

Modular temporary housing for situations of humanitarian catastrophe

Juan Pérez-Valcárcel (a), Santiago Muñiz (b), Emilio Mosquera (c), Manuel Freire-Tellado (d), Jorge Aragón (e), Alberto Corral (f)

ABSTRACT

The search for architectural solutions for emergency situations is an important line of research. In this article, the most appropriate conditions for the different situations that can turn up after a disaster will be analyzed and proposals for temporary housing will be presented. These are possibly the most suitable solutions for developed countries. The design and calculation of an experimental wooden module, built at the University School of Architecture in A Coruña, which has served as a prototype to analyse its viability in practice, will also be presented. Finally, there will be a critical review of the results and possible improvements detected.

Keywords: Shelters; temporary housing; post-disaster housing; modular building; parametric design; sustainability.

(a) Dr. Architect. Full professor. ETS Arquitectura, A Coruna (Spain). ORCID: 0000-0002-6440-5432

(b) Dr. Architect. Professor. ETS Arquitectura, A Coruna (Spain). ORCID: 0000-0002-2687-1010

(c) Dr. Building Engineer. Professor. EU Arquitectura Técnica, A Coruna (Spain). ORCID: 0000-0002-6417-2114

(d) Dr. Architect. Professor. ETS Arquitectura, A Coruna (Spain). ORCID: 0000-0002-8101-0088

(e) Dr. Architect. Professor. ETS Arquitectura, A Coruna (Spain). ORCID: 0000-0002-3699-2852

(f) Architect. Ubuild Company (Spain). ORCID: 0000-0003-3498-9462

Corresponding author: valcarce@udc.es (Juan Pérez-Valcárcel) ORCID: <http://orcid.org/0000-0002-6440-5432>

Publicado en:

Pérez-Valcárcel, J., Muñiz, S., Mosquera, E., Freire-Tellado, M., Aragón, J., & Corral, A. (2021). Modular Temporary Housing for Situations of Humanitarian Catastrophe. *Journal of Architectural Engineering*, 27(2), 05021004. [https://doi.org/10.1061/\(ASCE\)AE.1943-5568.0000471](https://doi.org/10.1061/(ASCE)AE.1943-5568.0000471)

© ASCE: American Society of Civil Engineers.

1. INTRODUCTION.

The question of temporary housing which can be used in the aftermath of a disaster is a subject of extensive debate. The effects of climate change have increased awareness of the issue and drawn attention to the need to take mitigation measures in the face of possible disasters. Many proposals have been made, including those of Shigeru Ban, winner of the 2014 Pritzker Prize (Jodidio, 2015). Complete studies on the state of the art have also been carried out (Felix, Branco, Feio, 2013). Similarly, various international organizations such as UNHCR (United Nations High Commissioner for Refugees) or SPHERE (Sphere, 2018) have developed important work to define the minimum conditions that proposals must meet in order to be effectively implemented. The Sphere Project establishes a set of universal minimum standards, the result of the collective experience of many international organizations. Their criteria have been taken into account in the design bases of the proposals. This article presents a solution based on the principles of sustainability, constructive effectiveness and energy efficiency, which is intended to be a useful proposal.

Natural disasters are a major social concern around the world. Floods and mudslides, hurricanes or earthquakes can kill large numbers of people at any time and in any place, leaving survivors in highly vulnerable situations. According to available statistics, a total of 850 natural disasters occurred in 2018, with losses of 12,800 lives and damage amounting to \$140 billion. In addition, 289,300 victims of various wars and a total of 16.2 million displaced persons were affected in the same year. In these conditions, the need to develop valid solutions to help all these people is of the utmost importance. One of the most necessary aspects is the design of architectural solutions to house these groups and provide them with the necessary services. Housing as a shelter is a basic need so that family life can be developed with comfort, protection and privacy. After a disaster, it is necessary to resolve the housing issue immediately, because the loss of housing means much more than a material loss: it entails a loss of dignity, identity and privacy (Barakat, 2003).

Housing for emergency situations need to have specific features that make them useful for solving the problems that arise. Firstly, they need to be transportable, since existing permanent buildings are assumed to have been destroyed or damaged. For transport to be easy and economical, the building needs to be as light and compact as possible. All this must be compatible with the need for large enclosures that can serve the affected population.

The situation after a disaster is often chaotic. Infrastructures are often destroyed and there are urgent and pressing needs. In addition, the scale of the problem often exceeds expectations, leading to hasty solutions. This is why solutions are frequently more feasible than adequate (Davidson et al. 2007; Davidson, Lizarralde and Johnson, 2008). The psychological effects of excessively rigid and dehumanized solutions, such as containers, have also been described (Caia, Ventimiglia, Maass, 2010). It is therefore necessary to make design provisions before the disaster and not when the situation can no longer be remedied, and to consider other factors than purely utilitarian ones.

Furthermore, the solutions proposed have often been designed with excessively generalist criteria without taking into account the specific conditions of each situation (Aquilino, 2010; Muñoz, 2017). Therefore, on many occasions they may be valid short-term solutions, but not particularly suitable for situations that persist over time (Barakat, 2003; Twigg, 2006). Moreover, these solutions can even be a source of social conflict if they do not take into account the cultural conditions of those affected. The case of "La Virgencica" social housing in Vallejo Acevedo, built to house the victims of the floods in the Sacromonte region of Granada (Spain) in 1962, is very significant. Sacromonte is a neighbourhood inhabited for the most part by a gypsy population, with typical cave dwellings. The solutions based on criteria of modern architecture were totally alien to the gypsy culture at that time. Despite having won an international architectural competition, it had to be demolished in 1982 after the model of coexistence failed spectacularly and it became the most conflictive neighbourhood in the city (García Lozano, 2016). This situation has been repeated on several occasions, such as in what is known as the "Jungle of Calais" in which an intervention by the French government in January 2016 had to be dismantled in February. Or the case of temporary accommodation after the earthquakes in L'Aquila (Italy) or Lorca (Spain) where there are still groups that have not been able to return to their normal lives.

Disaster solutions are usually considered in two phases. First, it is necessary to provide those who have been affected with immediate shelter. In this first phase the textile tent or systems based on it are quick, economical and easily assembled solutions that are unbeatable (Ros García, Sanglier Contreras, 2017). Its main disadvantage is its poor quality and low durability. It has been found in

several refugee camps that textile tents with a projected durability of one year, barely exceeded six months (Muniz, 2017). It is then necessary to provide more durable solutions, since it is very likely that the affected populations will have to remain in a precarious situation for a certain period of time. Until a permanent solution is possible, it is necessary to provide temporary housing with adequate standards of comfort and security. It is also highly desirable that this housing can be deconstructed and reused when it is no longer needed because it has been replaced by permanent solutions.

The definition and benefits of temporary housing are not simple, nor is there unanimous agreement among specialists. According to the definition provided by UNDR0 (1982), there are eight types of post-disaster shelters, including a specific section for temporary housing.

Our team is currently working on a research project titled "CODEMOSCH: Construcciones Desplegables y Modulares para Situaciones de Catástrofe Humanitaria" (Expandable and modular constructions for humanitarian disasters) to analyse possible solutions for emergency situations in developed countries (Pérez-Valcárcel et al. 2016). Two types of solutions have been considered: modular housing for family accommodation and deployable structures for community facilities, as they are the most appropriate solutions for these functions.

