

Option One-second Iteration

Analysis, evaluation and redesign of a rural housing prototype

Diego Alejandro Velandia Rayo¹

¹Universidad de los Andes, Bogotá, Colombia.

¹dvelandi@uniandes.edu.co

In 2005, the rural housing deficit in Colombia was 1,600,000 units, which is equivalent to 68.25% of the total households. This very high number shows the difficulties faced by public policies on rural housing. This deficit is partly due to logistical problems related to the supply of materials and complexity in construction processes. It is necessary to explore new alternatives to offer more and better homes at lower costs. The research project presented in this manuscript started in 2013 as an initiative to reduce the housing deficit. It proposed to build a rural housing prototype integrating digital manufacturing processes. The performance of part of the structural and enclosing system was evaluated during a first iteration process to include changes in a second iteration later. With the adjustments to the design process discussed here, the prototype is expected to be built and tested to measure its efficiency and functioning.

INTRODUCTION

Public policies on rural housing in Colombia face complex difficulties due to very high housing deficits. For example, in 2005, the rural housing deficit was equivalent to 1,600,000 units, (68.25% of the total number of households). The main reasons are linked to logistical problems related to the supply of materials and complexity in some construction processes (Simioni 2007). This highlights the need to explore new alternatives and technological possibilities to produce more and better rural housing at lower costs (Ottokar 1997).

The present research project, which started in 2013, aimed to build a rural housing prototype integrating digital manufacturing processes. This process comprises different stages and principles, which have been modified and refined through iterations. A first prototype was initially consolidated and built (Velandia 2015). Its monitoring, analysis and eval-

uation allowed further adjustments to improve efficiency and performance during a second iteration.

The structural and enclosure components of the prototype were designed and the mechanical system is in the process of definition and consolidation. The entire prototype is expected to be built in the near future to be lived in and tested by a family.

INTEGRATED DESIGN PROCESS

This work suggests an integrated design and production process, which goes beyond a single housing prototype by exploring the potential of digital manufacturing, exposed in previous literature (Barrow 2006). One of the main objectives of the process is to allow variations, from the definition and integration of dynamic parameters, which can be adjusted according to specific conditions, generating different options in the final result (Duarte 2001).

In this context, four design principles were used

as the theoretical framework for the integrated design process of the rural housing prototype. These, among other aspects, allowed different actors to be involved in the definition of dynamic parameters (e.g. according to the conditions of each user, context and materiality) and manage the different stages of design, manufacture and assembly.

The four principles were:

1. Definition of a context, population or environment: These definitions should not be either too specific (as there are very few opportunities to replicate the methodology) or too general (as there is not a single answer that solves all the problems). This stage implies the recognition of possible local technologies and materials, climatic or geographical aspects.
2. Integration of the design, manufacturing and assembly stages: The CAD / CAM tools are fundamental at this stage. It is argued that the elements and prefabricated systems are the primary strategies, to guarantee quality, precision, control in the execution, stability and habitability of the house (Ulrich 2012).
3. Community inclusion and empowerment

during the process: Tangible and intangible aspects must be recognised and linked to the integrated design process. This implies the analysis of relevant cultural, social, economic and traditional aspects, which could be integrated into the home. It also implies the identification of local materials and technologies that can be used. The community should be involved through training processes to understand and apply the technologies to be used in the construction and manufacture of the houses. This could improve their skills, abilities and knowledge and also improve the socio-economic conditions of the community.

4. Definition of a strategy and scope for user participation. It is aimed that the house users could be directly involved during its construction. Therefore, the user participation strategy must be as clear and as simple as possible. The final objective should be to guarantee the construction quality, despite the qualification of the available workforce.

