Option One: A Model of Participatory Design to Construct a Rural Social Housing From Digital Fabrication

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Option one is the first prototype in the process of construction, based on the application of integrated processes of digital fabrication: This methodology was developed through a research project which explores options of rural public housing. The design process is integrated with other variables such as: participative design, directed self-build and the integration of tangible and intangible aspects. Parametric modeling was used as a strategy to create an integrated process of design, production and assembly based on a code created in grasshopper. Once finished, the housing unit will be handed over to a rural family. This will allow for doing follow-up and evaluation.

Keywords: Parametric modelling, Social housing, Digital fabrication, Integrated process

INTRODUCTION

In Colombia in the year 2005, the housing deficit (urban and rural) was 36% which is equivalent to 3,800,000 units. This is to say that one of every three housing units either did not exist or had habitability problems.

Of these 3,800,000 units, 1,600,000 correspond to the rural sector, a quantity equivalent to 68% of the rural housing units. The means that two of every three rural housing units either did not exist or presented habitability problems. This is due, in part, to the fact that State policies favor the production of urban housing principally because rural housing presents logistical problems related with the storage of materials and the complexity of construction processes, which makes the development of State policies and the distribution of resources difficult. These aspects are even more evident and create a stark contrast in a varied and uneven topography and culture such as that of Colombia.

This research proposes the development of a rural housing unit prototype based on an integrated process of digital production as a possible strategy to reduce the housing deficit. Such a prototype must include the specific conditions found in rural Colombia and defined in the research as tangible and intangible aspects. They must also guarantee minimal conditions of habitability and sustainability.

HOUSING CONSTRUCTION IN COLOMBIA

Two processes are used for housing production in Colombia: processes of self-build and industrialized processes. Even though directly related with economic aspects of the construction industry, they also impact social, cultural and even educational aspects of the community.

Normally, the processes of self-build are associated with low quality and poverty due to the fact...
that the very owners or occupants of the housing unit are those who build it without minimal standards in terms of habitability and stability. Generally, these are informal processes without major technical support which leads to construction deficiencies related to long periods of construction, inefficient uses of resources and non-compliance with minimal standards of habitability and stability, among others (Alvarado 2010). In fact, the processes of self-build as a strategy to face the problem of public housing are criticized since they can show a lack of governmental presence (Marcuse 1997).

Nevertheless, the processes of self-build of housing have a potentially positive impact in social terms when there is an adequate assistance on the part of State entities. This impact is related with: Inclusion of the community in the decision-making processes, the possible generation of more economically accessible projects, the training improves and creates new skills in the owners that construct their own housing units and new employment opportunities are created. The owner is integrated into the design process while respecting their socio-cultural conditions. Local resources are used which creates desirable local social and economic dynamics (Simioni 2007).

Furthermore, industrialized processes (Echeverry, 2000), generally applied by construction companies guarantee a higher quality when compared with the self-build processes due to the use of repetitive and standardized processes. Among the advantages are: less construction time, less waste of resources, non-dependency on factors related to climate, possible reuse of resources and the continuous presence of assistance and technical support (Alvarado 2010).

Even though the industrialized systems can guarantee a better quality in the final product, they can also present problems and disadvantages related to intangible aspects such as: the non-inclusion of the community in the decision-making process, inflexibility and almost no capacity for adapting the housing to the needs of the users, reduction in the workforce used during the construction process, having an impact on the levels of unemployment, possible cost increases due to the utilization of specialized workers, material and element transport and little sense of belonging on the part of the owners due to the widespread growth of housing units. In summary, industrialized processes can get to the point where they ignore the cultural, social, economic and environmental contexts of a community (Alvarado 2010).

Therefore, it is very important to guarantee quality housing in terms of an adequate process of design and construction which includes the participation of the community. These two aspects imply that the housing unit, as a finished product, must include tangible aspects related with the quality of the materials, the finishing touches, processes, resources, environment, habitability and stability as well as intangible aspects related with social, cultural and economic issues (Arango 2003).