This paper deals with modular buildings, and specifically with modular timber systems. For this purpose, the UBUILD system (Corral, 2108) has been used, which allows for very precise construction by elements in such a way that their assembly on site is very simple and high quality. In order to avoid the above-mentioned problems, it has been designed as an answer to the needs of accommodation in disaster situations in a European environment. Due to its simplicity, it could be adapted to other standards, but it has been specifically conceived for this environment. On the other hand, UBUILD allows for a very highly automated process, drastically reducing the time between BIM design processes, by connecting them directly to a digital CNC manufacturing process.

2. POST-DISASTER TEMPORARY HOUSING

2.1. General aspects

First of all, it is necessary to classify the housing solutions that can be provided in the event of a disaster, in order to focus the scope of the proposal. The last widely used classification is that of Quarantelli, which defines four solutions, although according to the definition provided by UNDR0 (1982), there are eight types. For the purposes of this paper, the Quarantelli classification is considered more appropriate. These types can be adjusted to possible stages in post-disaster reconstruction (Quarantelli, 1995). The project SPHERE have included them in your manual (2018):

1. Emergency shelter: a place where a family stays at the site of the emergency. This may be a public facility or the home of a friend or family member. The provision of food or services is resolved in a community setting.
2. Temporary shelter: a place where a family stays immediately after a disaster and for a short period of time. It can be a tent, a self-built shelter, a public facility, the home of family or friends, or a second home. Depending on the duration of the stay, forms of food supply and other services, especially medical services, will be determined.
3. Temporary housing: a place where a family resides temporarily, for a mid-time and resumes its domestic and, if necessary, work activities. It can be a temporary prefabricated house, a winter tent, a self-built shelter, a mobile home, an apartment or the home of a family member or friend.
4. Permanent housing: the place where a family will reside definitively after the disaster. This refers to the family returning to their rebuilt home or moving into new permanent housing in their own community or a new community.

The issue has attracted the attention of international agencies such as the UN Refugee Agency, UNHCR (United Nations High Commissioner for Refugees), International Federation of Red Cross and Red Crescent Societies, IFRC and OCHA, national agencies such as FEMA and also NGOs such as Shelter Centre or Oxfam International, which have developed a wide range of response manuals.

In these manuals, the accommodation solution after a disaster is categorised according to the time that has elapsed since the event. The IRC Shelter after Disaster manual simplifies to three-phase strategy (emergency shelter, transitional shelter and permanent housing) and a two-phase strategy (extended emergency shelter and transitional-definite housing), establishing differentiated strategies and solutions for each phase.

In developing countries, prefabricated construction has not always been considered a main option when responding to an emergency. The reasons are in the high cost of manufacturing and transportation, delay in delivery time or difficulties in assembly due to lack of technology and knowledge. These reasons, which are true in those countries, are often extrapolated to developed countries with sufficient technological resources. It is clear that sometimes housing solutions poorly adapted to the host population have been abused, or even the adoption of modules not initially thought of as transitional housing (Muñiz, 2017). But that does not disable these types of solutions, it simply forces a careful design that takes into account other sociological factors.

The evolution of the construction systems of this type of construction has made prefabrication no longer only an option for temporary and emergency housing, but that it is being used at this time as an option to take into account, even for permanent housing with high performances. There are projects such as "Healthy housing for displaced people", from the University of Bath, which are studying this problem from this new perspective (Klansek, 2020).

Most of recent proposals that have been developed fall within the scope of temporary or transitional sheltering, according to the criteria used. The reversibility of the process has been considered nowadays an aspect of interest (Bologna, 2004). In many cases, temporary housing is used for long periods of time, which may exceed its useful life, although this is not its function. They should only be used for the time necessary to be replaced by permanent housing. In this case, they should be easily removed, stored and, if necessary, reused. This will be one of the objectives of this research.

2.2. Implantation solutions for housing modules.

The vast majority of the proposals for transitional housing developed are for family housing. Military barrack-type residence models have also been proposed that are easily transferable to single person situations following a humanitarian disaster. Organizations such as Sphera have highlighted the need for a detailed analysis of the type of occupants for whom this type of shelter is intended.

It should be noted that the housing proposals condition the type of grouping that can be made with them: it is clear that proposals with openings (doors or windows) on all sides require isolated installations, and that the dwellings can only be grouped if their geometry allows it and if there are no openings on the sides intended for contact. The revision of the models proposed previously from this perspective makes it clear that most of them are conceived as isolated elements, although there had been designs whose composition would allow for arrangements in pairs and rows, with the expected improvements in terms of their thermal conditioning, safety and reduced land occupation.

Despite the small housing space allocated (3.5 - 4.5 m²/inhabitant), the Sphere Project standards for field layout indicate an area of 45 m² per inhabitant, which implies a density of 222 hab/Ha (which for a family composition of 5 members gives - 44 dwellings/Ha). This is an intermediate density, which implies a high land occupation, and therefore, with reduced free space.

It is clear that the same density can be achieved with different forms of occupation, but the type of building used conditions the resulting perceived density -the environmental quality or its inverse, the perceived crowding level (Bedoya, 2004). In this sense, the proposed density, without being excessive, is not very suitable for addressing with single-storey solutions (Hany Abulnour, A. 2013). Perhaps for this reason it is possible to try to increase density with less land occupation—an interesting objective given the problems of available land in Europe and Japan—with proposals for grouped prefabricated dwellings on several floors. There are interesting proposals in Turkey (Modular and Mobile Solutions), in the Netherlands (Spacebox, G+2, Cocon B.V.), Germany (Fagus, Procontain, CHB Bonitz, Ungrund GmbH and Algeco, with G+1 / G+2), and also in Japan (Shigeru Ban Architects, G+2) (Muñiz, 2017)

The proposals contained in this article are based on modular solutions that can be grouped in rows and can also be stacked in groups of two or three floors. We will see that the versatility of the UBUILD system used allows the housing unit model to be adapted to the specific needs of both the population to be housed and the territory itself.

2.3. Infrastructures and installations

Infrastructure and facilities are fundamental elements of any settlement. At the very least, it is necessary to provide for water supply and sanitation, which can be designed as under or above-ground networks, taking advantage of the free space of the house, which must be separated from the ground. Electricity supply is equally necessary, but in this case, self-sufficient solutions can be considered, if circumstances allow.

Some extremely useful elements are solar collectors and panels, which are a good option for resolving domestic hot water and lighting, or at least as a complementary solution. With groups of two or three floors there is enough space on the roof for these to be installed.

2.4. Types of housing units

In designing the different types of housing units, it is important to take into account the psychological battered conditions of the people by the trauma they have just experienced (Caia, Ventimiglia, Maass, 2010), and also the social conditions of the population being housed. However, it is also essential to take into consideration the economic and sustainability aspects, since the available resources must be distributed in such a way that they reach all those affected and must be solutions that are as sustainable as possible. They must also be sensible solutions, without superfluous design elements (Kronenburg, 2009). This is why international associations define minimum standards to be able to accommodate the population in a dignified but inevitably austere manner (Cruz Roja, 2008; IFRC. OCHA, 2015; IOM, 2011).

