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Towards a shape grammar based computational system tool for generating a sustainable and integrated urban design

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Abstract. The ongoing research project called “Emerg.cities4all” is focused on the development of a generative computer-aided planning support system for cities and housing to low-income populations, using a descriptive method as the Shape Grammars and based on multi-agent rule-based system. The goal is to develop a system that could reveal the cultural, social and spatial dynamics involved in the genesis of informal settlements (favelas, musseques and caniços) and use it to generate contemporary humanized urban morphologies. The multi agent shape grammar implementation could generate automatically designs according to different types of users: urban planners, architect and local end users. This paper presents the methodology and the initial results of the research, using an informal settlement as a case study.

Keywords. Shape grammar; Multi-agent systems; Urban design; Informal settlements; Emerg.cities4all.

INTRODUCTION

The economically underdeveloped countries, witness a rapid urbanization with deepening poverty, mass homelessness, environmental degradation and increasing of informal settlements. In recent years the governments of the Portuguese-speaking of Africa and Brazil have sought to address the housing needs by launching state programs to encourage construction. Brazil launched the program My Home, My Life (Minha Casa, Minha Vida), Angola has launched the National Housing Construction Program (Programa Nacional de Construção Habitacional, PNCH) and Guinea-Bissau established the United Nations Program for Development / Equipment Fund of the United Nations (Programa das Nações Unidas para o Desenvolvimento/ Fundo de Equipamento das Nações Unidas, PNUD/FENU).

Recently large massive housing blocks have been constructed offering identical typological dwelling types that does not suit the needs of the population neither the characteristics of the site or the local lifestyle. This inequality between rigid and repetitive housings and the need to answer different situations including time variables is one of the most complex challenges in nowadays architecture (Alvarado et al., 2003). Faced with these inappropriate solutions it is necessary to define more efficient
ones based on the implementation of sustainable housing units at all levels—ecological, social, cultural and economic. Unless sustainable housing solutions emerge soon urban developments will create even greater injustices and inequalities than those currently present in nowadays society (Turner, 1972).

For these disadvantaged groups, it is necessary to develop strategies that may guarantee: (1) to strengthen local workmanship logics (materials, human and cultural); (2) a humanized, evolutionary and diverse urbanization, adapted to local logics; (3) fast and efficient project processes, customized and based on generative systems that guarantee the diversity, evolutilional capacity and adaptability to various realities (either cultural or amongst different domestic groups); and (4) efficient production and construction processes, aided with new technology and adapted to local materials. This paper suggests that it is necessary that the urbanization and construction proposals promote the local lifestyles and social organization of each territory.

In order to integrate these concepts in a computer-aided design planning system tool we propose a methodology for approaching both the urban design and housing design that uses shape grammars (Stiny and Gips, 1972) to deliver a system of alternative solutions instead of the usual unique and definitive solution. The generative computer-aided planning system for cities supports shape grammars descriptions as the core descriptive method for city design. The system is conceived to generate proposals for urban configurations and low-cost evolutionary housing, according to procedures and methods used in the studied countries. The grammar formalism is being used to encode rules to generate urban and housing units’ solutions which should be modular, progressive, adaptable, customized and affordable.

**RESEARCH METHODOLOGY**

The methodology used to develop shape grammar based computational system tool for generating a sustainable and integrated urban design encompasses five stages. The first stage includes three steps: state of the art, the definition of the case studies (favelas, musseques and caniços) within the different countries proposed [FIGURE 1] and the definition of the key parameters used in the analysis. Three scales of information are explored: urban design, housing and construction system. In the second stage we will define several analytical grammars covering urban, housing and constructive scales, with the rules inferred from the different informal settlements and informal low-income houses analysed. In the third stage three originals grammars knowledge based are created (one for urban design, another for housing and other for construction system). The fourth stage consists in the designing of the agent parameters and agent system. In the final stage the design system is implemented and its user interface is developed. This paper presents some results from the first stage regarding the need to define the scope of the grammar and the key parameters that will later be inferred into rules. For this purpose we use an informal settlement as a case study.

