strategy to produce new designs. This way, design is not properly an invention, the creation of something absolutely new (Terzidis, 2006) in that novelty must be the result of discovery.

Discovery, in this sense, is the act of unveiling, for the first time, something that already existed. Following this logic, urban design as a process of creation can be seen as bounded by the limits of preservation: any newly conceived thought, process, or form involve the reordering of previous ones. If this holds, light should be shed over the ontological relations between the different parts or stages of the design process. Such study involves the establishment of explicit and systematic links between the form of precedent urban representations, its visual reasoning, its genetic principles of geometric compositional attributes and its generative considerations.

Visual reasoning in design is viewed here as a transaction between knowledge structures and design representation (Oxman, 1997). In this way, to reconstruct the origin of forms implies the singling out and, at the same time, the unification of references present in each image displayed before our eyes. This way, the human being does not inherit concepts but the ability to build these through description retrieval mechanisms (Hillier, 2003).

If form is the visible configuration of content with power of recognition (Arnheim, 1954) urban representations are the core of statement strategies (in urban design) whereby images are fixed during the design process. The shape provides a *schema* (Euclid) or a recognizable image. Shapes or *schemas* exist as projections of the creative world, and these demand a protocol of recognition of the structure of thought of who designed them (Côrte-Real, 2001). The term *schema* is widely used in cognitive sciences generally to designate a mental structure that encapsulates basic knowledge about types of objects or actions.

The decoding of urban cartography, presume that graphical objects are cultural artifacts, which coexist and constitute juxtaposed different figurative codes. Decoding requires an analogue study to the syntax of a text (Jacob, 1992) and could serve as the basis for an investigation on the existence of geometric patterns or consistencies that can be identified behind an apparent random form. The decoding of Portuguese colonial urban representations, not only may serve to demonstrate the power of Portuguese urban planners' knowledge to configure geometric structures, inductors of reason and proportion, but also the essence of the invariant features of many Portuguese urban planimetric systems.

Geometric structures appear to be a crucial ingredient in understanding the mechanisms of design-thinking and design-making. Goel (1995) argues in favour of the existence of structures postulating that some shape transformations lead to refinements of the concept design whilst other types of transformations may lead to different concept designs. The arrangement of structures determines the identity of the pattern to such an extent that a given outline may produce completely different patterns depending on what structure is perceived in the design (Arnheim, 1966; Prats and Earl, 2006). To bring this structure to surface without contextual knowledge is difficult because structures are rarely explicitly represented in Portuguese urban cartography. Thus, it is necessary to shed light first in the geometric knowledge held by Portuguese urban planners'. The basis for this study is the documentation of principles and rules found in treaties, where theoretical and rational discourse on urban order and unity finds in geometry one of its most solid foundations. Thus geometry is not only crucial for the construction of mental models, but also in verbal discourse, through the well-defined conception of space regulated by Pythagorean number and by the relationships between Euclidean geometrical shapes.

The operative dimension of geometry, a cognitive instrument for urban development, becomes a preparatory science, a mental discipline, an abstract discourse that enables models to be built from conceptual structures of knowledge in visual reasoning in design (Oxman, 1997). This in turn provides for the recognition of specific representations of proportions, symmetries, rhythms, eurhythmics, spatial geometric transformations and other aspects. In other words, it is an example of a rigorous thought process that provides order to the composition and configuration of urban design. A kind of support that seems to disappear after the construction is completed, but that can be recalled at any moment as long as the genetic principles, or its DNA, are acknowledged.

Once the DNA is known, the data obtained (analysed, interpreted, and confirmed) can be codified into a computational structure capable of simulating the mental structure. Associating vocabulary, shape rules and organized hierarchical actions to algorithms we may well provide the basis for a description of the cognitive process involved in the conception and execution of certain actions (Minsky, 1985), through the application of generative systems. If this holds, it is possible to simulate the mental structure deployed by Portuguese urban developers through the interpretation and manipulation of the geometrical representation models of Portuguese urban spaces.