A large number of proposals have been made. By way of example, we can cite some references that set out the general conditions that these homes should have and study their various typologies (Davis, 1980; Johnson, 2008; Félix, Branco, Feio (2013); Muñiz, 2017). Some interesting solutions with deployable structures have also been proposed (Pérez-Valcárcel et al. 2019; Aragón et al, 2019). In a line closer to the proposal of this article we can cite examples of modules with sandwich panels (Arslan, Cosgun, 2007) or with cellular panels (Garofalo, Hill, 2008).

When designing this type of housing, it is advisable to take into account a series of constructive factors.

It is convenient that the house is built in depth, with a narrow front. This allows for clusters with less developed access roads and shorter service networks such as water, electricity and sewerage. Also the fact of having terraced houses on the long side, improves thermal conditions and can result in significant energy savings.

Groupings of housing modules on one floor require a large amount of affected soil, which in Europe is very expensive. Two- and three-storey clusters should be envisaged. A good solution is to provide access to the upper floors via an external gallery which would have a staircase every few modules. Accessibility for people with reduced mobility is resolved per se, as there are homes on the ground floor.

Staircase cores can perform two important functions. Firstly, they allow the groupings of modules to be of different heights. This means they can be adapted to sloping terrain, without the need for major ground conditioning works. Secondly, they allow the alignments to be rotated without the need to modify the prefabricated modules, which would be complex and costly.

The modulation of the dwellings should be designed in such a way that they can be replaced by permanent conventional dwellings as soon as possible. Prefabricated modules can be reused, and the installation networks can serve the new housing without the need for new layouts.

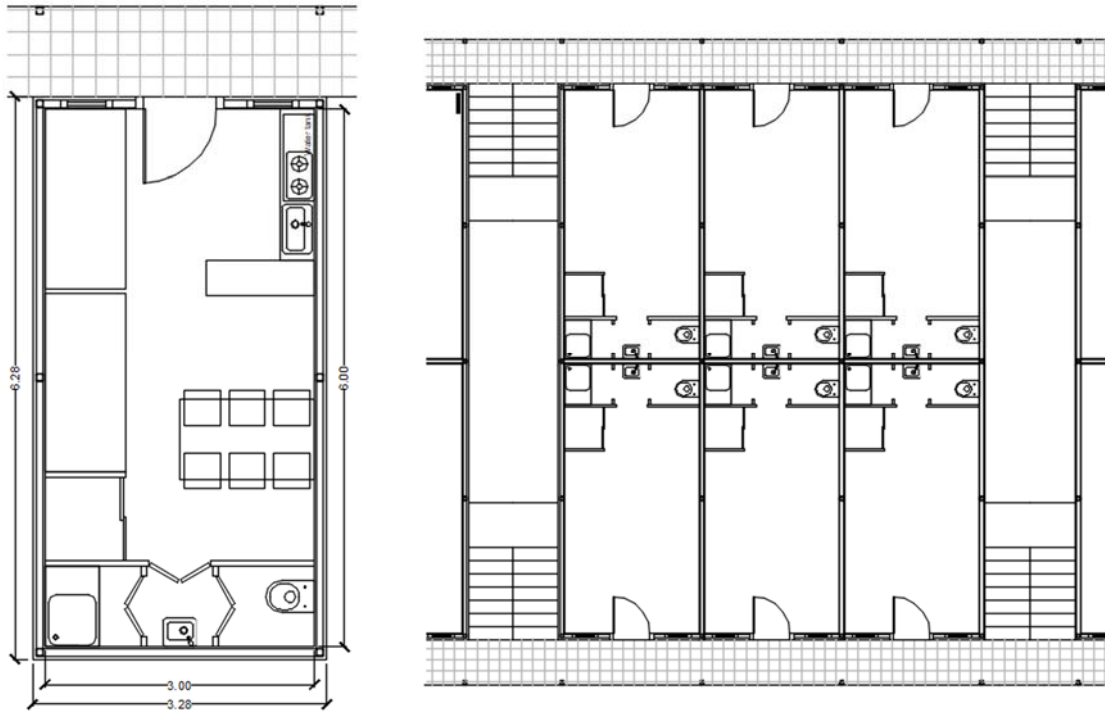


Figure 1.- Type 1 housing unit and grouping system.

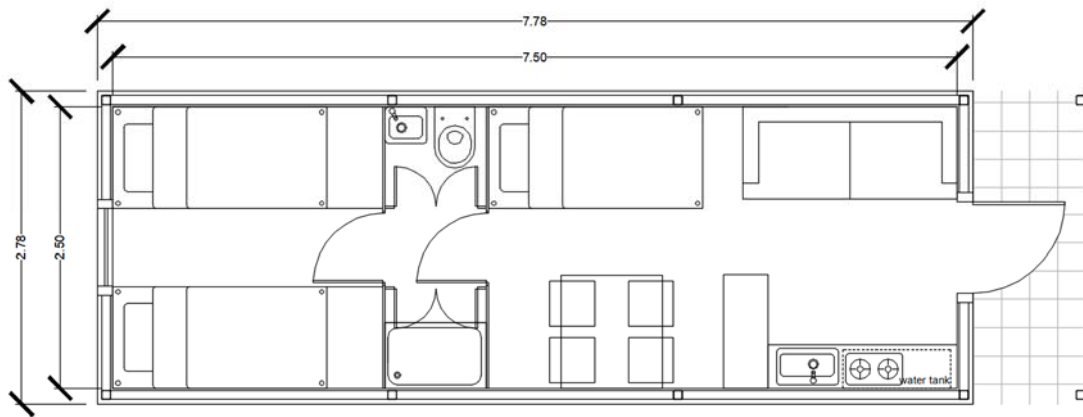


Figure 2.- Type-2 housing unit

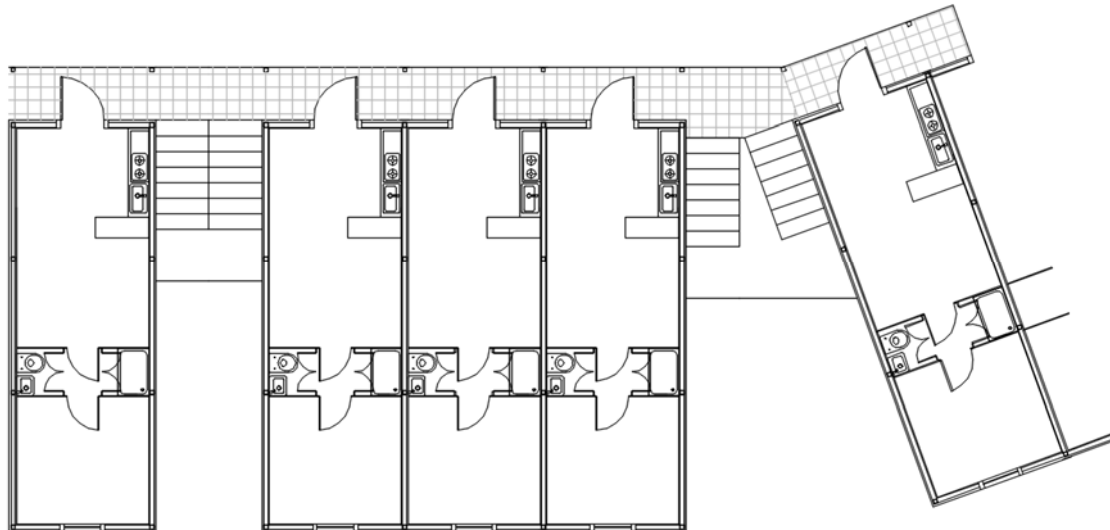


Figure 3.- Group of Type-2 housing units with possible change in alignment.