Several approaches have been done to support an alternative to mass housing production: (1) “support’s system” from SAR led by John Habraken (1972); and (2) integrated planning support system for low-income housing in Chile by Dirk Donath and Luis González (2006). The act of housing production is understood as a process instead of a static end product, and the housing as an open system (Habraken, 1972) which merges various logical and physical components (Gonzáles and Donath, 2003). Along with these assumptions we consider that diversity and adaptability yield a better match between the building environment and the life it shelters (Habraken, 1988).

Based in these statements, the emerg.cities4all research suggests that is necessary to begin with an analytical grammar since it enables to analyze how existing informal settlements and houses are generated and what cultural, social and spatial dynamics are involved in their growth. Despite the terrible living conditions offered in informal settlements,
we believe that the adaptability and evolutiveness characteristics of their houses as well as the social relations of their inhabitants have some degree of quality and positive aspects to be retained in each case/grammar rules to be introduced into the system.

Informal urban settlements and previous social initiatives for cities with low-income housing in Portuguese-speaking countries are being examined in order to establish the key parameters to urban and housing design and the input initial data and knowledge for the computer system application.

With respect to urban and housing design the key parameters are geographic, social, economic, ecological and cultural. The variations of each house subsequently will be affected by each of the land lot’s ecology, social, cultural and economic specificities. With respect to the computer system application it is further necessary to identify and classify two kinds of knowledge: global knowledge and expertise knowledge. This distinction would provide a convenient separation of knowledge and is essential for computer-aided planning system for cities.

**CASE STUDY**

The case study chosen for the current analyze is the Marçal musseque west of Luanda in Angola due to its characteristic slum layout organization. Through the analysis of this example it has been possible to infer humanized logics and rules. As Grilo (2010: 280) stated “they are self-organised structures that are sensitive to the internal logic of the spontaneous process by which they grow and to their codified rules. These processes are generated on the basis of a mutual interaction between self-planning and self-organisation, which gives rise to complex functional configurations”. Informal settlements called musseques house the urban poor in Luanda and other large towns in Angola. In the 1974’s map of Luanda two major areas of slums could be distinguished: (1) west - Sambizanga, Mota, Lixeira, Marçal, Rangel and Cazenga; and (2) South - Catambor and Prenda. The musseques emerge from the exodus of rural families to the city, and became crowded with hundreds of thousands of refugees during the 1980s and ‘90s. The social relations that emerge in urban areas based in strong relationship between the neighbours are inherited from the ones occurring in rural areas. These relations are clear in the urban voids. The musseque is closed within twisted streets, narrow streets and small “squares”, most of them pedestrian.

To structure the analytical grammar a decision about what kind of approach is the most correct to follow - a bottom-up or a top-down - is required. Both seemed possible and will be used. In this paper we focus on the top-down approach. This approach provides a centralized form of controlling the description of the design as it progresses from the larger to smaller scales (Duarte et. al, 2007). In the Marçal musseque we focused on some urban aspects: (1) the limits of the neighbourhood; (2) the main entries (3) the urban voids urban space - main streets, narrow streets, dead end street, small “squares”; (4) the green public space; and (5) the built space [FIGURE 1].

These analysis allow us to define some preliminary conclusion: (1) following the logic of the formal urban settlements the public space has a hierarchy: main streets, secondary streets, etc.; (2) the main streets define urban blocks; (3) the built space begins to develop along the main streets and when it is completed it begins to grow inside the blocks; (4) the empty spaces such as small squares and green zones, results as leftover spaces emerging from the topography, from the morphology of the territory or from the need to create social and cultural recreation areas; (5) the built areas are connected to save space to built more construction; (6) the saved space to built more houses is used as social and cultural recreation urban areas – small “squares” and green areas – and assumes an important presence in urban composition; and (7) the presence and dimension of living spaces and green space is directly related to the number of existing inhabitants. This basic knowledge is essential to infer urban grammar rules of the existing practices and to consider new possibilities of creating living environments.
SHAPE GRAMMAR BASED COMPUTATIONAL SYSTEM TOOL ARCHITECTURE

The generative computer-aided process will be based on a multi-agent rule-based system architecture. Each agent participates in the design process with different specific expert knowledge, based on shape grammars and other knowledge representation models. Agents participate in organized groups within the different phases of the generative process (architecture, urbanism, construction). Different interaction protocols and workflows would result in different generative/emergent solutions.

