Generative Design Systems for Housing
An outside-in approach

Gabriela Celani [1], Regiane Pupo[2], Gelly Mendes[3] and Érica Pinheiro[3].
[1]School of Civil Engineering, Architecture and Urban Design (FEC), São Paulo State University at Campinas (UNICAMP), Brazil
[2]Ph.D. Program in Architecture and Building, FEC-UNICAMP, Brazil
[3]Master Degree Program in Architecture and Building, FEC-UNICAMP, Brazil
http://fec.unicamp.br/~celani/ pesquisa.htm

Abstract. *The present paper describes an undergoing research that aims at developing a generative design computer implementation with an outside-in approach, OIDS. The system will allow developing and visualizing context-based housing development designs. This approach will include both natural characteristics of the site and the existing neighboring buildings. It is argued that certain common urban design practices are the result of a simplification due to difficulties in dealing with the irregularities of the natural environment, which often requires the use of time-consuming methods. The computer-based application will provide tools for dealing with such difficulties, allowing designers to describe their own design rules. In an initial phase of the project, a tool that can subdivide irregular land parcels into equally sized areas has been developed. In further stages, other environmental variables will be addressed, such as solar aspect and prevalent wind directions. Eventually, even the designs of interior layouts should result from exterior forces. The resulting generative system is expected to facilitate and encourage the use of a more organic approach to building siting and design, bringing about the important discussion about which should be the main forces in the generation of the built environment*

Keywords. *Generative design; context-based design; housing design; building siting; urban space simulation.*

Introduction: CAD and generative design systems

In the past few years, different theoretical approaches in architectural design have been developed, significantly changing the scope of the work of the architect. According to one of them, the generative approach, the new role of the architect would be to develop design tools, and not necessarily specific buildings directly. There are different lines of research within this approach, ranging from parametric design (Monedero, 1997) to evolutionary computation (Frazer, 1995, Bentley, 1999). The present work will focus on the use of shape grammars (Stiny, 1975) as a generative tool.

Generative design systems are concerned with productivity, variety and formal innovation. One of the advantages of using generative system is the possibility of developing families of objects with formal and constructive coherence (Fischer and Herr, 2001). It is possible, for example, to have a generative system design a complete housing complex where each house is different, but all of them follow the same language, such as shown in Duarte´s (2001) implementation of Siza´s Malagueira development. However, according to Caldas and Duarte (2004), “the impact on practice of any of these paradigms has been low so far”, probably due to the “lack of computer implementations” (p.5).

The implementation of the generative approach into computer-aided design tools presents many advantages. Computer-based implementations can produce a large number of design alternatives in a relatively short period of time, and they can be visually evaluated with rapid-prototyped models. Constructive difficulties of such architectural diversity can be solved with the use of automated fabrication machines that can easily produce any custom parts (Shelden, 2003) from the CAD models. In the future, it may even be possible to automatically cast whole buildings in concrete or other materials, based on digital models (Khoshnevis and Bekey, 2003).

On the other hand, despite CAD’s original aim to help in all the different aspects of design, even today its use is mainly been restricted to representation. Mitchell (1975, 1990) argues that more efforts should be done in the development of CAD systems that can truly participate in the design process. This situation could change with the development of generative design implementations that are easy to use and present a real advantage in relation to traditional design practices.

Precedent work: simulation, analysis and synthesis

A number of computer-based applications for generating urban space have been developed in the past years, with different objectives. Some of them aim at exploring possible urban patterns at a theoretical level, sometimes using advanced methods such as cellular automata (Batty et al., 1997). Other systems allow to analyze existing urban patterns by implementing, for example, space syntax theory (Jiang et al., 2000). A more pragmatic approach has been to simulate the results of building regulations in the urban environment, allowing to evaluate their consequences in terms of thermal and visual comfort, such as in CityZoom (Grazziotin, 2004).

Although these applications may be considered generative systems, since they can generate unexpected scenarios based on pre-established rules, they are not directly concerned with building design synthesis or the generation of novel architectural shapes, but rather with the simulation and evaluation of possible urban configurations.

The implementation developed by Duarte (2001) for generating designs based on Alvaro Siza’s Malagueira housing development, on the other hand, has a completely different approach. Questions such as diversity and similarity, and massification and customization, are addressed. Duarte’s research started with a profound analysis of a corpus of different designs developed by Siza for the Malagueira neighborhood. The author inferred composition rules from these designs and defined a shape grammar that was implemented in his system. The system could then recombine these rules, generating new, yet perfectly plausible, solutions. Duarte’s work is therefore directly concerned with design and composition, both in terms of the housing unit and the urban environment.