Pythagorean-Euclidean geometrical genesis, genetic and generator principles

Since time immemorial man has researched and studied the geometrical models present in nature, the human body, the universe, and in aesthetics, searching for a universal law of geometry, a law of harmony that could explain them. Different geometrical archetypes and numerical rationales were established in the search for necessary logical relationships that would satisfy both the rational mind and the eyes. The interpretation of order has evolved throughout history together with the evolution of philosophical and scientific thought. Under the power influence of Pythagoras, Plato, and Aristotle, geometry and philosophy became intertwined proofs of statements. Plato would have recourse to the fundamental content of Pythagorean philosophy in his dialogue *Timeus*, where he expresses his admiration for numbers, proportions and geometry. In the Republic he describes his idea of geometry as *"a mental activity more valuable than a thousand glances, for only through it can the truth be grasped"* (Plato). The admiration for geometric order is also manifested by the Greek mathematician Euclid. His work The *Elements* was the first systematic discussion of geometry and the first text to talk about the theory of numbers.

Effectively, Euclidean geometry is one of the foundations of philosophical and scientific thought, appearing in the treatises and compendia of the major schools of Europe in the 16th-18th centuries. This approach emerges as a way of conceptualising and systematising knowledge, allowing us to identify today the structure of the geometrical thought of the urban planning apprentices and to decode the origins of the logic of urban design (Paio, 2007).

The formal axiomatic Euclidean geometry, geometric constructions based on the compass and an unmarked straightedge, was fundamental to the Portuguese urban planners' framework of thought of doing and built urban design (Pereira, 1999) of the Portuguese School of Military Engineering and Urban Planning, in 16th -18th centuries, as it was to the European congeners. As acknowledged by Portuguese architect António Rodrigues (1576), *"are necessary, indeed Vitruvius stated that one could not be called a perfect architect without being an expert in them. They are the following: Knowing the art of accounting in order to declare the expenses incurred by the building; it is necessary to be an expert in Geometry. Who is curious about this art should study Euclid and there will find many things of use; it is necessary for the architect to know how to sketch for through this he shows his designs and how to build them, as well as each of the other things that understanding has declared.* Its use is multiple, not only to determine the proportion related to the construction of shapes, but to built scales and measuring instruments. The urban planners' students have to learn, among other matters, "*the principles of practical geometry necessary to intelligence and fabrica of Military Architecture*" because *"who was not good as a geometer and arithmetic, will fail without knowing is mistakes and only will discover them when the object is built"* (Pimentel, 1650). The apprehended practical geometric principles were essentials to the exact representation of urban design and now they allow seeing the unseen, the abstract mental processes and logical visual reasoning involved in the construction of creative mental structures. Thus, we shall call the design an abstract graceful pre-ordering of the points, lines, and figures, conceived in the mind and contrived by an ingenious artist (Alberti, 1550). Alberti made a significant contribution to our way of design bolding abstraction, i.e. by separating the conceptual design of an object from its material expression (March and Stiny, 1985).

In this paper we will demonstrate some of these basic genetic and generators principles that will be fixed as rules for generating planimetric proportionate and symmetrical systems: Position, direction and limit; Generative shape; Square-based proportion: Ad-quadratum and tripartition and The diagonal.

Position, direction and limit

The manifestation of an action or thought necessitates a point of origin or departure. In mind the point represents a unitary focus of conscious awareness (Critchlow, 1976). In geometry it represents the center, the point of the compass, an elusive controlling point of all forms. If the manifestation of the point is indicative of the departure from its starting place, then direction is implied. It represents the geometric axis, essential to define symmetry. The limit is defined when a circle is completed and the unity is obtained. The circle expresses domain and periphery (Figure 1). Elements present in the Alberti (1550) treatise, "*All the citizens are concerned in very thing of a public nature that makes part of the city: … then certainly it requires the most deliberate consideration in what place or orientation, and with what circuit of lines it ought to be fixed" and "platforms should all terminate within a Circle, and indeed from a circle is the best way of deducing them."*

Generative shape

As a result of the Pythagorean-Euclidean structural thought it was possible to deduce a method of design, starting from a basic shape as the natural division of the circle. The equilateral triangle, the square and the pentagon are the three primary plane shapes which have its own archetypal behaviour in terms of itself and, in different ways within its own matrix. This enable from these three shapes to reconstruct the planimetric systems, which secondary elements could be generated (Figure 2).

