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LOW-COST SUSTAINABLE TIMBER FRAMED DISMOUNTABLE MODULAR HOUSES: CONCEPT & DESIGN GUIDELINES

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Considering the current situation of the housing deficit, its continuous geographic variability, and the sustainable exploitation of forests in Latin America, sustainable construction can meet low-cost housing needs through the use of self-built houses, with special reference to wooden houses. Based on Leonardo's self-supporting bridge, a model of a quality self-built house was developed to highlight some guidelines for simple production assortments, easy transportation, and smooth assembly processes. Environmental sustainability was reinforced by the use of wood from renewable forests as the predominant material and by the extended-life design, which offers the possibility of disassembling and reusing major building components for a portable and "evolving" house whose volume expands and shrinks over time according to the needs and financial resources of the people living in it. The deconstructable wood building system can then become an effective response to support social policies that involve local communities in sustainable development and participatory construction as tools for achieving adequate quality housing at affordable financial and environmental costs, promoting a sustainable way of living based on mutualism and cooperation.

Keywords: Housing deficit, Self-building, Incremental/evolving house, Sustainable forestry exploitation, Leonardo's self-supporting bridge.

1 INTRODUCTION

The housing deficit problem in Argentina and Latin America is an aspect associated with poverty.

Argentina does not escape the global problem of the housing deficit, as a result of population growth and urbanization. In the northern and coastal provinces of Argentina, which include the provinces of Chaco and Formosa, the housing deficit situation is further aggravated, mainly due to two issues: on the one hand, the northern provinces are among those with the lowest socio-economic indicators (income below the national average, etc.), and on the other hand, there is the problem of flooding (provinces bordered by rivers that cause flooded on unprotected areas), which is aggravated by global warming and climate change (increased precipitation and average temperature).

The northern region of Argentina has the worst rates of housing deficits in the country. In return it has the largest forest volume (native and implanted) but this resource is not perceived as a building material. For this reason, low-cost dismountable wood houses could represent a new benchmark towards a sustainable development of the forest resource, poverty reduction, to increase

employment and generate local labor, by manufacturing wood elements for construction, and substituting products imported from other regions (e.g., cement and steel).

2 SUSTAINABLE TIMBER PRODUCTION CHAIN FOR BUILDING

2.1 Wooden Houses

Latin America contains valuable forest resources, which contributes in a vital way to the development and the well-being of society, considering either from the ecological point of view or from the socioeconomic point of view even if in some cases (e.g., Paraguay and Chaco) in the last three decades the area of productive forests has declined due to the conversion of the forest land to pastures for livestock and with the aggravating factor of creating an ecosystem of greater fragility (Gasparri 2009). Rethinking the timber building component production can locally promote the sustainable development of wood industrial exploitation.

On the one hand, it should be mentioned that, due to cultural factors, timber construction is nowadays considered of lower quality than concrete and brick construction in Argentina. This assumption is based on negative experiences that construction companies have carried out in the past, building prefabricated timber houses of very low quality, mainly due to the lack of knowledge of proper construction techniques with this material (Bottan and Eguren 1996).

On the other hand, wood houses are the traditional *vivienda rural* that is typical of the northern subtropical region of Argentina. The so-called *casa rural* was born in close contact with the territory and its climate, so much that home is a simple shelter from bad weather and only destined for basic functions such as sleeping, cooking, and even giving refuge to domestic animals. As a result, the *vivienda* has no definite boundaries, there is no clear or fixed separation between inside and outside, and it is not even possible to "crystallize" certain functions within it.

Rethinking the traditional self-built wooden house and how we can adapt to today's mobility problem could be a sustainable answer to housing needs and manage the psychological gap between a generic low-cost house and "my house", which is a real cognitive bias (Blasi 2018).

2.2 Transportation

A simple and modular self-build system is designed to be feasibly mountable by inexperienced builders and also needs to have easily transportable and manageable components packaging, especially for off-the-grid constructions.

Concerning the sustainability of the whole building process, storage and transportation costs can be significantly reduced by the use of space-efficient flat-packs for building components, together with their modularity and easy-to-handle size. In fact, the flat-pack concept in based on transportation of large amount of products with a minimum volume without compromising their thickness, thus reducing the damage risk during transportation process, even when using small vans or other makeshift means of transportation.

Nowadays the flat-pack philosophy is getting a great response in ready-to-assemble furniture supply chain (Dowdy 2020), which is mainly based on some key performance like lightness, quickness, accuracy (precision, clarity and linearity in the conception of the component and its package) and multiplicity (simplicity in assembly allows interchangeable workers during assembly).

The transposition of these key elements to the wooden building components supply chain for self-build systems can provide the same benefits, in order to achieve a high level of quick and easy assembly, which is a key feature for a really feasible self-construction and also subsequent demountable, portable and relocatable operations.

More importantly, flat-packed small building components is the safest way to transport them to construction sites, especially with the use of small vans or makeshift vehicles, that could be quite common in Latin America disadvantaged contexts (Figure 1).