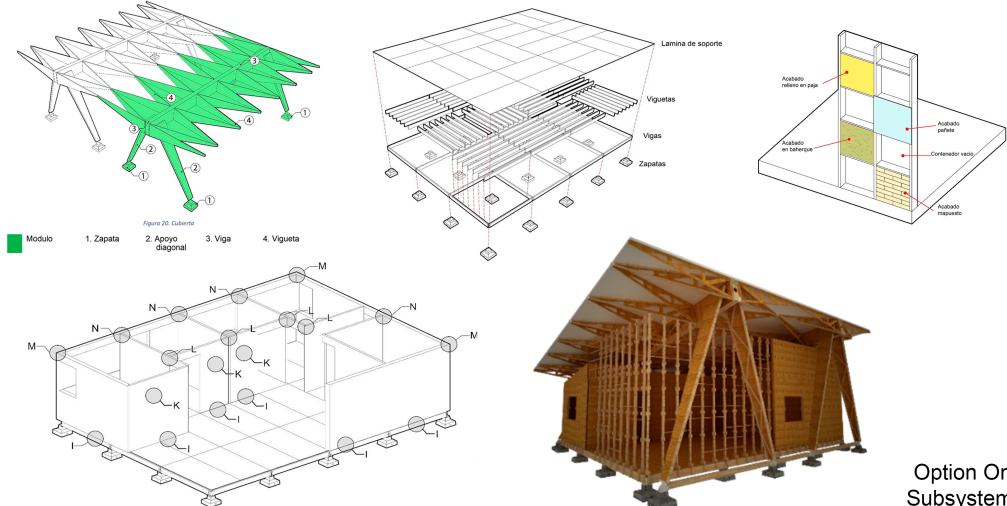


Figure 1
Option One.
Subsystems

OPTION ONE: THE FIRST ITERATION

A prototype of rural housing was proposed in past research by applying the four design principles mentioned above, divided into four subsystems: roof, base, enclosure and mechanical system (Rush 1986). Each system works independently allowing greater flexibility and the possibility of future adjustments and modifications, similarly to the user participation strategy (Velandia 2015). For the present project, it was decided to use timber (pine and OSB boards) as the primary material for the structural and enclosing system. All components were manufactured using a CNC router. The general system is complemented by steel joints to assemble the different elements and components.

The fundamental characteristics of each subsystem were:

Roofing:

- It consisted of two self-supporting modules. A total of 8 supports were used..
- 9m long main beams and 2.6m long joists.
- A prefabricated, reinforced-concrete slab-foundation.
- Steel joints system for wood-wood and concrete-wood assemblies.
- Pine , OSB boards and steel were the predominant materials.

Enclosure:

Base:

- It comprises a sandwich type system, with a central core onto which different finishes can be attached. The core consists of a structure and enclosure in pine and OSB boards. The final coating is a composite enclosure, which is fabricated using local materials.
 - A mechanical joint between the enclosure system and the base is proposed, to allow and facilitate the elements' change or modification (spatial flexibility).
 - It was decided to use connectors different to nails or screws, as these may be unavailable in remote areas.
 - The primary materials were pine and OSB boards
- The base was structurally separated from the roof to increase the degree of spatial flexibility. The total initial base area was 72 m2.
 - The base was proposed as a modular system, which could be extended in the future by the addition of modules.
 - 2.40 m long beams and joists to match the OSB board size.
 - Prefabricated, reinforced-concrete slab-foundation.
 - Steel joints system for wood-wood and concrete-wood assemblies.

Figure 2
Option One.
Second iteration.
Construction
process



Option One
Construction process



Figure 3
Students group

- Mechanical joints to link to the enclosure system.

Mechanical system:

- Elements and components designed to be attached after the construction of the base and enclosure.
- Modular elements that allow updates and modifications.

FIRST ITERATION: ANALYSIS AND EVALUATION

The first approach to the manufacture and assembly of the prototype showed different essential aspects for the re-evaluating and improvement during a second iteration. One of the conditions to be verified and evaluated was that a group of 4 to 6 people could assemble the prototype without the need for specialised machinery or tools.

The analysis and learnings from the first approach could be summarised as follows:

- The foundation used was very heavy, which

made it challenging to move elements from one site to another. It was necessary to decrease the final weight of the foundation components and to think about a transportation strategy.

