Generative House: Exploration of Digital Fabrication and Generative System for Low-cost Housing in Southern Brazil

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ABSTRACT

Generative House is a collaborative exploration of advanced technologies for lower- and working-class housing carried out by industrial and academic partners in southern Brazil. It seeks to test generative procedures and digital manufacturing to develop a flexible building system for low-cost sustainable housing in order to inspire future developments in this field by developing an urban grammar through manufacturing models and generative programming, as well as parametric design of panels assembled using digital fabrication. Scale models and full-scale prototype with timber boards have been built, demonstrating the feasibility of the approach proposed. However, further refinement of the adopted procedures and technical applications is required.

KEYWORDS: low-cost housing, generative programming, parametric design, digital manufacturing, collaborative development.

The population of the earth has increased ten times during the last two centuries, reaching eight billion of people, and it continues to grow (UN, 2005). Life expectancy has also doubled in the same period, from 40 to 75 years, which means that world demand for housing will dramatically increase in the years to come. Urbanization rates also increased from 30 to 80% in the same period; gross income and people's mobility grew in similar ranges, creating demand for better solutions that meet the needs of different climactic and socio-economic conditions. Despite all of these changes, design and construction have maintained traditional building procedures—construction is economic sector with the lowest productivity and industrialization rates (Haskwell, 2004).

Fossil fuels now have a very short availability horizon due to dramatic increase in demand that is a response to the growing consumption of transportation fuel, construction materials, and heating and cooling systems for buildings. Global warning also compels us to make hard choices that require changing many processes, in particular the way in which we build and use of facilities, which are responsible for most of the world's energy consumption and carbon production. Types of architecture and their elaboration have to be changed radically over the coming decades in order to face these new environmental and social challenges.

Technological evolution based on scientific knowledge and mass-production has advanced rapidly during the past two centuries, leading to alterations in the modes of production. However, architectural production is far removed from these procedures. Design is usually thought of as an isolated task, aesthetically focused on creating unique products; construction consists of linear handicraft sequences. This is particularly the case in developing countries where the demand for new buildings is very high. Governments of developing countries are promoting massive plans for low-income housing. This endeavor should be accompanied by novel approaches to production both in design and manufacturing.

Customized mass production of housing was proposed in the seminal work of the SAR-group (Habraken, 1979). However, its implementation with automated technologies has been limited. The Digital Fabrication Group of MIT, headed by Larry Sass, digitally manufactured a complete cabin called an "Instant House" in wooden boards. It established a constructive shape grammar and presented the possibility of mass production, however, the initiative was not developed (Sass, 2005; Botha & Sass, 2006; Sass, 2007; Cardoso & Sass, 2008). Other recent experiences involving the design and elaboration of housing prototypes have been "Draw-Built-Cut" by Tajima and Chang in AA in London, and "FabLab House" by IAAC in Barcelona. These examples demonstrated the digital production of smallscale buildings, but failed to relate these to corresponding urban settings.

Low-cost housing involves relatively low financial resources per unit when part of large-scale plans. This may imply identical units in which diversity is achieved through variations in urban configuration. Family makeup and changes made over time also determine variety and adaptations (Garcia et al., 2009), requiring flexible housing solutions. Several computing tools suggest design strategies for diverse arrangements, such as evolutionary algorithms (Hemberg et al, 2009; El-Zanfaly, 2009) or urban grammars (Paio & Turkienicz, 2009). These capabilities can be explored for large-scale housing, supported by a constructive system that manages design variety.

CasaG

The Generative House (CasaG) constitutes an example of the utilization of advanced technologies in low-cost housing design, and was carried out by an international partnership between industries and academia in southern Brazil. Generative procedures and digital manufacturing were tested, and inspired the development of a sustainable building system for low-cost housing. The project structured urban and constructive grammars so as to stimulate flexibility and mass production of housing. In an exercise carried out in two workshops held at the SimmLab (Laboratory of Urban and Architectural Simulation) of the *Universidade Federal do Rio Grande do Sul*, PortoAlegre, Brazil in June-July and August-September, 2010, graduate and post-graduate students tested cutting-edge systems targeted to high-scope goals in order to encourage innovation in design, planning and construction.