One of the recurrent criticisms made by NGO stakeholders regarding modular housing is its poor geographical adaptability. Many of the solutions are designed for centralised manufacture and subsequent transportation, over long distances. This generates problems of scarcity, delay, transport, etc. In addition, a given workshop would have to have an extraordinary capacity to be able to supply a large number of these models in the short time available after a humanitarian disaster. The modules proposed correspond to models fully parameterized in BIM, which can be sent by means of a simple e-mail, and this file can be opened and interpreted by a numerical control manufacturing machine. Today an increasing number of carpentry workshops have these systems, so the local construction would be almost immediate and achievable by the available workshops. This is a scalable manufacturing system according to the requirements, and as close as possible to the area where the buildings are located.

Two types of modules have been analysed for the present research. Type 1 modules are designed for the grouping of 4 persons in a single space (Figure 1). They have a bathroom that is divided into three partitions for simultaneous use, a living-bedroom space and a kitchen. It is a temporary dwelling for groups of persons of the same sex with no family ties. Its interior dimensions are 3.00 x 6.00 m. They are grouped in pairs, so that the bathrooms are attached, reducing the necessary facilities to a minimum.



Figure 4.- Cluster of Type-1 housing units



Figure 5.- Type-2 housing unit

Type 2 modules are designed to accommodate families up to six people. Their interior dimensions are 2.50 x 7.50 and they are grouped perpendicularly to the gallery. They consist of a front area with a kitchen, living area and a bedroom area, for night use. By day, the beds located in the access area fold up, allowing a common use of this space. In the rear area there is a bedroom with up to four bunk beds. In the intermediate area there is a partitioned bathroom with an area for a toilet and washbasin and another one with a shower.

In both cases, the upper floor is accessed by staircases that lead to a gallery which connects to the houses.

Both versions are designed to allow for modular construction. For this purpose, all the elements must be light enough to be handled by two people without special technical knowledge. The idea is that it can be easily assembled by the affected persons themselves without any more resources than two simple scaffolding sections or tools other than a screwdriver.

2.5. Construction details

In order to design this type of solution, it is necessary to take into account a series of constructive conditions. There are two basic premises: lightness and low cost. These two determining factors are essential in the definition of possible solutions and affect all of the construction systems to be used.

2.5.1 Foundations

As the modules are very light, the loads transmitted to the foundation are very low. However, this same lightness presupposes that the effect of the wind can cause traction on the windward side. Without a suitable anchoring system, the module or the module group could tip over.

The solution proposed consists of using ballast anchors as indicated in the photograph below, which are embedded in the ground at the bottom of a small footplate which is then filled with concrete. The panels that support the building are then attached to this base.



Figure 6.- Foundation fasteners.

2.5.2 Structure

The proposed structural system is a structural box whose bases are formed by a rectangle of wooden beams joined by uprights of the same material. Trusses are fitted over the beams, forming a grid with panels that are placed between them to form the floor. The walls are formed by wooden sections following a system similar to the light frame, which form the resistant framework. Beams are then laid over this framework to form the next level.

The modular design of these uprights is suitable for fitting the enclosure panels between them with the right dimensions and weight. This is an important conditioning factor to allow for a fast, easy installation process.

2.5.3 Enclosures

The enclosures consist of a double-skin façade: the exterior consists of panels fitted between the uprights with a rainscreen façade, while the interior consists of prefabricated panels. These panels must have all the necessary elements incorporated, such as insulation, finishes, electrical mechanisms, installation tubes, etc. The exterior and interior panels are separated by an air gap.

2.5.4 Roof

The roof is one of the most challenging elements. In rainy or very rainy climates it is very difficult to find economical solutions that are effective against water leaks. The solution proposed consists of placing a polybutylene reinforced cover over the module or group of modules that is fixed to the

upper lattice. It is also planned to install an eave that prevents rainwater from running down the façade.

2.5.5 Facilities

Most of the layout of the facilities must be designed in such a way that it is incorporated into the prefabricated parts and that it is not necessary to assemble it on site. In the proposed solution, the panels have a lower hole that is covered with the skirting board and allows the general conduits to pass through. Specific modules have been designed to contain the different elements of the electrical, plumbing, heating and sanitation installations. Different passive conditioning solutions have also been created, which will be described below.

3. DEFINITION OF THE WOODEN MODULE CONSTRUCTED

These constructive conditioning factors can be addressed with different materials, depending on the characteristics of their implementation and their availability and cost. In this specific case, the material used is wood.

Wood is a material that has clear advantages for this type of construction. Regardless of its workability characteristics, structural capacity and environmental sustainability, it offers the equally important advantage of being available almost everywhere. This makes it possible to largely avoid the transportation of materials from distant locations, making it possible to reduce the carbon footprint. It is generally possible to use wood available in any geographical area where the construction is required.

These characteristics have made wood one of the most widely used materials for this type of building. Numerous proposals can be cited, such as single-family modules (Sener and Altun, 2009), houses built after the Katrina disaster (Gunawardena et al. 2014) or the "mediagua" houses in Chile (Public Edification..., 2014).

The module proposed in this article is based on a strict modulation in order to reduce costs as much as possible.

3.1. General aspects

The proposed solution is based on the design of a 2.50 x 6.00 m. type 2 wooden experimental module with a capacity of 4 to 6 people. It has all the essential elements for the daily activities of a family or a group of people. It consists of a fixed bedroom, a bathroom with toilet, washbasin and shower, a kitchen area, and the living area, which can be transformed into a bedroom. The module has passive conditioning systems and adequate insulation. These aspects will be tested during the study phase.

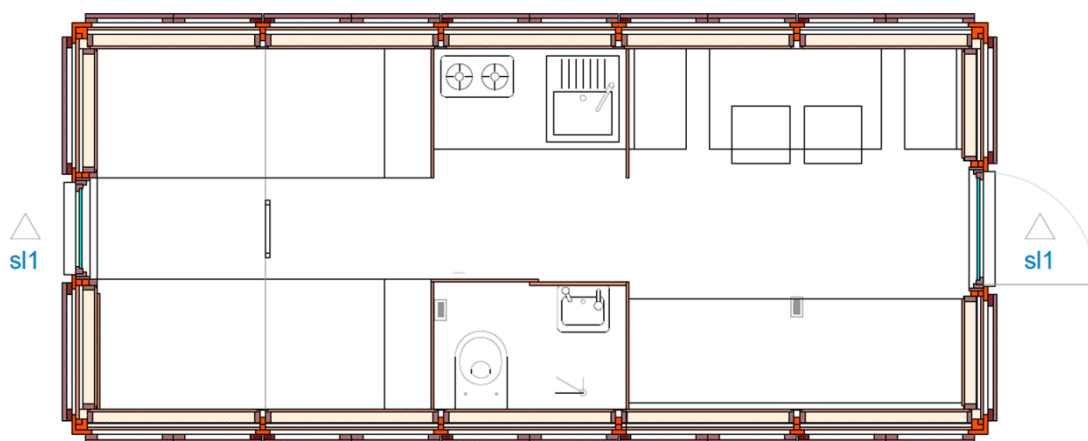


Figure 7.- Experimental module.

