A Grammar for Portuguese Historical Urban Design

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Abstract. This paper suggests that Portuguese historical cities were based on a structured knowledge-based process from where it's possible to retrieve not only a generative parametric urban grammar but also to construct a computational model capable to generate Portuguese planimetric proportionate and symmetrical urban grammar. The grammar is described graphically and discursively, followed by the introduction of a 2D shape grammars interpreter UrbanGENE. The 2D shape grammar interpreter will allow the user to interact with the genetic and generative principles of Portuguese historical urban design from 16th to 18th century and additionally be deployed in urban history teaching and learning.

Keywords. Urban design; Shape grammars; Generative and parametric design; UrbanGENE.

Introduction

In the last decade, urban history has been very important to the dissemination of Portuguese urban design, built in Africa, Asia, America and Europe from the 16th to 18th centuries. Cities evolved from planned, regular and erudite principles of precision and standardization (Delson 1979; Araújo, 1992; Teixeira and Valla, 1999; Rossa, 1999). However, urban history falls short of a description of the form-making logic and relationships embedded in categories, classes and geometrical rules present in the morphology of these cities.

In order to analyze the design knowledge embedded in Portuguese cities, it was defined a Corpus of 30 Portuguese treatises (practical geometry, military architecture, military engineering, etc), used in military classes of the Portuguese's schools from the 16th to 18th centuries and a sample of 75 Portuguese urban historical cartography [FIGURE 1]. A theory, Shape Grammar (Stiny and Gips, 1978) has been adopted to support the analysis of the form-making logic, description, interpretation, classification, evaluation and generation of urban design language (Steino 2005; Duarte et al, 2007). This method allowed the inferring of grammatical rules of composition based on the written description of the Portuguese treatises and also the geometrical decoding of ideal urban plans and built cities from the 16th to 18th centuries.

The analysis of the treatises has furnished, in two steps, the primary genetic and generative principles of Portuguese urban design. The first step disclosed a Pythagorean-Euclidean geometric genesis, the
geometric operations necessary to build the syntax of the Portuguese urban plans (Paio and Turkienicz, 2009a). The second step has exposed the Vitruvian urban genesis present in the treatises, ideal cities designed according to rational and geometric criteria (Table 1). In other words, geometry applied to the Compositio (composition) of buildings and cities and 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 pars (part) of the elements in each section or the whole of the design, on which basis the system of commensurabilities is defined” (Vitrúvio, 2006).

Through the analytical decoding of the sample’s grammar, it was possible to progressively depict geometric and topological attributes and to establish two sets of categories and classes (Mitchell, 1998). These were geometric-configurational and topological-functional (Table 1).

Each category was divided in four classes. The geometric-configurational category is strongly Euclidean knowledge-based and is constituted by 7 different elements: Position, Direction, Limit, Generative Shape, Diagonal, Proportion and Symmetry (Paio & Turkienicz 2009a). The topological-functional category is related to urban elements: Streets; Urban

Table 1
Analytical and descriptive Corpus decoding steps.
Blocks; Main Buildings and Squares. The two categories are related in that it is possible to associate the category’s four classes one to another. Classes of the geometric-configurational category were used to generate symmetrical and proportional layout where the geometric structure has been deployed to generate streets and urban blocks. The definition of the point (geometric center), the direction (vertical and horizontal axis), allowed operations such as rotation and, further on, the positioning of the church and town hall (or military buildings) and the location of one or more than one squares connected to the main buildings.

The knowledge embedded in the treatises confirmed the power of Portuguese urban planners to configure geometric proportionate structures along with invariant features of many Portuguese planimetric urban systems. These invariances have enabled the development of a parametric shape grammar capable to capture the genetics of the Portuguese urban plans ranging from the 16th to 18th centuries.

A historical urban grammar

A parametric urban shape grammar that characterizes the Portuguese historical urban design plans has been developed. The proposed grammar is defined in the Cartesian product of algebras of points and lines labeled and parameterized (U12 V12 W12). The grammar formally specifies the generation of each design in its language and classifies them into basic schemes types present in Portuguese treatises (Figure 2). Each type is defined formally by a planimetric proportionate and symmetrical system based in generative principles. Complex compositions are characterized as variations of these simple types.

