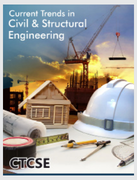
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**Research Article**

# Emergency Modular Buildings in Developed Countries: CODEMOSCH Project

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## Abstract

The objective of this research is the development of temporary buildings that can be available for an emergency situation and be implemented quickly and efficiently in the area affected by the emergency. The methodology adopted consists of the development of a system of pre-storable modules that take up as little space as possible, can be used immediately and, when they are no longer needed, can be repaired, stored and reused in other in other situations requiring their use. When the emergency occurs, they are transported in compact blocks and installed wherever they are needed, with minimal site preparation and using reduced auxiliary means. The basic idea is a container that can be resolved in various ways, of which this study has focused on three: modules assembled in a workshop and transported directly to the emergency site, modules built in pieces and assembled on site, and folding modules in which the facades, side walls and interior partitions are folded into a very compact package that allows for easy transport and particularly rapid assembly. In all cases, innovative solutions are presented which considerably improve on previous proposals. The three modules mentioned have been built at the ETS of Architecture of A Coruña (Spain), which has allowed us to analyse their viability in practice and to detect points of improvement for further research in this field. Finally, a critical review is made of the results and the possible improvements detected.

**Keywords:** Temporary housing; Shelter; Post-disaster housing; Modular building; Sustainability; Disaster relief; Emergency; Refugees; Transitional

**Abbreviations:** UNHCR: United Nations High Comissioner for Refugees; IFRC: International Federation of Red Cross and Red Crescent; OCHA: United Nations Office for the Coordination of Humanitarian Affairs; OXFAM: Oxford Committee for Famine Relief; FEMA: Federal Emergency Management Agency; UNDRO: United Nations Disaster Relief Office; IDMC: Internal Displacement Monitoring Centre; IOM: International Organization for Migration; CODEMOSCH: Deployable and modular constructions for humanitarian disasters

## Introduction

Day after day, the media show images of displaced people in dramatic situations, resulting from natural disasters, war or other human conflicts. According to the Global Trends report of the United Nations High Commissioner for Refugees, UNHCR, in mid-2021, the number of displaced people in the world reached 89.3 million, the highest number since the Second World War [1]. All of these people are usually hosted in refugee camps. UNHCR defines them as “human settlements with an anatomy and characteristics designed to care for those fleeing war or armed conflict. They are generally located in border territories, not far from conflict zones. They must be designed to meet the basic needs of the people they accommodate: shelter, food, education, health, among others. Although a refugee camp is designed to house the population on a temporary basis, reality shows that the vast majority of the host population spends several years in them, so that the camps often turn into cities of hundreds of thousands of inhabitants, with all the consequences that this implies. A significant example is Dadaab, the largest refugee camp in the world according to UNHCR, created for victims fleeing the war in Somalia, with more than 240,000 refugees, and in operation for more than 20 years)

https://eacnur.org/es/actualidad/noticias/emergencias/dadaab-el-1o-de-los-8-campos-de-refugiados- mas-del-mundo

The management of these camps will have complex logistics. There are various publications and guides, which compile the different experiences that have taken place, normally published by international agencies and non-governmental organisations. For obvious reasons, many of these recommendations refer to non- developed countries, which makes them very useful in that environment, but less suitable for camps located in developed countries, although the problem has reached these countries as shown by the experiences of Moria in Lesbos (Greece) or Calais (France) [2]. In addition to the serious refugee problem, many other situations may make emergency buildings necessary. Firstly, migratory movements, which is an increasingly pressing problem, especially in the countries of southern Europe and the USA. However, natural disasters such as earthquakes, floods, volcanic eruptions, etc. should not be forgotten either. In all these cases, solutions must be simple, cheap and reusable in order to optimise their cost and have them available as quickly as necessary. All indications are that the current climate change situation will make weather phenomena increasingly damaging.

This article analyses various solutions proposed during the development of a research project carried out by the authors [3]. In this project, two types of buildings have been analysed. On the one hand, buildings intended for accommodation, for which various proposals based on transportable and reusable modules have been studied. On the other hand, buildings for community services such as canteens, medical services, religious services, meeting centres, etc. were studied. For these buildings, the use of deployable structures was proposed, a type of solution in which our team has extensive experience. Given the scope of the project developed, this article will analyse the proposals designed and built for emergency modular buildings, leaving the buildings for community services to be developed in subsequent publications.

## Study of the Basic Requirements and Parameters of Refugee Camps

To analyse this aspect, it is useful to use the recommendations of intergovernmental organisations that have been studying the issue for a long time, such as the UNHCR Emergency Handbook, Shelter after disaster, Sphere Handbook, etc., which provide a wealth of information. Thus, UNHCR establishes three types of settlement: dispersed settlements, mass settlements and camps [4]. In the first, refugees settle with relatives or in inhabited areas that host them. It is quick to implement and low-cost, although it will present social and management problems with the displaced population. Mass settlement will consist of seeking shelter in pre-existing facilities such as sports halls or schools as a temporary or transit situation. The advantages are immediacy and the fact that urban services are often available. The problem is that these services are overloaded; facilities are damaged and lost for their original use [5]. Finally, camps are places built ex-process to accommodate a particular group of refugees. UNHCR points out that they are the worst possible option, but often the only viable one. They usually occupy undeveloped areas, which means that all the logistical problems involved in occupying a site for a large number of people have to be solved. One advantage of this system is that services can be centralized in a more efficient way, as well as facilitating the management of the refugee population. There are many disadvantages, such as overcrowding and the often unhealthy and inhumane conditions.