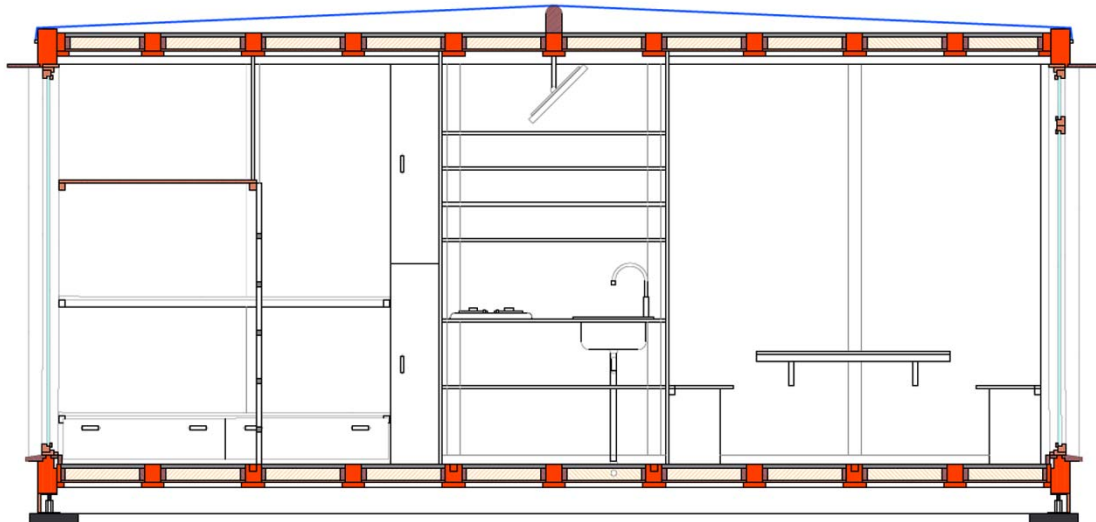


Figure 8.- Experimental module.

The outer shell is fixed, but the inner partitions are fully configurable and can even be modified by the user. This provides the necessary versatility to be able to adapt to the personal circumstances of the group of refugees who live inside.

3.2. Description of the UBUILD construction system

The constructed module was created using an industrialised system, called UBUILD [7]. It is a system based on the previous premises, but in which whole pieces are made using a numerical control machine. In this case, a Homag model Venture 10L CNC machine was used. The system creates the joints with direct splices, without using hardware. It requires a screwdriver as the only tool and can be mounted by two people in one day, as the building is assembled by fitting the pieces and screwing them together, although the optimum number of people would be four. It does not require auxiliary equipment for assembly, although it must be transported by truck, and it is advisable that the truck has a small crane to unload the packages in which the module is transported.



Figure 9.- General scheme of the UBUILD system

Figure 9 shows a detailed scheme of the system. Basically, it is a light frame construction which has been broken down into a series of standardised and machined parts. This allows the number of different construction elements to be optimised to a minimum, simplifying the construction. The parts are supplied in a properly machined condition so that they can be fitted directly to each other, making the construction rigid enough to be able to carry out the assembly process with very limited equipment. Figure 10 shows the cutting machine used and some of the assemblies used in the

construction of the module. They correspond to the joints at the ends of the beams, which are the most complex.

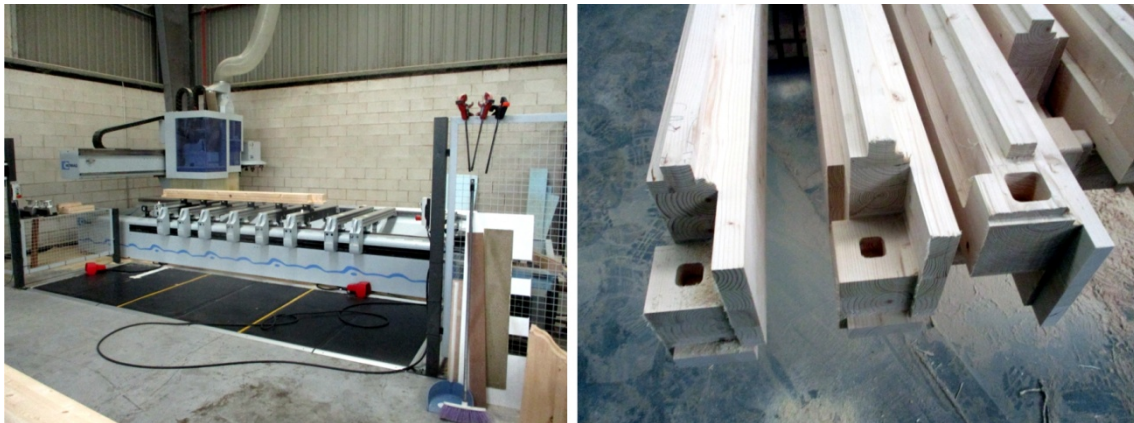


Figure 10.- Numerical cutting machine and some assemblies made for the built module.

The system involves first mounting two beams in the lengthways directions of the construction measuring 120x240mm, into which the 100x200 struts that will form the floor are fitted. The shapes of the ends make it possible to tongue and groove the beam, giving it the necessary length according to the type of construction. Normally each piece covers a length of two facade modules, which is also the distance used to support the struts on the floor. On the top it has 3 notches which is where the façade uprights and the joints where the system's beams will be fitted.

The facades are constructed with uprights embedded in the lower beams and joists, at modular distances of 550mm. The floor structure is repeated on these uprights, in this case on the ceiling, thus allowing several uprights to be stacked. The roof can therefore be a wooden structure, although other solutions can be used, as will be seen later.

All of the wood components are made of GL-24h glued laminated spruce wood and are treated for outdoor conditions in use class 3, according to the specifications of the Spanish CTE-SE-M standard, equivalent to Eurocode EC-5.

To build up the outer walls, the necessary panels and insulation or doors and windows are fitted in place, depending on the case, as this is possible thanks to the modular nature of the system. The doors and windows would be delivered fully assembled on site and would only need to be installed.

The buildings are raised above the ground using adjustable metallic plots that are supported on the foundations. In any case, the loads to be transmitted to the ground are very low, so the foundation is light. Foundation solutions can also be considered based on tyres filled with concrete or earth, depending on each specific situation, anchored to the terrain using bars. A lattice of beams is mounted on the supports, which have a screw to allow them to be levelled, ready for the different parts to be fitted together. Only a few screws are needed to secure them firmly in place.

Once the resistant framework has been completed, the panels that form the floor, the enclosures and the ceiling are installed. The enclosure pieces are sized so that their weight is manageable. They already contain the insulation material so that interior comfort is guaranteed. Next, a coating is placed in the coverings formed by a ventilated façade, and an awning is placed on the roof to ensure that it is waterproof. The prototype has been built specifically for a rainy climate, so that the slope of the awning runs outwards, allowing for easy water evacuation. For dry climates where it is convenient to collect the water or when the water supply is precarious, the cover is designed with the slopes facing inwards, allowing the water to be collected.