Figure 1
Basic genetic and generators principles: Position, direction and limit

Square-based proportion: ad-quadratum and tripartition

Throughout the history of architecture and urban design there has been a quest for a system of proportion that would facilitate the technical and aesthetic requirements of design. As Scholfield's (1958) states, the common denominator of most systems used in fixing architectural proportion, is an attempt at *"the creation of order apparent to the eye by the repetition of similar figures, and that this is accompanied by the generation of patterns of relationships of mathematical proportion between the linear dimensions of the design".* Two Square-based proportions can be highlighted: the duplication of the square and division of a given distance equally into three (Figure 3). Fundamentals recognized by Alberti and followed by the Portuguese treatises. Alberti (1550) acknowledged that a simple process of halving or division by three would give rise to relationships in the design which would be most readily appreciated visually (March and Steadman, 1971).

The diagonal

Such proportioned system would have to ensure a repetition of a few ratios throughout the design and that is ensured by using the diagonal. Jay Hambidge (1967) refers to the diagonal as the most important element of a square and rectangle. This important fact was supposedly discovered by the Greeks. It is the 47th proposition of the first book of Euclid and the Pythagorean Theorem. Once again, Alberti (1550) *"then having marked the Point of Intersection by the assistance of the Diameter and Gnomon, and by drawing other lines at equal distances, fitted to the Square, we may completely effect our Purpose: And it will be of no small Convenience to terminate the Ray of Sight with a Line in those Places which lie higher than the rest"* (Figure 4).

A generative urban grammar for Portuguese colonial cities

This work adopts the shape grammar theory for codifying rules (principles) (Stiny and Gips, 1972). Shape Grammar represents a systematic method for studying the form-making logic. It proved to be powerful in shape analysis, description, classification, and generation. It have been used in many studies of languages of designs, or style, from Palladian Villas (Stiny and Mitchell, 1978) to Wren's language of city church designs (Buelinckx, 1993), from Traditional Chinese Architecture (Andrew I-Kang Li, 2000) to Mughul Gardens (Stiny and Mitchell,1980; Knight, 1989). Their purpose is to elucidate the languages by articulating complete generative definitions of those languages. A complete definition specifies all and only the designs in the language. A generative definition specifies the member designs by generating

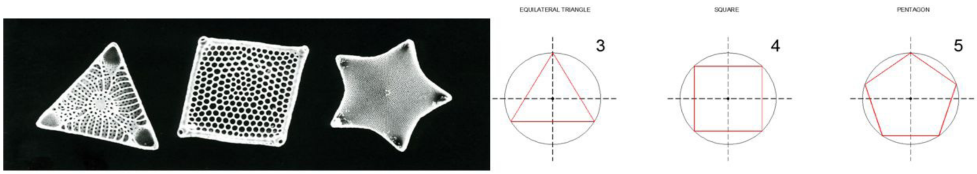
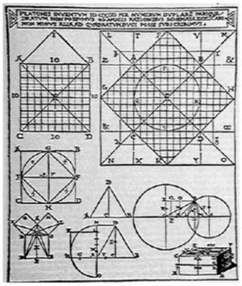


Figure 2
Basic genetic and generators principles: Generative shape



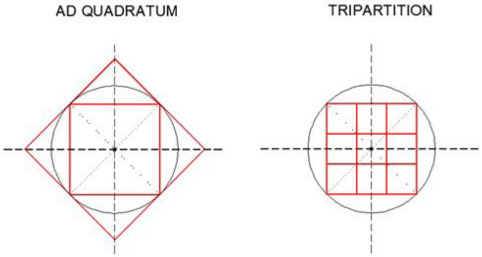


Figure 3
Basic genetic and generators principles: Square-based proportion

them.