Stages of the Urban Grammar developing process

An urban derivation has four stages, two to generate the planimetric proportionate and symmetrical system and two to generate a planimetric urban system, as follows: (1) define position, direction, limit and generative shape; (2) define the rules of proportion and symmetry; (3) define streets and urban blocks; (4) insert main buildings and squares. Each stage has a specific set of shape-rule schemata. These stages

Figure 2
Tree diagram to illustrate the basic schemes types grammatically inferred from the Portuguese treatises.
are sequential, using a step-by-step process to generate Portuguese urban plan from the 16th to 18th centuries (Paio and Turkienicz, 2009b). Transitions between sequential rules application and stages are controlled by the Shape-Grammar Meta-Language (SGMT) descriptors (Liew, 2004). SGMT’s established an alternative method to write grammars for design introducing seven descriptors for shape grammar language. These explicitly determine the sequence through which a set of rules is applied, do restrict rule application through a filtering process and use context as to guide the rule matching process (Liew, 2004). The grammar has 5 types of rules: 1) GC_rules: rules associated to the geometric-configurational category; 2) TF_rules: rules associated to the topological-functional category; 3) CHG_rules: rules to change labeled lines (linetypes, colors); 4) ERASE_rules: rules to erase elements; and 5) OPRTV_rules: operative rules to divide, join, stretch, extend, cut. The rules are marked as combined rules (cbn) (ones with an obligatory condition and necessary preceding rules) or single rules (opt) (ones without an obligatory condition or optional rules) (Table 2).

In order to demonstrate the urban grammar developed so far, an example of a Portuguese urban plan derivation process is illustrated and described...
Stage 1: define position, direction, limit and generative shape

In the first stage of the urban grammar, the user defines the basic geometric generative principles of the planimetric proportionate and symmetrical system. The initial shape for the Portuguese urban grammar consists of a single labeled point, labeled O, with a par coordinates (0,0) (Figures 3 and 7). This stage is composed by seven rules, that permits to the user manipulate dimensional parameters and the generative shape. The first step inserts the geometric axis1 (x, y) to symmetry and proportion and indicates that the user is in stage 1. The second step inserts a circle, which will be dived in equal parts defining the generative shape (equilateral triangle, square or pentagon). In this step the user has dimensional parameters (r max. ≥ radius ≥ r min) to define the circle position and the limits to work. These parameters are associated some labels (frt – fortification; sq – square) that are linked to some following shape rules. In this case the parameter used was labeled has a frt that will only permit to the user work inside of the generative shape. The final step inserts the generative shape in this case a square labeled (lim) (Table 2), (Figures 3 and 7).

Stage 2: define proportion and symmetry

In the second stage of the urban grammar, the user operates shape rules to create a symmetric and proportionate structure, based on a generative shape selected in the stage one. The application of rule (chg_axis_stage2) carries the derivation into stage 2. The sequential steps emulate the similitude to the operation with the compass and the straightedge. In order to clarify the following steps, an example shows a set operations (steps) that can be manipulated by the user: Step 1. Rule GC_4_SYMMETRY define all the axis of symmetry; Step 2. Decide the square-based proportions needed to work: tripartition (division in 9 square lattice) or ad-quadratum (geometrical progression 1:√2) (Table 2). The derivation shows that the user has chosen the tripartition (GC_5_PROPORTION); Step 3. Define the repetition: division of the tripartition-square, the user has several labeled and parameterized rules to choose. The user has chosen the repetition-divison 1 with three dimensional parameters options (dtrip5= 0.46 dtrip4; dtrip5=0.5dtrip4; dtrip10=0.77dtrip3) (Figure 4); Step 4. The user has rules CHG, OPRTV and ERASE to apply (Figure 4). The regulating structure is defined by lines originated from the square-based proportion and results in a particular grid whereby streets, blocks and main buildings will emerge in the following stage. The result is a consistent geometric structure which regulates the planning of the Portuguese urban plans at many scales (Figure 7).