- Many of the steel joints significantly increased the weight of the components, making them difficult to handle, transport and assemble. An interdisciplinary effort was necessary to re-design and optimise the joint system of the entire prototype.
- Some joints presented precision and constructive stability problems, when added after the prefabrication process (e.g. perforations or screw fixing). It was necessary to define the location of additional elements more accurately to avoid problems of precision and technical coordination.
- The 9m long beams for the roof were challenging to assemble. The main beam was very heavy. The beam supports located at 4.5 m above the floor were also complex to assemble due to excessive weight. It was necessary to modify the dimensions of the larger ele-

Figure 4
Enclosure system



ments to reduce their weight and make them easier to manipulate.

- Eliminating the use of screws was an initial goal. However, it was necessary to use them in different elements and components of the prototype. One of the future objectives is to continue developing fastening systems other than screws or nails.

Figure 5
Option one.
Foundation system.



First
iteration

Second
iteration

Option One
Foundation system

OPTION ONE: SECOND ITERATION

The second iteration of the housing prototype began by making adjustments within the integrated design

process, based on the analysis and learning from the first iteration.

The adjustments made were:

- In order to reduce the length and weight of the elements, the total area of the base was reduced from 72 m² to 48 m².
- The roof beams were reduced from 9 m to 6 m in length.
- The height of the beams' supports for the roof was reduced by 1.5 m.
- The foundation was redesigned to reduce weight, integrate elements to facilitate the transport of the main components and an additional joint to assemble the foundation with both the roof and the base systems.
- The heavier joints were redesigned to reduce weight and facilitate their handling and assembly.
- The use of screws as a joining system was reduced to the minimum.

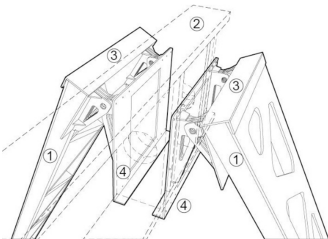
Once the prototype was adjusted, the new elements were fabricated, and the assembly and assembly process was defined. Due to resources and time restrictions, it was decided to build only one of the roof-system modules, and half of the base system, as well as the assembling elements for one of the enclosure-system modules.

The construction of the prototype was included as part of an academic exercise at the University in the summer of 2018. A team of approximately ten

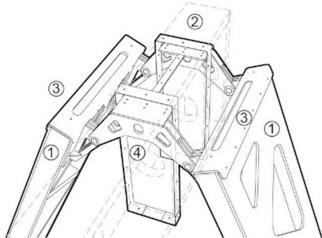
people (between teachers and students) with no previous experience or training in construction was involved in this exercise.



Option One
Metal joints system



Option One
Structural joint



First
iteration

Second
iteration

SECOND ITERATION: ANALYSIS AND EVALUATION

The construction of the roof, base and enclosure was carried out successfully. The total effective construc-

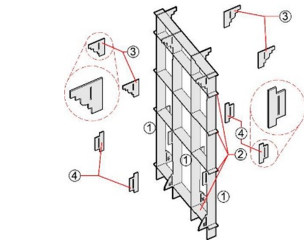
tion time was 10 hours (having all the prefabricated elements ready). The fabrication and assembly of the second iteration of the housing prototype allowed the identification of some positive aspects and other aspects to be reviewed.

Positive aspects:

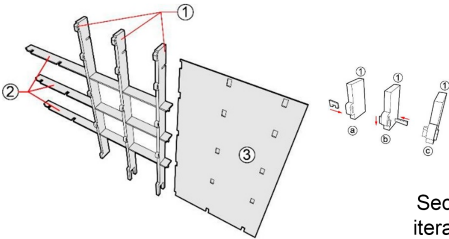
- The process of prefabrication of elements was successful. It was not necessary to modify or elaborate on new elements. In general, the construction system was efficient.
- The manipulation of the individual elements and components did not present significant difficulties. This showed that the adjustments in terms of dimensions and weight of the elements were appropriate.
- The performance of the steel joints was good, except for some particular cases, where they were still very heavy or difficult to assemble.
- The students (unskilled labour) experienced a fast learning curve regarding the manufacturing and assembly process. This evidenced the importance of including this aspect from the early stages of the design.