**DESIGN, PRODUCTION AND ASSEMBLY: INTEGRATED METHODOLOGY BASED ON CAD / CAM**

A desirable scenario for a housing prototype is one in which the advantages of the industrialized processes (tangible aspects) are combined with the self-build processes (intangible aspects) (Arango 2003). This means a number of important variables to control. If the entire design, production and assembly, management, administrative, integration and even the visualization of information processes are centralized, they all become key and determining factors that would affect the final product (quality). In this scenario, the CAD/CAM tools, as processing and information integration and production tools, become a viable alternative (Barrow 2006).

Computer application experiences (CAD) in participative design and self-build, demonstrate that the use of computers with specific methodologies can help to facilitate the integration of the owner into the decision-making process while allowing for specific conditions to be adapted through real time modifications which update relevant data for the sub-
sequent cost structure and definition of workshop plans for construction elements and components (Ottokar 1992). The supervision and accompaniment of qualified personnel during the entire design process will assure acceptable levels of technical-constructive quality (Ottokar 1992). Nevertheless, when the CAD tools are only applied in the design stage and not in the stages of production and construction, it is less likely they reach acceptable levels of quality (Ottokar 1992), due to the fact that what is defined and controlled in the design process are not necessarily maintained as the same characteristics in the production and construction processes (Ulrich 2012).

To be able to have control over the different construction phases of a building (design, fabrication and assembly), CAD/CAM processes can be used which recently and slowly have been more involved in the field of architecture. The CAD/CAM processes commonly applied to industrialized processes of mass production, allow the phases of design, production and assembly or the fabrication of an element to be integrated into a “digital continuum” (Kolarevic 2005).

If this is indeed desirable in the field of architecture, the projects or buildings seen as products are not repeated with the same frequency of an industrialized product and possess a certain level of individuality that is difficult to standardize and mass produce (Ulrich 2012). This is precisely the huge difficulty or the great challenge to overcome: how to produce individual or personalized architecture despite the use of systematized, repetitive and modular processes (Ulrich 2012).

However, recent research in the field of digital fabrication and specifically in Computer Assisted Design Systems (Ulrich 2012) shows that when these processes are not applied to the same object as a final product (which would create mass-produced buildings) but rather, quite to the contrary, a methodology is created in which individual architectural designs are systematically analyzed under specific parameters, to be broken up into constructible parts, which can later be recombined in a new process where they are itemized to be produced and assembled, singular buildings can be obtained under systematized and standardized processes (Ulrich 2012). The basic principle is that each building possess some degree of modular repetition and therefore can be defined using a specific module. This implies systematizing the production process but allowing it to have flexibility and the capability of being personalized in the moment of reaching the final product (Ulrich 2012).

This is the scenario in which it could be proposed that rural public housing be based on an integrated digital process (design, production and assembly), being aware of tangible and intangible aspects, which would allow having a degree of personalization or individuality in the final product (Duarte 2001), maintaining an adequate level of quality throughout the process.

**STRATEGIC DESIGN STAGES**

The principal objective of the research is to propose a digitally integrated design, production and assembly process of a rural housing unit in the Colombian context which takes into account both tangible and intangible aspects.

Four general and abstract principles were proposed as strategic work stages. These should be present and recognized in any project under development:
1. Definition of a context, population and/or setting: It should not be too specific (there would not be much opportunity to replicate the methodology) or to general (there is not one answer to all problems). This implies recognizing possible technologies and local materials, climatic and geographic aspects, etc.

2. Integration of the stages of design, production and assembly, Figure 1: the integrated process must seek to guarantee habitable and stable public housing.

3. Integration of the tangible and intangible aspects of the possible users, Figure 1: this implies recognizing cultural and social aspects, etc., which are relevant and which can be introduced into the housing.