Initial Module

The Generative House project initially researched environmentally-friendly industrial products for manufacturing building components. Composite-wood boards were chosen as the main material to be used in the construction because of their good physical properties, local provision, their originating from reforested woods, and their ease of manufacture. A regional industry supplied products and technical support. Panels were designed and tested with laser-cut 1:10 models. Full-size boards (1.84 x 2.75 meters) with maximum lengths close to the house's floor-to-ceiling height defined double walls, and an assembly system composed of perforations and joints was made out of the same material. Windows, doors, ceilings and floors were linked to the walls for structural support and assembly. In addition, a tridimensional module was established (2.60 x 1.70 x 2.60 meters) providing multiple alternatives of windows and doors. Additional coatings were considered because composite-wood boards do not have enough resistance to humidity and fire; proper thermal and acoustic insulation was provided. Studies of local weather and housing regulations were carried out parallel to the review of general requirements. Also several possible housing plans based on the initial module were studied to test the affordability of diverse room arrangements.

Urban layouts

A variety of housing alternatives to compose urban arrangements was tested through digitally manufactured models in order to select configurations with growth flexibility according to predefined living complexities. A great diversity of module groups were produced in white-plastic models 1:100. Several growth arrangements were studied following generative rules (shape grammar) and photographed step-by-step to allow further review of ventilation and orientation according to weather conditions and high density requirements. This procedure allowed researchers to define a basic configuration consisting of a row of 6-7 modules with a second adjacent row of 3-4 modules, a group called "embryo", with highest growth potential in few steps. This basic configuration allows for a basic 36 square meter house with two bedrooms, services and social space; consecutive enlargements of similar sizes reach 240-300 square meters in two stories. Testing different growth sequences, such housing types preserved good ventilation and functionality patterns, enabling out-door yards. The pattern generated adequate (proportionate) dimensions for local streets so as to encourage social interface in local public spaces. This system of arrangement was programmed in Rhinoceros-Grasshoper with a cellular automata plug-in in order to reproduce alternatives of growth and urban layouts. To define a rectangular grid according to the constructive modulation, attractor points were determined so as to encourage the initial house to be set in different lot positions on the block. An algorithm allowed random growth then refined through several recursions with the high percentage (80%) of coincidence with the tested models. This rate was used to accomplish a computer procedure to achieve the conditions and flexibility demonstrated by the models.

Constructive System

Development leads to the refinement and completion of the constructive system in order to enable a variety of layouts. This task involved the review of the design and properties of several components such as walls, windows, doors, roofs and floors. It establishes modular dimensions and varieties according to locations in the layout, but also offers the possibility to change and enlarge the configuration. The assembly system was developed to relate all components through a modulation and used a minimum number of joint pieces, including corners and connections to roof and floor, and also provided alternatives for windows and doors according to the modulation in order to maintain structural continuity.

Complete 1:10 models of several units composed of two or three modules were made, with diverse possibilities of design and materials. The models were elaborated in 3 millimeter wide composite boards using a laser cutter. Some production difficulties were encountered due to the size of the model elements, such as laser beam adjustments due to board displacements causing minor errors affecting the overall assembly, as well as problems adjusting roof inclination with perpendicular cuts in order to afford supporting pieces and slots.

Full-scale Prototype

The last step of the project, currently in development and not to be completed until the Sigradi conference, is a full-scale prototype of the building system. Several changes of technical details due production conditions were carried on through CNC-machines for larger formats and products—in this case, with industrial boards cut into panels measuring 120 x 240 x 1.8 centimeters. This modified the procedure of cutting and assembly, as well as the roof system, corners and floor. The prototype will be assembled in a commercial showcase (*Expo-Acabamento + Congreso Internacional de Arquitetura e Design*, FIERGS, PortoAlegre October 20-24th), exhibiting diverse development models and urban arrangements.