The following diagram [FIGURE 2] represents the system architecture.

A global knowledge base kb supports shared urban, architecture and construction knowledge. It supports also social, cultural, economic and ecologic criteria to be taken into account during the generation process.

There are two kinds of knowledge representation models involved in the system: geometric knowledge and non-geometric knowledge. The former is represented by means of shapes and shape grammars rules. The latter is represented by logic relations adequate to capture the different properties, constraints and criteria that must be satisfied. A rule-based system is the natural choice for uniform knowledge representation with both kinds of knowledge. The forward and backward reasoning rule mechanisms usually supported by such systems (Russel and Norvig, 2003) provide both production system capabilities for shape generation and also
reasoning capabilities to analyze if conditions and criteria are fulfilled during design process.

Concerning the multi-agent system paradigm (Weiss, 1999), our approach offers two main advantages applied to city design. First, in practical applications, huge and complex problem data, computations and reasoning processes may be conveniently distributed and modularized by using agents as the main module units. Second, a kind of emergence can happen when unexpected design solutions come up from the agent collective behavior due to autonomous agent direct or indirect interaction.

In our system architecture agents are organized in groups according to expert knowledge categories. Each agent, $a_1$, ..., $a_n$ in a group gives its contribution in building solutions according to its individual expert knowledge $k_{b1}$, ..., $k_{bn}$, respectively. For instance, urban agents deal with specific knowledge on streets, squares, and city blocks; architecture agents deal with specific knowledge on functional organization of houses like the articulation of private areas, social areas and service areas; construction agents deal with specific knowledge on construction aspects like foundations, floors, walls and roofs. All the agent cooperation and interactions should follow previous established criteria.

Different agents may be used with different specific roles and expert knowledge in a natural way for different practical aspects. We may even conceive competing agents with different and opposite approaches to city design, each one using different criteria and geometric styles, i.e., different shape grammar rules.
The *geom* component deals exclusively with adequate graphical representations of shapes (Krishnamurti, 1980, 1981), shape compositions, shape transformations and other operations for application of shape grammars rules to shape compositions (addition, subtraction and product).

The *interface* component allows the interaction with users of the system, providing separate tools for graphical and symbolic definition of shapes, shape grammars rules, styles, agents and their expertise, groups of agents, cooperation protocols and workflows. The graphical interface is oriented for architect and urban planner experts, whereas the symbolic interface is to be used by computational knowledge experts. Local end users can generate incremental solutions. For local users, not knowledgeable in digital expertise, it is important that the interface of the system can be really used. Common forms of interaction, like scroll, pop-up windows or menus, pull-down menus, drop-down list menus, are in fact hidden input information mechanisms, being barriers for non digital used users: they can create resistance for system use if not correctly addressed.

The information to be introduced to the system is organized to avoid these barriers adopting a direct You See What You Input (YSWYI) approach. All the information is present in the screen. Successive screens are organized to contain all the information to be introduced, from urban information to housing and construction. The information to input is visually present, all the time, in the screen, and checkboxes, text boxes and push-buttons are used extensively to avoid barriers. Reading and interpreting what is read should be the only pre-requisite to the user: the You See What You Input (YSWYI) interface approach building simplicity and usability in the real world.

**DISCUSSION**

Previous social urban solutions for low-income housing are based on uniform repetitions of pre-defined plans for houses that do not fit either familiar or cultural needs. Our research is based on the assumption that it possible to generate modular, scalable, adaptable and affordable mass-customization (Duarte, 2005) solutions for urban and low-income housing design if supported by a computational generation tool based on shape grammars.

We believe that the computational development of a system supporting work with shape grammars must be based in the system’s ability to represent knowledge on computing and reasoning with shapes and shape spatial relations. For that purpose the most appropriate is to use Artificial Intelligence techniques and tools, namely rule based systems and logic (actually, shape grammars systems are rule based systems) and multi-agent systems.

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**REFERENCES**