4. Definition of a strategy and scope for user participation. This basically depends on how much the user may want to be involved in the quality and/or stability of an element or of the very housing unit. From this point of view, three levels of participation or interaction can be identified, Figure 2:

   • Interaction in assembly: the individual or group user receives a pack of elements or components and with a clear instruction manual, is able to assemble everything. In this case, the quality of the final product is provided through the simplicity in the assembly process and through the quality of the instructions. At the end, the user should not affect the quality foreseen and calculated by the assembly system.

   • Interaction in the fabrication: The user or group of users produce an element or component with a predetermined level of assistance by qualified personnel. In this case, if the user intervenes directly in the fabrication, the quality of the end-product could be affected in a significant way.

   • Interaction through modification: The user may modify determined elements in an already assembled system without compromising the general stability of the housing unit.

OPTION ONE: APPLICATION OF THE STRATEGIC STAGES

The four general principals were applied to the prototype called Option One:

Stage one: One-floor house, located on the savannah of Bogotá, specifically in the rural zone of the municipality of Suesca. Cold climate. A predominance of rock and dirt as building materials can be observed. The housing unit will be inhabited by a family made up of a mother, head of the household, and four children.

Stage two: The phases of design, fabrication and assembly were integrated in a parametric model (grasshopper), keeping the following specific characteristics in mind for Option One:

   • Maximum area of 72 square meters, approximately

   • Rectangular floor module equivalent to two OSB sheet material: 2.44m x 2.44m. and a total area of approximately 6 square meters.

Figure 2
Definition of user participation strategy.
This with the purpose of avoiding unnecessary cuts and material waste.

• The proportions of the floor of the house are 3 x 4 modules. This in response to the scenarios discussed with the family unit who will live there.

• The definition of the spaces is determined by the dimensions and the grouping of the modules.

Stages three and four: The stages of design, fabrication and assembly are integrated. Each one of these three processes is carried out individually. Each has stability and habitability requirements, the integration of tangible and intangible aspects and a user participation strategy.

OPTION ONE: INTEGRATED DESIGN PROCESSES

DESIGN STAGE

Four basic systems are defined (Rush 1986): structure, exterior enclosure, interior enclosure and mechanical system. Each system must be independent to reduce problems in the interaction between systems and with the user.

The parametric model (grasshopper) is made up of four systems. Each one has independent parameters which allow for variations within some predefined ranges. This allows for interaction with the user to bring him/her into the decision-making process on variations such as area, height, inclination of the roof, height of the platform, projection dimension, etc., Figure 3.

Structural system. Responsible for the stability of the housing unit. The structure is divided into two independent components to avoid unwanted interactions: roof which determines the upper limit of the housing and a platform which defines the lower limit and the total floor area, Figure 4. It is decided that the structure be fenced to avoid unwanted interactions with the enclosure system. This creates an open floor plan and allows for flexibility in the internal design of the housing unit, Figure 4. Assembly intervention is defined as an intervention strategy of the user based on the prefabricated system of elements whose fabrication and assembly process must take into account that the workforce used is not well-trained. Thusly, the user is made part of the process but the end quality should not be affected.

Exterior and interior enclosure system. This is located between the roof and the floor (container space). It is possible to propose different configurations based on non-structural elements on the plat-
The three user intervention strategies can be applied: for assembly, for fabrication or for modification.

**Mechanical system.** Assembly interaction and modification interaction are defined as user intervention strategies. This implies that the system would be made up of ‘plug-in’ type elements that can be installed, modified, updated complemented, etc., in accordance with the specific needs.

**FABRICATION STAGE**

Each system has an associated parametric model in Grasshopper which allows for fragmentation, Figure 5. The fabrication of each part is done with the available machinery in the Fab-Lab of the Faculty of Architecture and Design at the Universidad de los Andes.

**Structural system.**

- **Roof:**

  Radiata pine lumber and metallic roof as main materials. Tests have been done to scale 1:10 through laser cut. The roof is supported by pre-made shallow foundations in reinforced concrete.

- **Platform:**

  Radiata pine lumber and 9mm OSB sheets as main materials. The platform is made up of lumber cut frames over which OSB sheets are placed. The platform is supported by pre-made shallow foundations in reinforced concrete.