3.3. Definition of the enclosures

The Ubuild profile system makes it possible to create four different façade configurations.

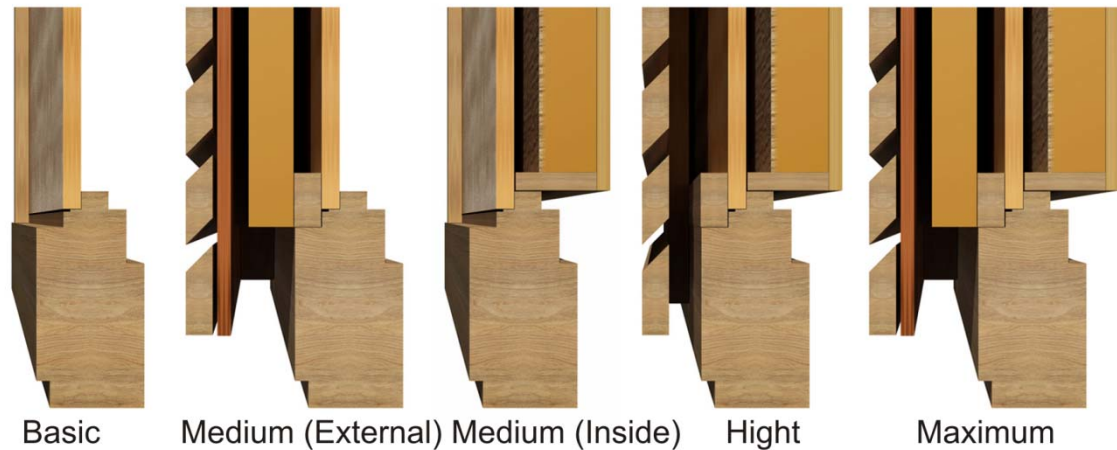


Figure 11.- Construction configurations for the façade

These configurations are scalable, making it possible to start from a basic configuration and add components to achieve better specifications. The basic configuration consists of a simple exterior panel and is used for non-inhabitable constructions. The medium configuration adds an interior insulation panel to which the necessary installation elements are incorporated. It is a configuration suitable for climates with minor thermal differences. In more demanding climates it can be adapted to a high configuration by adding a ventilated facade (rainscreen). In the maximum configuration, external insulation is also added. In the case of emergency shelters this scalability is very necessary, as it allows the construction system to be adapted to the climatic needs of the location where the emergency module is to be installed.

In addition, these configurations make it possible to create passive and active thermal regulation systems, which results in significant savings in heating or cooling systems, as the case may be.

The façade materials can be of different types, depending on the finishes desired, both exterior and interior. For this prototype, the so-called "high configuration" has been used, consisting of an outer panel of 12mm cement bonded wood particles, forming a 30mm ventilated facade. The formation of the enclosure panel is, from outside to inside, a 20mm marine grade phenolic plywood with birch finish, 75mm Rocabit-75 rock wool insulation and 15mm OSB interior panel.

With regard to the carpentry, the window is made of PVC with 'Thermaclit' type glazing with 6+6+4mm glass. The door is made of glass with the same composition.

3.4. Definition of the roof

The roof structure is similar to the floor in that it is made up of a horizontal framework of wooden beams and joists, with insulated panel filling. The slope is formed on this slab with prefabricated OSB panels, and on top of them a 5 mm-thick textile cover of polybutylene PVC reinforced with fibreglass is laid. The roof has passive systems for thermal regulation. It will normally be equipped with photovoltaic panels to provide energy. This tarpaulin is firmly fixed to the module with typical fastening systems.

3.5. Structural analysis of the complete building

The structural framework of the building is based on a timber framing system.

The building transmits very light loads to the ground so the foundation is shallow, as described above. However, this same lightness means that the effect of the wind can cause traction, which must be taken into account.

The calculations carried out were:

- Stability of the assembly in the construction phases.
- Own weight including partitioning.

- Variable actions: Overuse, wind and snow.
- Seismic actions.
- Thermal actions.

All these calculations have been carried out in accordance with Spanish regulations (Technical Building Code) which require performance similar to that of the European reference standards, known as Eurocodes. Both the final limit states and the service limit states contained in these regulations have been analysed. The complete building has been calculated with a commercial software, Cype 3D from the company Cype Ingenieros, with a university license. The verification of the different elements of the module is systematised in a computer routine implemented in spreadsheets developed by the team members.

The results obtained show that with the profiles used, buildings of up to three storeys can be constructed without problems.