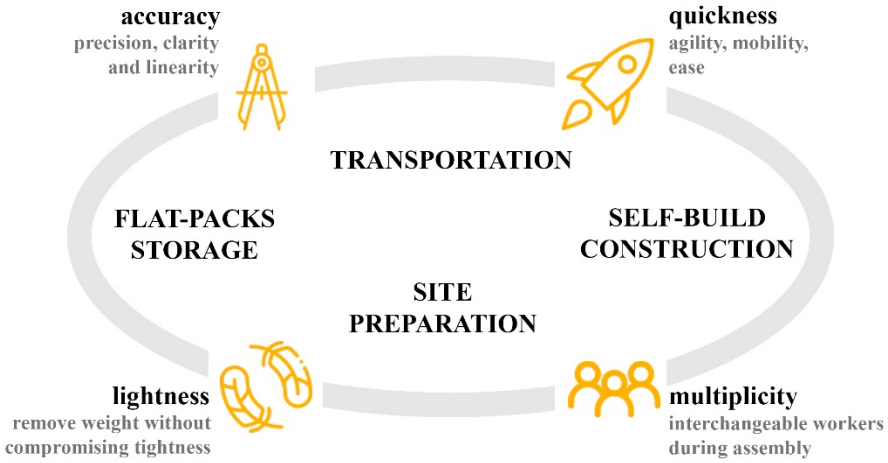

Figure 1. Flat-packed building components supply chain and key elements for a feasible self-building timber house.

3 GUIDELINES FOR A SELF BUILDING TIMBER HOUSE

3.1 Design Criteria

Designing for self-building requires special attention to the needs of the user not only as an inhabitant, but also as a builder and a manager. As a builder, on the one hand, the user must be able to actively participate despite inexperience. Therefore, the entire process must be simplified by using small and lightweight components, preferring easy and repetitive operations and reducing the need for construction equipment. As a manager, on the other hand, the user must be able to control the resources and how they are employed. Therefore, the project must be flexible and adaptable according to changing needs and economic affordability. Based on these criteria, the following will describe the initial results of a research that aims to provide a technological solution for self-building.

The proposal has been inspired by the self-supporting bridge designed by Leonardo da Vinci (Bernardoni *et al.* 2005). Often used for educational purposes, thanks to its constructive and structural simplicity, the self-supporting bridge is known as one of the best examples to describe the principle of reciprocal frames. A reciprocal frame is defined as a configuration of elements that support each other in order to achieve a span greater than the length of its individual elements. Adopting this principle can be particularly useful for self-construction because it enables to reduce the size and weight of structural elements, making it easier to transport and handle components on site.

3.2 Structural Concept

The structure, following the idea of Leonardo's bridge, is conceived as a succession of timber arches composed of longitudinal beams and connected by cross beams. Below each arch, two timber columns are placed in order to provide more stability. Longitudinal beams are modular elements that have the same shape and size, except for the ends, which, however, are made by

cutting a modular element into two equal parts. The modularity of the scheme has the advantage of reducing production costs, as well as simplifying material storage and site operations. The ideal solution is reached when the beams have a module of 3 meters. Different sizes can also be adopted, but variations in net interior height must be taken into account.

Three rows of longitudinal beams are placed side by side to form an arch. The central row is staggered by half a module from the other two, so that the parallel beams can be mutually constrained. Parallel beams are fixed together with bolted joints that are located at one third and two thirds of their length.

Foundations consist of two cast-in-place concrete beams that can be imagined as "rails" on which the arches can be moved in order to avoid tolerance issues. As for the columns, since they are not part of the main structure, they can be fixed on low-impact foundations (for example, scrap tires filled with compressed gravel are used as foundations in some ecological buildings). After pouring the concrete, each arch is assembled on the ground, then lifted and brought into position along foundation "rails". Once erected, the first arch is held in place with struts into the ground, while the others are fixed to each other by bolting the cross beams (Figure 2).

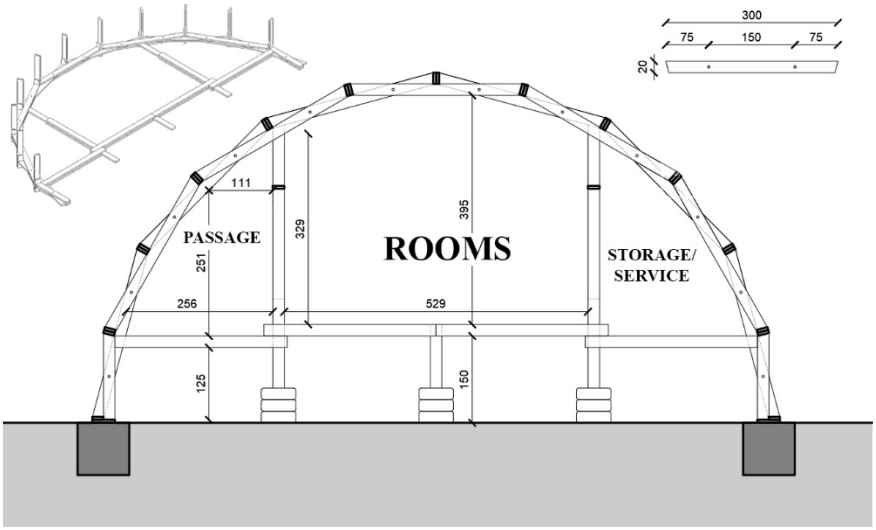

Figure 2. Center: cross section of the structure highlighting a possible separation in three functional areas; top right: beam module; top left: 3D model of the first arch as mounted on the ground before lifting.