However, only recently relevant work was produced in urban grammars. The first case study was defined by Catherine Teeling (1996), who wrote a grammar to encode the generation of urban form using a specific section of the docklands in Friedrichshafen in Deutschland. Beirão and Duarte (2005) also studied urban grammars, but the objective was to use it as methodology for flexible and sustainable urban design in response to particular contexts. Another important contribution for the study of urban grammars was the parametric grammars to describe morphological characteristics of the ancient fabric of Marrakech Medina (Duarte et al, 2007). This study intended to provide a computational framework that can assist designers in the design of new Muslims urban designs that maintain traditional spatial and compositional principles while satisfying the requirements of contemporary life. Even so, many of their potentials are still far from being entirely explored, especially in the area of understanding the morphology of urban precedents based-knowledge.

Geometric method for generating planimetric proportionate and symmetrical systems

The Grammatical inference was defined as a task of logically inferring a finite set of rules from the systematic investigation of a corpus of 75 urban cartographic Portuguese representations and 30 treatises. The corpus was analyzed by decomposing them into a vocabulary, which represents the lexical level, and rules, which represent the syntactic level of their structure. Spatial relations or geometric principles of vocabulary elements are defined in terms of decompositions of the original urban designs representation and founded in treaties.

The Portuguese treatise reveals a strong classical component of Vitruvian genesis. A language ideally suited to the expression of this fundamental principle, the experiencing of parts and a whole. In other words, geometry is applied to the *Compositio* (composition) of buildings and cities and *"rests on Symmetria (commensurability), a principle that architects should submit to with great care. Commensurability is born of Proportio (proportion). Proportion consists of the Commodulatio (modular) ratio of a certain Rata*

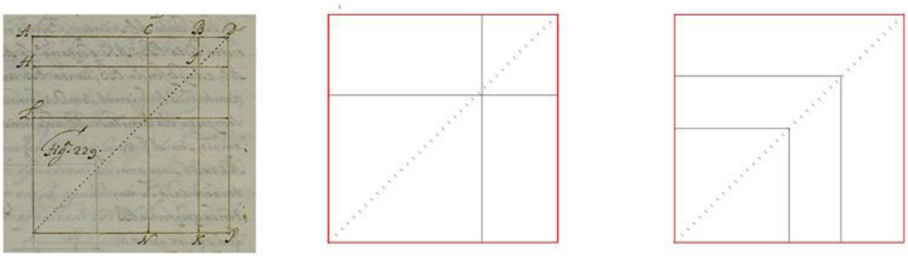
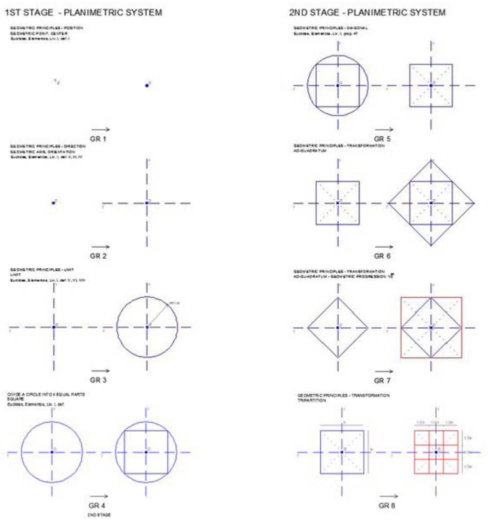


Figure 4
Basic genetic and generators principles: the diagonal

Figure 5
Some shape rules for generating Planimetric proportionate and symmetrical systems