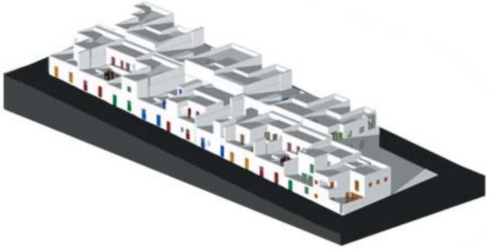

Figure 1. A housing block developed with Siza's design grammar (source: Mitchell, W., Knight, T., Duarte, J. and Yee, S. 4.185 Workshop, Spring 2000, available at http://architecture.mit.edu/prtfolio/studios/sp00/4185/).

Objectives: context-based design

The present research project aims at developing a computer implementation for designing housing developments with a context-based approach.

Most generative design implementations developed so far are mainly concerned with formal issues, such as proportion and composition, or functional goals, such as internal circulation and distribution. Duarte's (1998) generative system is an exception, since it takes into account the context. In this case, the goal was not simply "the random generation of houses but the generation of a house for a given context" (p.41). In a similar way, the outside-in design system outlined in this paper - OIDS - will consider exterior forces from the built surroundings, but also from the natural site, as the main influences for developing the buildings' siting and layout.

The influence of the natural environment on building and urban design has been present since the very beginnings of urbanization. Serra (1987) asserts that important researchers on urban development, such as Marx, Childe, Mumford and Hauser and Shnore have acknowledged "the importance of the natural, hydrographic, topographic, climatic etc., conditions" (Serra, 1987, p.53) on the urban form. Still according to Serra, "the form of the natural space not only determines the placement of agglomerations ... but also the very form of the city" (ibid.).

The organic approach to urban design, based on the topography of the site, was theorized by Camilo Sitte, who was inspired by the spontaneus growth of medieval towns. Sitte developed this approach as a possible alternative to the haussmanian transformations that were being applied to Vienna at the end of the nineteenth century (Choay, 1965). The respect to level curves and water courses, some of Sitte's principles, can result in winding routes, which can jehopardize circulation, a strategic aspect of the industrial city. In fact, this strategy is sometimes deliberately applyed to areas where this "side-effect" is desirable, such as residential condominiums, even if the land is flat. OIDS will include tools that automate procedures that would be time-consuming if applyed by hand, such as laying out streets on a sloped site with the minimum possible steepness, or dividing irregular shaped areas into equal size parts.

Architectural contextualism, a response to the character and proportions of surrounding buildings, is also another common practice in architecture. OIDS will allow designers to describe their own spatial relation rules for dealing with existing neighbor buildings, as well as siting rules for a given natural environment.

Besides topography and neighbouring buildings, other environmental variables will be addressed in the development of the system, such as solar aspect and prevalent wind directions. Density rates may be defined according to steepness and relative altitude, to minimize sliding risks. The program will also try to find the best possible alignment for buildings in asymmetrical plots. Eventually, even the designs of interior layouts should result from exterior forces, with certain functions being attracted or repelled by natural conditions such as light and winds, or by neighboring conditions such as the presence of other buildings and streets. As a result, the designs generated will be a direct response to the context.

Figure 2. The land-parceling tool: different subdivisions of an area into equal size parts.

OIDS's tools: street layout and land parceling

Urban design and building siting that are not context based are sometimes the result of a deliberate formal approach to design, or even an attempt to show man's power and technical development. Such practice, however, may also result from a mere simplification of procedures that would otherwise be too time-consuming. Street layout and land parceling, for example, often result in an orthogonal grid. This kind of pattern is obviously more appropriated for flat areas, but because it has the advantage of allowing to easily subdivide the land into equally-sized plots it is sometimes applied to sloped areas as well, resulting in steep streets, land sliding and other problems.

Tools for helping dealing with the irregularities of the natural environment will be included in OIDS. For example, the results of the application of a tool for subdividing blob-shaped parcels into equally sized plots is shown in figure 2.