Conclusions

This experience tested advanced technologies of design and manufacturing to develop a flexible building system for low-cost sustainable housing. It developed an urban grammar through manufacturing models and generative programming, as well as a parametric design of assembled panels using digital fabrication. Several material models and tests of constructive behavior were performed. It has inspired the construction of a full-scale prototype using industrial timber boards, on display in a public showcase. The collaborative work between faculties and students from different institutions and countries and different companies demonstrated the feasibility of the proposed approach. On the other hand, it revealed the need for the detailed refinement of such technical procedures, building attributes and applications. This work is meant to inspire future developments in the field, in order to target the exploration of new technologies to meet the world's urgent housing needs.

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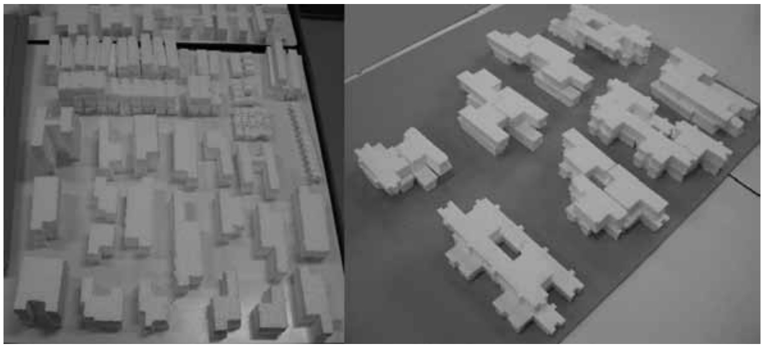

Figure 1. Manufacturing models of housing arrangements

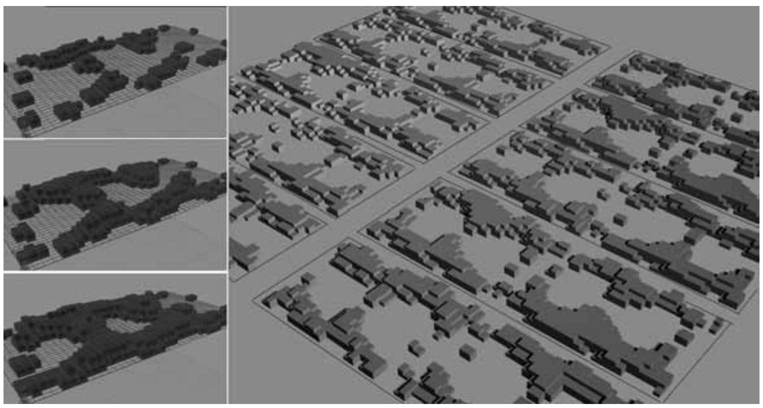

Figure 2. Generative programming of urban arrangements

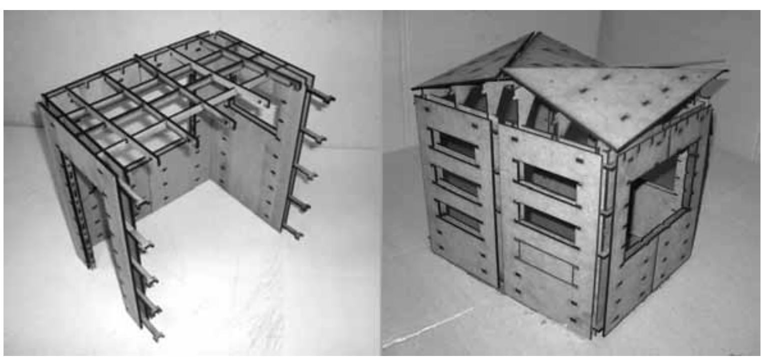

Figure 3. Scale models of the constructive system

Figure 4. Manufacturing of the full-scale prototype