3.3 Layout

The two rows of columns, in addition to providing more stability, are useful for separating the house into three functional areas. The one in the middle is the most suitable for the rooms, considering its shape and size. As for the side areas, one serves as a passage and the other for storage and service areas (Figure 2). Thinking of it in an ecological way, it is possible to use the passage as a greenhouse, facing towards the sun, and the other area as a thermal storage, filling it with thermal mass materials (Figure 3). This scheme, which is similar to the one of an earthship, can be adopted to provide passive solar heating and cooling, taking advantage of the angle offered by the shape of the structure (Figure 4). Thinking even further, it is possible for the inhabitants to use the greenhouse as a vegetable garden and produce food for themselves. Beside these ones, other passive design strategies can be applied depending on local conditions.

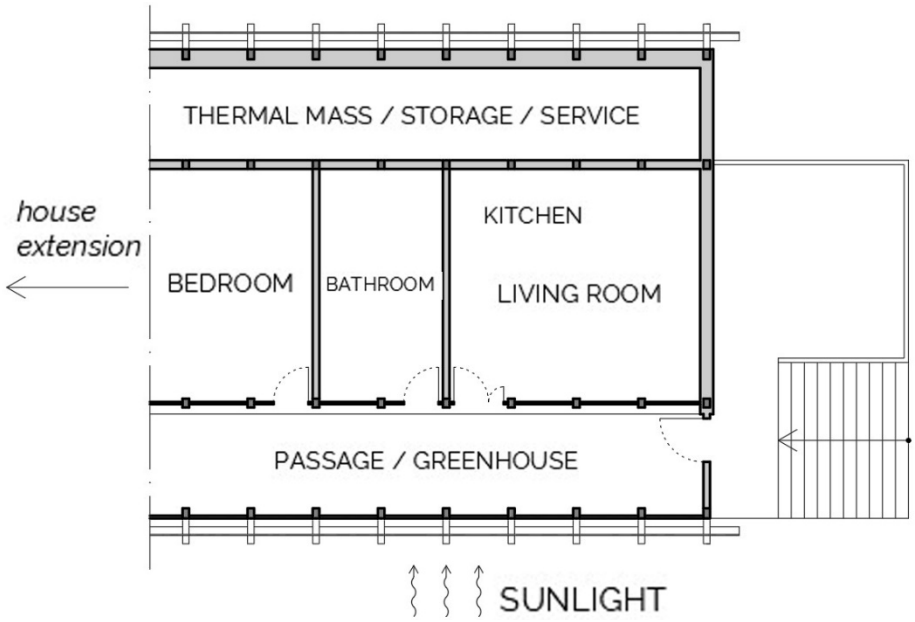

Figure 3. Model floor plan, with a possible distribution of rooms by adopting passive design strategies.

Figure 4. Passage used as a greenhouse within an earthship (Urbannext.net, 2022)

Apart from this functional scheme, somehow forced by the structure, the project is not intended to define any internal distribution of spaces. It is a purpose of self-building approach to let people decide how to organize their own place. As proposed by the Dutch architect Nicolaas John Habraken in 1962, the idea is to separate the "support", provided by the designer, from the "infill", left to the free expression of the inhabitant. In this way, the house works as an open system, being

always subject to change according to the needs of the users. This is not only true in terms of internal variations, but also in terms of external extensions.

4 CONCLUSIONS

The shape of the structure allows what is called "incremental housing": by adding one or more arches, it is possible to get other rooms whenever they are needed.

"Incremental housing" also relates to an economic matter, because it enables people to distribute financial investments over time. More than that, this kind of building makes those investments reliable. With the only exception of foundations, the system is easily demountable and transportable elsewhere due to dry assembly and the small size of the elements. This means that in case of relocation the house can be moved without the need to be resold on site, where the price could not be adequate for the original resource commitment.

Timber deconstructable building system could be an effective response to support social policies that involves local communities in sustainable development and in participatory construction as tools for appropriate quality housings at affordable financial and environmental costs, promoting a sustainable way of living based on mutualism and cooperation, and even a self-construction process. In recent years the National Government has been promoting wood construction to reduce the housing deficit, and different tangible acts have been carried out, such as the approval of the Argentine Regulation on timber structures (CIRSOC 2016) and its *Suplementos* (CIRSOC 2020) or subsidies to entrepreneurs in the forestry industry: a technological shift about timber construction towards prefabricated compliant wooden elements for self-buildings is at hand.

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