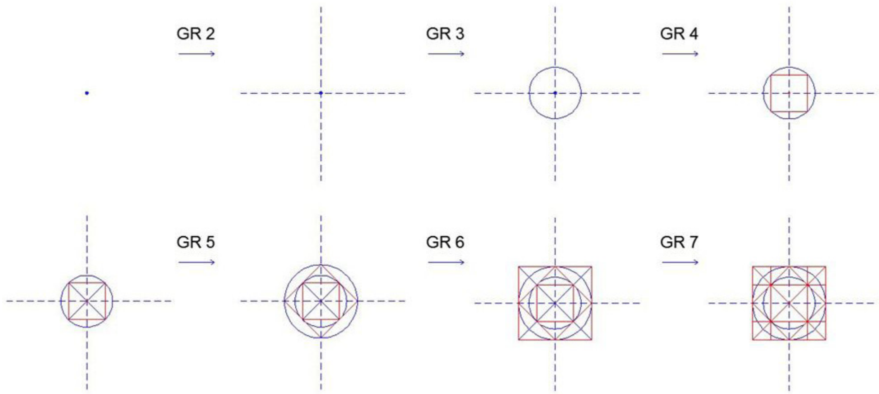
pars (part) of the elements in each section or the whole of the design, on which basis the system of commensurabilities is defined"(Vitruvius). These geometrical relationships led to a method for generating planimetric, with a logic or law of proportional formation that controlled and regulated the arrangement of the main elements in a composition. This system of proportionality sought to establish general lines, a sort of structural skeleton, which functioned as an imaginary grid. Like it was stated by Alberti (1550) *"the geometrical mean is very difficult to find by numbers but it is very clear by lines".* As a result, it was possible to capture the variety of planimetric systems into a reduced number of parametric *schematas* to develop a parametric Portuguese urban grammar (Duarte, 2008; Knight, 1998) and give rise to individual designs (Figure 5).

It contributed to the organization of the elements in the composition, following a sequence of shape-rules (Figure 6), seeking to visually unify multiple elements and relating them to each other within the same family of proportions. From the obtained results, it is possible to tentatively define a theory of possible mental processes and create a generative urban grammar tool to generate planimetric proportionate and symmetrical urban systems. At the same time it is possible to retrieve rules that are embedded in the Portuguese geometric and urban knowledge in the 16th to 18th centuries.

Conclusion

This paper's has shown that grammars can be effectively used to unveil the geometrical principle of order of historic Portuguese urban plans as well as the underlying cognitive or mental design processes that produced the plans. This was made possible through the judicious recovery of the main configurationally elements of genetic urban precedents and the representation of these elements as constituents of the visual conception of the models rather than

Figure 6
Generating a planimetric proportionate and symmetrical systems



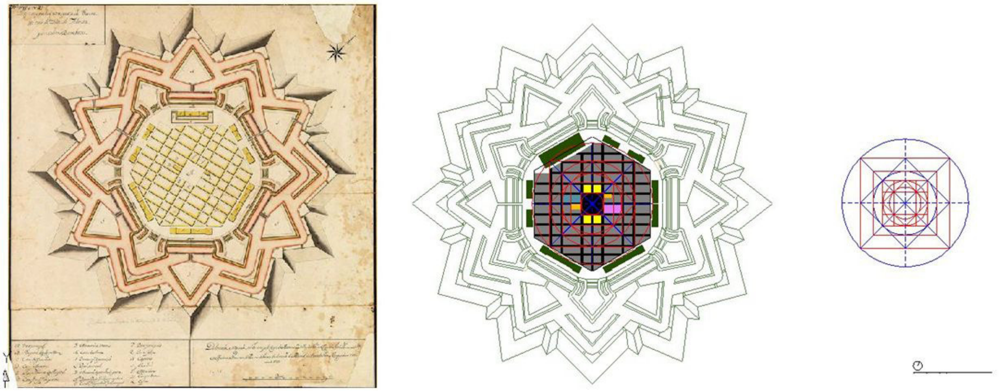


Figure 7
Planimetric proportionate and symmetrical systems. Derivation of an existent urban design

formulae or recipes for the reproduction of processes of design. In addition, this paper seeks to offer a new agenda addressed to the teaching of geometry in schools of architecture and urban design. This new agenda has, a departure point, the demonstration that geometry is a fundamental cognitive instrument for urban developers, and, if ignored, may well alienate an essential component of the design learning process from its outset.

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