The user is prompted to inform the desired approximate area of each plot, and the resolution of the division. The default value is 1.000 pieces, but higher resolution rates will generate more precise results with a slightly longer delay. The algorithm subdivides the given irregular-shaped figure into 1.000 or more polygons. These polygons have their areas added to a variable until the desired area is reached. Each time the desired area is reached the program draws a line delimitating the plot. For higher precision, an error diffusion procedure was included in the algorithm. Figure 2 shows different subdivisions of an irregular shaped area into equal size parts.

The tool described above simply implements the concept of differential calculus into a CAD environment. This procedure could be easily performed step by step in a regular CAD system. However, because it is possible to automate the CAD system, a large number of repetitive steps can be performed very quickly, turning what would be otherwise time-consuming into an easy to apply and to understand design tool.

OIDS's generative system: building siting and layout

After the street layout and land subdivision are ready, the process of generating houses will start in a random order, simulating the natural process of occupation of a neighborhood. Each new house will be generated according to a set of neighboring rules. Figure 3a shows a set of possible initial designs for the houses (vocabulary) and Figure 3b presents a set of desired neighboring relationships for one of them. Whenever more than one alternative is possible, the solution will be chosen randomly among the available ones. Alternatively, the designer will be prompted to deliberately choose a spatial relation among the allowed ones. A number of different building layouts can thus be created and evaluated.

Figure 3c shows two possible urban space configurations based on the vocabulary and neighboring rules above. The next challenge in the development of the system will be to combine these type of neighboring rules with other rules related to natural characteristics of the site, such as light and wind.

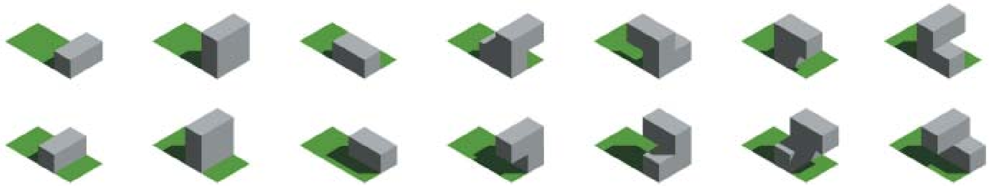

Figure 3a. Different housing units (vocabulary).

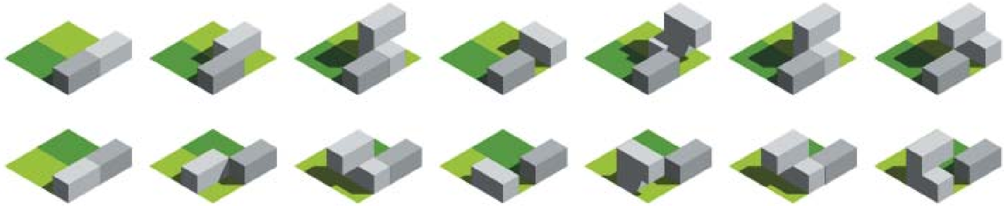

Figure 3b. Possible neighbour relationships a housing unit.

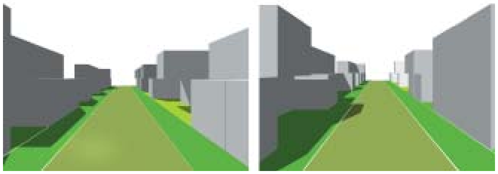

Figure 3c. Possible cluster designs generated from units and rules above.

Discussion

A generative design system for laying out housing developments with an outside-in approach to design has been outlined in this paper. In the proposed system, the characteristics of the natural environment and existing neighboring buildings will be used as the main forces in the generation of housing designs. So far, a tool for helping subdividing irregular land parcels has been developed and a set of possible initial buildings and neighboring situations has been sketched out, which will allow to implement a first prototype of the system.

Although the system is still under initial development, it is important to discuss, at this point, its objectives and possible applications in order to assure the relevance of the final outcome. In the next stages, more site-adjustment tools must be developed and the user must be able to insert his or her own initial forms and spatial relations. It is not clear, at this point, if the generation of interior layouts in terms of exterior forces will be successful, and more research must be done in this area, perhaps by means of case studies.

In summary, this research project will address not only the problem of generative design systems, but also important architectural questions such as the design process, environmental comfort, housing design, context-based design and urban design. The final outcome, OIDS, is expected to facilitate and encourage the use of a more organic and contextualized approach to housing development design. It is also expected to bring about the important discussion about which should be the main forces in the generation of the built environment.

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