Figure 6
Steel joints system

Figure 7
Option One.
Structural joint.



Option One
Enclosure system



First
iteration

Second
iteration

Figure 8
Option One.
Enclosure system.

Figure 9
Final Result



- The modules of the enclosure system performed well in terms of their manufacturing and connection to the base. No screws or nails were used.
- The articulated joints that linked the roof support to the foundation displayed excellent performance, facilitating the manipulation and assembly of the structural modules.

Aspects to review:

- The modifications made allowed to reduce the weight of some elements and components considerably. However, the handling of some of them, especially the roofing components, presented difficulties. This implies the need to rethink the elements of the structure and the construction systems in order to make them lighter and more comfortable to manipulate. In this area, new and more efficient alternatives must be sought for the beams and supports of the roof modules.
- Although in this second iteration, the weight of the steel joints was reduced, it is important to continue developing lighter and more effi-

cient joints, to avoid the use of screws as much as possible.

Pending issues:

- It is expected to build the whole prototype in the near future.
- It is expected to define a specific context for the location of the prototype, in order to integrate local materials, particularly for the enclosure system.
- It is necessary to integrate the development and production of the mechanical system into the prototype.

DISCUSSION

It has been demonstrated so far that an integrated digital manufacturing process applied to rural housing is viable, combining technical-constructive variables, context variables, and user variables.

The second iteration - as part of a continuous process of evaluation and learning - also showed a wide margin of optimisation and improvement in performance, which the housing prototype can have.

The time used for the prototype's assembly during the second iteration (10 hours), exceeded the initial expectations, validating the decisions regarding the design of elements and joints.

Additionally, the process showed that unskilled labour could be involved, without affecting the final quality of the product.

All of the above suggests that a rural housing prototype with the characteristics shown here is viable and applicable to the Colombian context, with the currently available technology.

However, further development is necessary regarding technical aspects (e.g. the mechanical system) and financial aspects to allow an integral evaluation of the economic viability of this type of technology for a rural environment. A fundamental step for this is to have the prototype built in its entirety, which is expected to happen at the end of 2019. This will help to evaluate the integrated digital manufacturing process and the overall performance of the construction.

REFERENCES

- Barrow, L 2006 'Performance House: A CAD/CAM Modular House System, Synthetic Landscapes', *Proceedings of the 25th Annual Conference of the Association for Computer-Aided Design in Architecture*, Louisville, Kentucky, pp. 104-121
- Duarte, J 2001, *Customizing mass housing: A discursive grammar for Siza's. Malagueira houses*, Ph.D. Thesis, Massachusetts Institute of Technology
- Knaack, U and Chung-Klatte, S 2012, *Prefabricated systems: principles of construction*, Birkhäuser Architecture
- Kolarevic, B 2005, *Architecture in the digital age: Design and manufacturing*, Taylor & Francis
- Marcuse, P 1992, 'Why conventional self-help projects won't work', in Mathey, K (eds) 1992, *Beyond self-help housing*, Mansell, London, pp. 15-22
- Meijs, M and Knaack, U 2009, *Components and connections: principles of construction*, Birkhäuser Architecture
- Ottokar, U 1992, 'Computers, participation and self-help housing', in Mathey, K (eds) 1992, *Beyond self-help housing*, Mansell, London, pp. 269-282
- Rush, R 1986, *The building systems integration handbook*,

Wiley

- Simioni, D and Szalachman, R 2007, *Primera evaluación del programa regional de vivienda social y asentamientos humanos para América Latina y el Caribe*, CEPAL, Santiago de Chile
- Velandia, D. 2015 'Option One: A model of participatory design to construct a rural social housing from digital fabrication', *Proceedings of the 33rd International Conference on Education and Research in Computer Aided Architectural Design in Europe*, Vienna, pp. 531-539