4. CONSTRUCTION OF THE PROTOTYPE

4.1. Construction of the module

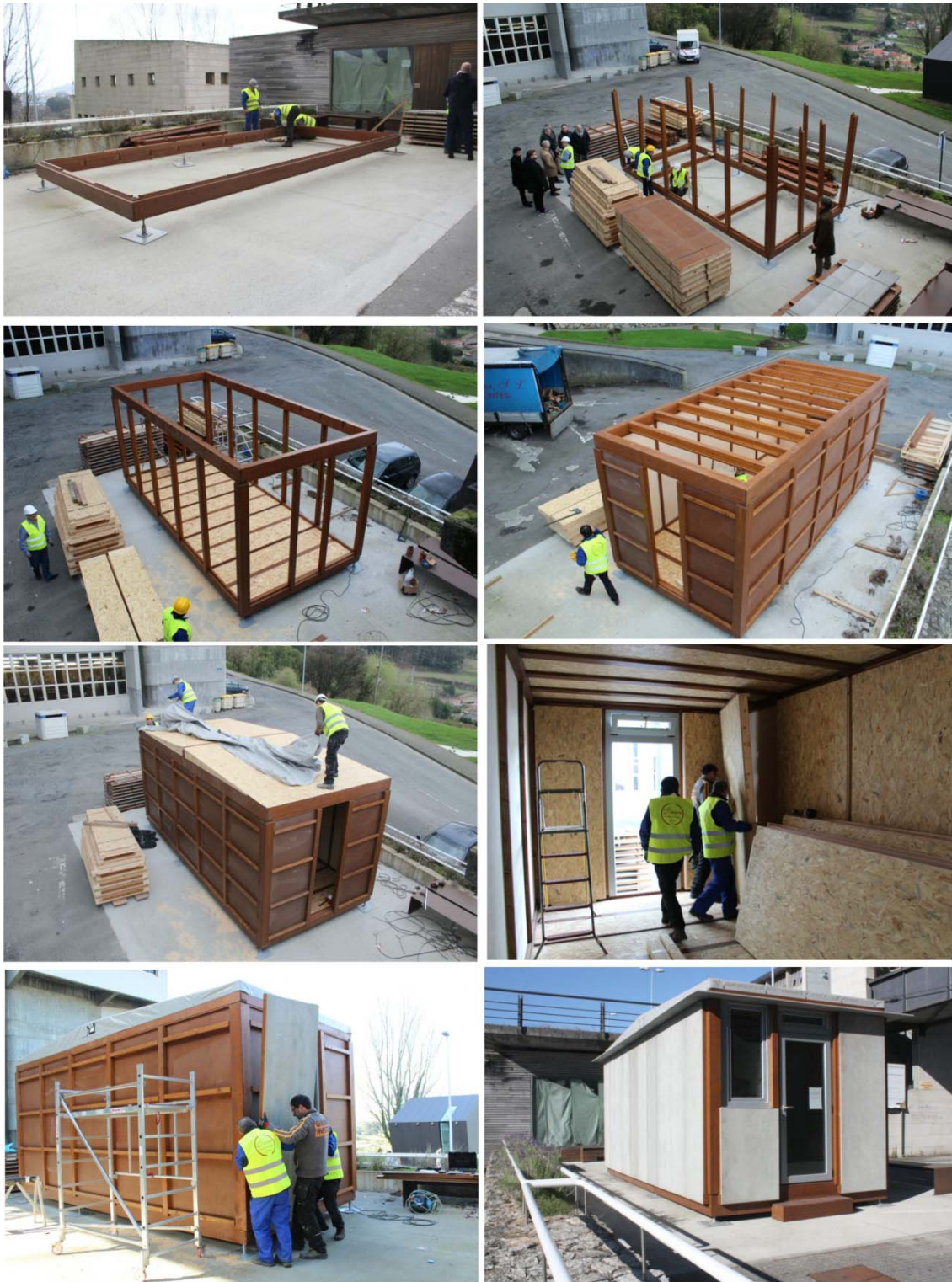


Figure 12.- Construction stages of the experimental module.

The unit was pre-assembled in the workshop in order to analyse the points that could be improved before the final assembly.

The assembly on site was carried out in an area attached to the construction and structures department, in order to connect the equipment for measuring temperature, humidity and other factors to be analysed. The module was installed on an existing concrete floor. The floor had an appreciable slope, which has demonstrated the effectiveness of the proposed adjustment system by means of support plots.

Figure 12 shows the different assembly stages.

- a.- Levelling the supports and positioning the perimeter beams on them. This is a particularly delicate phase that has required a very careful planning, since small errors can cause misalignments in the assembly.
- b.- Positioning of the wooden pillars in the holes provided in the perimeter beams. At the same time, the floor joists are placed and fixed with simple screws.
- c.- Fitting of the floor panels and the upper level perimeter beams on the columns.
- d.- Laying of the wooden panels that define the basic configuration (figure 12) This makes it possible to detect possible misalignments in the verticality of the columns and correct them. Then the beams of the upper level are installed.
- e.- The roof panels are placed and over them a series of inclined boards that serve as support for the textile roof. The roof is then extended and tensioned.
- f.- Once this phase is completed, the outer shell is completely built in the basic configuration. From this point, the interior sheet panels are installed, moving on to a medium configuration.
- g.- The outer panels are fitted in place, obtaining a high configuration. This is considered to be the appropriate configuration for the heavy rainfall conditions in Galicia.
- h.- Finally, the carpentry and the upper guttering are installed, at which point the module is complete.

As it is an experimental module, the interior partitions and furniture have not been included. In a real module these elements would be assembled and connected to the installation networks, leaving it ready for habitation.

4.2. Monitoring

The module was designed with the intention of studying how it behaves in an annual weather cycle. For this purpose, a Davis weather station, Vantaje Pro 2 was used, equipped with Weather envoy and WeatherLink v 6.0.3 software. In addition, six Therm La Mode GSP-6 data loggers were installed to measure temperature and humidity variations throughout the cycle to be studied. Thermal computer models are also being created to be able to contrast these data. Similarly, tests with thermal camera are planned, to verify the behaviour of the insulation material.

At present, these data are not available, as the time that has elapsed has only allowed the equipment to be tested and the measurements to begin. The results will be presented in future papers.

4.3. Set of housing modules

Several modules of the type indicated can be easily joined into groups of up to three floors, in a similar way to that indicated in section 2.4. It is advisable to group them in sets of three units, to better adapt to the possible irregularities of the terrain. To avoid joints that could lead to water ingress, it is convenient that the textile cover covers the whole set of modules. Possible level differences in the implantation on the ground can be easily adjusted in the stair core. A possible scheme of these groupings is shown in figure 13.



Figure 133.- Scheme of a grouping of houses on two levels.

5. CONCLUSIONS

Modular buildings are an optimal solution for temporary housing needs in emergency situations. The proposed modules have advantages in terms of their proportions, since for the same number of modules, it allows to minimize the length of the vias and the installation networks. The possibility of grouping them vertically is also a very interesting advantage.

The timber construction with a design appropriate for digital fabrication is a suitable solution to accommodation needs. The system used allows the different pieces to be defined by means of parametric design in a three-dimensional modelling program such as Rhinoceros 3D. The program allows the piece to be exported in STL format with the degree of precision required. This STL format is standard and can be applied to any numerical control machine generating its corresponding Gcode. This allows the pieces to be machined quickly and using the resources of the workshops that are closest to the affected area. This permits a faster response with fewer transportation requirements.

The design and machining of the pieces allows them to be assembled into one another without the need for auxiliary pieces. Nor is it necessary special machinery or tools. The whole module can be built with a screwdriver. From the resistance point of view, its behaviour has been fully satisfactory. In fact, it has withstood several storms with very strong winds in a very exposed situation, without any damage.

The construction of the indicated module has made it possible to analyse the problems of a real structure. The aspects that have caused the greatest problems on site have been the layout and adjustment of the façade panels. Laying out is a very delicate operation, because a small mismatch would make subsequent assembly difficult. In this case, the adjustment was made with wooden templates. It was very precise, but required an excessive amount of time. It is considered convenient to use metal templates, which are less deformable, and to place rings onto which a hoist can be attached in order to adjust the base more easily.

The side walls are composed of a Platform Frame type system with horizontal beams and vertical uprights. This adjustment was very satisfactory, although the necessary tolerances to fit the pieces together caused some slight angular distortions, which in some cases complicated the assembly of the façade panels. In this case, it was also useful to fit hoists in place that would allow for a precise adjustment.

The prototype has been planned and designed to offer not only simple accommodation, but some technical and human dignity. Their grouping is also contemplated in order to achieve groups that allow maintaining the social contacts of those affected and a reasonable quality of life

The proposals contained in this article are largely adapted to the standards proposed by the Sphere Project. Specifically, the built module conforms to the minimum standards of Sphere, due to the budget limitations of the research project. In section 2.5 other types of modules and groupings that can be built with the same system are described.

The prototype is viable not only in architectural and construction terms, but also in economic, storage and transport terms. It can be taken over almost immediately by any woodworking shop with numerical control machinery anywhere in the world, but it would be if it cannot access these technologies. In the latter case, it would be necessary to resort to manufacturing in industries with these resources and to resort to transportation to bring them to their final implementation. In this case, it would be necessary to analyze whether this option can compete with others.

This prototype has been specifically designed for oceanic or Mediterranean climates. It can also be easily adjusted to hot climates, but in its current configuration it would not be suitable for very cold climates with large accumulations of snow. However, structurally reinforced variants are being studied for this purpose. The prototype is being monitored in order to analyze its habitability, from an energy point of view. This phase is in the process of analysis.

Acknowledgements

The authors would like to thank Alberto Corral from the Ubuild Company and Carpintería Maciñeira (As Pontes, Spain) for his collaboration in the development of the module. Also to the interns Francesca Cetta, Tania Aldir and Joel Cotardo for their collaboration in the design of the modules and their graphic representation.