**Exterior and interior enclosure systems.** The enclosure is made up by two layers:

- **Basic enclosure**

  The first layer is a basic enclosure which creates minimal conditions of habitability and allows the unit to be used in the moment of finishing the construction. The material is wood (radiata pine and OSB sheets).

- **Compound enclosure**

  The second layer is an enclosure that is made up of the intangible aspects of the context based on the available materials and technology. In this specific case, an exploration with rock and dirt enclosures was explored. These enclosures are not part of the structure. It is proposed that this enclosure is built by the users.
Mechanical system. At the moment of publication, this mechanical system was under development.

**ASSEMBLY STAGE**

**Structural system.**

- **Roof**

Self-supporting modules are proposed whose geometry guarantees stability, rigidity and facilitates the assembly process, Figure 7. Each self-supporting module is made up of two double-jointed supports, a main beam and secondary beams which make up the surface of the roof. The entire roof system is designed to be moved by a group of between 3 to 6 persons.

Two modules are used in total which are supported by eight shallow foundations, Figure 7. The use of support joints and links allows each module to be assembled on site under a controlled setting.

- **Platform**

Modules with platforms equivalent to two sheets of OSB (2.44m x 2.44m) are proposed. Each module is made up of a framework of beams and small beams in wood on which OSB sheets are placed. Prefabricated shallow foundations in reinforced concrete support the modules.

**Exterior and interior enclosure system.**

- **Basic enclosure**

The basic enclosure is pre-made and ready to assemble. It is made up of panels structured in lumber (pine) and covered in OSB sheets. Depending on the case, each panel is coated on both sides or just on the one.

- **Compound enclosure**

For the compound enclosure, a structure-type furnishing is proposed which would be secured to the exterior enclosure and to the platform and which can be "filled" with local materials. The management and technological specifications to integrate local materials is still under development and testing.

Mechanical system. At the moment of publication, this system was still under development.

**CONCLUSIONS-DISCUSSION.**

This article demonstrates the current development of a research project which proposes the construction of a rural housing prototype (Option One) applying the methodology described here.

Although there are applications or research that may be similar to the work presented here, the specific contribution has to do with its local application. In Colombia, the technology of digital fabrication is slowly entering and applied mainly to rapid prototyping. Up to this moment, there have been no recorded applications to permanent housing projects esc 1:1. This research investigates the possibilities, challenges and difficulties to develop and construct a habitable prototype based on technology related with digital fabrication, available in Colombia.

A great number of the adjustments during the process are due to restrictions with respect to fabrication technology. This has led to adapting manufacturing processes with existing machinery and to think about acquiring new CNC machinery for specific processes.

Even if one of the objectives is to apply digital fabrication technologies, the local conditions in relation to the workforce, materials and construc-
Figure 7
Construction Process
tion technologies cause that within this process local technologies are integrated into the design process. In this way, a final product is obtained in which digital technologies are mixed with more traditional analog technologies.

In some cases, digital technology is applied to optimize or improve the quality of the traditional analog process. This can be seen in the construction of the enclosures, for example.

The use of grasshopper as a means of parametrically modeling has shown itself to be an efficient and feasible strategy. The three stages mentioned in this paper: design, production and assembly have been able to be effectively coordinated and integrated.

The norms developed and the methodology used have furthermore allowed for interaction with the user and to be able to make modifications in real time responding to their needs. The improvement in issues related with user interface and interaction are the objective of further stages in the research.

The structural system has shown itself to be stable and feasible for construction with self-supporting modules, with a construction system that does not require a great deal of training nor is it extremely complex. Tests have been carried out and it is feasible to construct the pieces esc 1:1, ready to assemble.

The proposed enclosure system allows for defining and integrating intangible aspects. The preliminary tests have shown that local materials can be integrated without compromising the structure. In accordance with the availability of resources, the users can complete and personalize their houses.

The housing unit should be constructed and occupied near the end of 2015.

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