Stage 3: insert streets and urban blocks

The application of the rule (chg_axis_stage3) leads the derivation into stage 3. The user has set-rules options to insert topological-functional attributes (streets and urban blocks). In the third stage, urban generative elements emerge according to set-rules as follows: Step 1. The rule TF_1_STREETS define first structure streets. In this step the user has dimensional parameters to define; Step 2. Define the final structure of streets, dimensions (w=width) and
stage hierarchy (if it's applicable); Step 3. The rule TF_3_URBAN BLOCKS defines urban blocks (ub) and is applied recursively; Step 4. Erase the streets structure and geometric structure no longer necessary (Figure 5). This step has OPRTV rules to join or divide that permit manipulate de urban blocks. This final step will highlight the urban blocks grid and the main axis, a fundamental step towards the final stage of the grammar (Figure 7).

Stage 4: locate main buildings and squares

The application of rule (chg_axis_stage4) carries the derivation into stage 4. The user has, again, set-rules options to locate the main buildings (church(ch), town hall (th), governor’s house (gvr_house), priest’s house (prt_house) and military buildings(mlt) and set-rules to locate the squares (civic_sq; church_sq or military_sq) with various formal shapes. All set
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of shape rules transmit the relation between the main axis and the main buildings and these with the squares. The first step the user has a rule, TF_6_MAIN BUILDINGS_MAIN_AXIS to define main axis to insert the main buildings (Figure 6). The following steps the user insert the chosen main buildings available. The derivation shows one way to insert the military building (tf_9_mb_mlt_1) and church (tf_7_mb_ch_2) and after the associated church-square (tf_12_sq_ch_2) (Figure 9). The final step of the stage and the grammar is the erase of the main axis (Figure 7).

The urban grammar presented here partially describes the universe of Portuguese urban plans. Specifically, it produces urban planimetric proportionate and symmetrical systems, orthogonal streets, urban blocks, main buildings (church, town hall, priest’s house, governor’s house, director’s house and military buildings) and squares. Other elements such lots, residential buildings and topographical features can be further inserted into the grammar as an additional stage.

UrbanGENE Interpreter
Shape grammar interpreters provide a quick method to move a shape grammar from paper to an implemented design synthesis tool (McCormack and
Figure 7
Derivation of a Portuguese urban design sample.
Cagan, 2003). According to Gips (2000) in this type of computer implementation of shape grammars the program generates shapes in the given language, either automatically or guided interactively by the user. Duarte (Duarte et al., 2007) classified the previous implementations of shape grammar into three groups: 1) visual implementation (Krishnamurti, 1980, 1981; Flemming, 1987; Chase, 1989, Tapia, 1999); 2) symbolic implementations (Heisserman, 1991; Shea and Cagan, 1998) and 3) implementation of set grammars (Wang and Duarte, 2002; McGill, 2002). Most of the examples of the previous shape grammar interpreter were focused on generating abstract shapes (Gips, 1975; Krishnamurti, 1981, McGill, 2002). The 2D shape grammar interpreter UrbanGENE is focused on producing urban representations which allows the user to interact with the grammar and to generate Portuguese planimetric proportionate and symmetrical urban systems. Screenshots of the UrbanGENE prototype are shown in figure 9 and 10 (Collaboration between the Computer Science Department at the Lisbon University Institute, Portugal and SimmLab-Laboratory for the Simulation and Modeling in Architecture and Urbanism, Faculty of Architecture – Federal University of Rio Grande do Sul, Brazil) (Figures 9 and 10). The codes of the generative system are written in Ruby Programming Language.

**Discussion and Conclusion**

This paper associates shape grammar techniques to structured knowledge-based research to describe a generative parametric Portuguese urban grammar.
The results showed that shape grammars can constitute a valuable basis for the understanding of the Portuguese urban design process as the method permitted to recover the elements of genetic foundation and represent these as constituents of visual reasoning processes.

From the obtained results, it can be said that is possible to create an interactive tool to support urban history teaching and learning. The descriptive and generative character of this tool will allow the user simultaneously to both interpret and simulate new designs based on theoretical knowledge, as well as to manipulate and generate various Portuguese colonial parametric urban design solutions.

Since the study of precedents is a current pedagogical strategy in urban design teaching, the experience may offer a new approach not only to the teaching of urban design precedents but also in the teaching of geometry in the schools of architecture and urbanism.

References

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