FUNDING

This work was supported by the Ministry of the Economy and Competitiveness of the Kingdom of Spain [grant number BIA2016-79459-R]. This study is a part of the research project "Expandable and modular constructions for humanitarian disasters"

DATA AVAILABILITY STATEMENT

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- (1) Aragón, J., Muñiz, S., Hermo, V., Mosquera, E. & Casal A. (2019). Modular housing for situations of humanitarian catastrophe in 4th International Conference On Structures & Architecture. Lisboa, Portugal. 2019. 2643-2698.
- (2) Aquilino, Marie J. (2010). Beyond shelter: architecture and human dignity. Architecture and human dignity. Nueva York : Metropolis Books, 2010. 9781935202479.
- (3) Arslan, H., & Cosgun, N. (2007). The evaluation of temporary earthquake houses dismantling process in the context of building waste management. In International earthquake symposium. Kocaeli, Turkey.
- (4) Barakat, S. (2003). Housing reconstruction after conflict and disaster. London: Overseas Development Institute.
- (5) Bedoya, F. G. (2004). Hábitat transitorio y vivienda para emergencias. Tabula Rasa, 145-166.
- (6) Bologna, R. (2004). Transitional housing for emergencies: temporariness and reversibility of the building process. In Proceedings of the 2004 international conference "Improving post-disaster reconstruction in developing countries".
- (7) Caia, G., Ventimiglia, F., & Maass, A. (2010). Container vs. dacha: the psychological effects of temporary housing characteristics on earthquake survivors. Journal of Environmental Psychology, 30, 60-66.

- (8) Corral, Alberto (2018). Ubuild System. Int. Patent PCT /ES2018/000064.
- (9) Cruz Roja Española/Spanish Red Cross. (2008). Catálogo de proyectos de alojamiento y construcción de Cruz Roja Española, 1987-2007. Madrid: Cruz Roja Española.
- (10) Davidson, C. H., Johnson, C., Lizarralde, G., Dikmen, N., & Sliwinski, A. (2007). Truths and myths about community participation in post-disaster housing projects. *Habitat International*, 31, 100-115.
- (11) Davidson, C., Lizarralde, G., & Johnson, C. (2008). Myths and realities of prefabrication for post-disaster reconstruction. In 4th International i-Rec conference 2008-building resilience: Achieving effective post-disaster reconstruction. Christchurch, New Zealand.
- (12) Davis, I. (1980). *Arquitecturas de emergencia*. Editorial Gustavo Gili, S. A. Barcelona.
- (13) Edificación Pública Dirección de Arquitectura Ministerio de Obras Públicas. 2014. Guía práctica para la vivienda de emergencia. Versión 1.0. Santiago de Chile: Gobierno de Chile.
- (14) Félix, D., Branco, J.M., Feio, A. (2013). Temporary housing after disasters: A state of the art survey. *Habitat International* 40 136-141.
- (15) FEMA. 2005, *Planning for Post Disaster Recovery and Reconstruction*, Washington D.C., FEMA (Federal Emergency Management Agency).
- (16) García Lozano, F. (2016). Antonio Vallejo Álvarez: arquitectura de la sensatez. PhD Thesis. Universidad Politécnica de Madrid.
- (17) Garofalo, L., & Hill, D. (2008). Prefabricated recovery: Post-disaster housing component production and delivery. Without a hitch: New directions in prefabricated architecture (pp. 64-71). (Massachusetts).
- (18) Gunawardena, T., Duc Ngo T., Mendis, P., Aye, L., Crawford, R. (2014). Time efficient post-disaster housing reconstruction with prefabricated modular structures. *Open House International* 39(3): 59 – 69.
- (19) Hany Abulnour, A. (2013) The post-disaster temporary dwelling: Fundamentals of provision, design and construction, HBRC Journal, <http://dx.doi.org/10.1016/j.hbrj.2013.06.001>
- (20) IFRC. OCHA. (2015). *Shelter after disaster*. Second Edition. Ginebra: International Federation of Red Cross and Red Crescent Societies.
- (21) International Organization for Migration (IOM). (2011). *Transitional Shelter Guidelines*. Shelter Centre.
- (22) Jodidio P. (2015). *Shigeru Ban: Complete Works 1985-2015*. Taschen
- (23) Johnson, C. (2008). Strategies for the reuse of temporary housing. In I.a. Ruby (Ed.), *Urban transformation* (pp. 323-331). Berlin: Ruby Press.
- (24) Klansek, T., Coley, D.A., Paszkiewicz, N. et al. (2020) Analysing experiences and issues in self-built shelters in Bangladesh using transdisciplinary approach. *Journal of Housing and the Built Environment*. <https://doi.org/10.1007/s10901-020-09783-z>
- (25) Kronenburg, R. H. (2009). Mobile and flexible architecture: solutions for shelter and rebuilding in post-flood disaster situations. In *blue in architecture 09_ Proceedings_IUAV Digital Library*.
- (26) Lizarralde, G., & Massyn, M. (2008). Unexpected negative outcomes of community participation in low-cost housing projects in South Africa. *Habitat International*, 32, 1-14.
- (27) Muñiz, Patricia (2017). *Viviendas prefabricadas en procesos de alojamiento de transición para refugiados y desplazados internos*. Haití, Japón, Siria, 2010-2016. PhD thesis. Universidade da Coruña. Spain.
- (28) Oxfam 2003, *Guidelines for Post Disaster Housing*, Version 1. Oxford, Oxfam.
- (29) Pérez-Valcárcel, J., Muñoz-Vidal, M., Freire-Tellado, Muñiz, S., Aragón, J., Mosquera, E., Hermo, V., Suárez-Riestra, F., López-César, I. (2016). *Construcciones desplegables y modulares para situaciones de catástrofe humanitaria (CODEMOSCH)*, Research Project, reference BIA2016-79459-R (MINECO). Spain.
- (30) Pérez-Valcárcel, J., Muñoz-Vidal, M., Freire-Tellado, M. Gómez-Magide, D. & Casal-Rodríguez, A. (2019). Expandable bar structures for emergency situations in 4th International Conference On Structures & Architecture. Lisboa, Portugal. 2019. 809-815.
- (31) Quarantelli, E. L. (1995). Patterns of sheltering and housing in US disasters. *Disaster Prevention and Management*, 4, 43-53.
- (32) Ros García, J. M., Sanglier Contreras, G. (2017). Análisis del Ciclo de Vida de una Unidad Prototipo de Vivienda de Emergencia. La búsqueda del impacto nulo. *Informes de la Construcción*, 69(547): e211, doi: <http://dx.doi.org/10.3989/ic.16.035>
- (33) Sener, S. M., & Altum, M. C. (2009). Design of a post disaster temporary shelter unit. *AjZ ITU Journal of*

the Faculty of Architecture, 6, 58-74.

- (34) Sphere (2018). Manual Esfera: carta humanitaria y normas mínimas para la respuesta humanitaria, 4ª ed., Geneva, Switzerland: Asociación Esfera. <https://www.spherestandards.org/es/manual-2018/>
- (35) Twigg, J. (2006). Disaster Studies Working Paper No.15: Technology, post-disaster housing reconstruction and livelihood security.
- (36) UBUILD. Prefabricated modular wooden houses. <https://www.ubuild.es/en/>
- (37) UNDRO. (1982). Shelter after disaster: Guidelines for assistance. New York: United Nations