However, many of these documents refer to spontaneous, transitional and temporary refugee camps that have arisen on the ground due to conflicts. In recent years, however, displacement camps of the permanent type on European soil, such as those on the island of Lesbos in Greece, have gained in importance. These new camps are medium- and long-term resettlements, and now more than ever they need to be planned and designed to offer not just simple accommodation but some technical and human dignity [6,7]. Both international agency and NGO staff often lack the practical knowledge to address technical issues that are extremely complex and potentially controversial. The SPHERE Handbook, a crosscutting document from several NGOs, sets out recommendations for camp design and management, which it calls the Design Norm [8]. These standards, many of whose parameters and guidelines we include in this paper are the result of the collective experience of many individuals and organizations and therefore do not represent the views of any particular government body or agency (Table 1). They start from the following units of development, always from the bottom up (starting with housing and ending with the countryside). The conditions for the establishment of a camp can be reduced to the need for a reasonably flat terrain, with a suitable climate, security and access conditions [9]. As the area allocated to each family/person, the standards are established in the Table 2.

For camps, an estimated minimum area of 45 $m^2$ per person, including the family land, can be assumed. This land includes general services, communal areas and administrative and storage buildings. In any case, UNHCR (2016) recommends not going below 35 $m^2$ per person [10]. The organization should be done by districts or sectors (1 per 5,000 persons), neighbourhood units (4 per district < 1,250 persons c.u.), cluster (10 per neighbourhood < 80 persons c.u.) and households (16 per cluster < 4-6 persons c.u.). A cluster is understood as a unit of dwellings and services: latrines, dining room and a communal space (15$m^2$).

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**Table 1**: Development units for the design of a refugee camp.

| Module | Composition | Approximate number of persons |
|---|---|---|
| Family | 1 family | 4-6 persons |
| Community | 16 families | 80 persons |
| Block | 16 communities | 1,250 persons |
| Sector | 4 blocks | 5,000 persons |
| Camp | 4 sectors | 20,000 persons |

**Table 2:** Generic indicators for the establishment of refugee camp areas. UNHCR 1996.

| Geographical environment | Area |
|---|---|
| Europe or Asia (cold winters) | 5.00-6.00 $m^2$ |
| Africa (hot climate) | 3.50 $m^2$ |
| **Allocated area per person** | **Area** |
| Minimum covered area per person | 3.50-4.50 $m^2$ |
| Minimum total area per person | 30-45 $m^2$ |

This starts by analysing the family unit, which, logically, will depend on cultural and ethnic criteria. Distance to water supply and latrines is analysed; the relationship with other members of the community and the type of habitual dwelling of the affected population. The so-called Transit Camps deserve special mention. These are designed to temporarily re-house refugees during their displacement and to be able to transfer the occupants to their final location. It has been a model that has worked quite well in Germany [11]. They are temporary facilities with short-term stays, in the order of 2-5 days, with a very high turnover of people. Their size will depend on the population to be managed. It has been a model that has worked quite well in Germany. Modules with a surface area of 3 $m^2$/person are used. For sanitation, 20 people per latrine and 50 per shower. For kitchen, the needs of 100 $m^2$ per 500 persons are assumed. Settlement access, road infrastructure and proximity to humanitarian transport hubs need to be evaluated. Site risks and site security should be analysed. Primary storage and food distribution points should be accessible by heavy trucks throughout the year. All other facilities can be accessible by light vehicles. Inland roads and tracks must allow safe movement through the camp throughout the year. The layout of paths should avoid isolated and hidden areas, as they present risks to the personal safety of users. The settlement is to be provided with appropriate accessibility measures for people with reduced mobility.

In order to meet these objectives, two types of buildings are necessary. On the one hand, it is necessary to resolve the accommodation, preferably at family level or at least in a small group with previous links, which avoids possible conflicts. On the other hand, it is necessary to resolve community services with buildings capable of adapting to different uses in order to reduce costs. This is very important, as available resources are often scarce and cost containment makes it possible to help a larger number of people. Neither can it be forgotten that we are dealing with very varipsional situations where the cultural or religious environment must necessarily influence the design of dwellings and clusters. This is extensible to the concept of "family": groups of women, children only, families that have been divided and all the possible social casuistry.

## Emergency Shelter for Populations in Emergency Situations

The issue has attracted the attention of numerous international agencies such as the United Nations High Commissioner for Refugees, UNHCR, IFRC and NGOs such as Shelter Centre and Oxfam International, which have produced a series of response manuals [12-16]. In these manuals, the shelter solution after a disaster is differentiated according to the time that has elapsed since the event. For example, the IFRC Shelter after Disaster manual distinguishes between a three-phase strategy (emergency shelter, transitional shelter and permanent shelter) and a two-phase strategy (protracted emergency shelter and transitional-definitive shelter), establishing differentiated strategies and solutions for each phase [14]. Quarantelli proposes a four-phase model (emergency shelter, temporary shelter, transitional housing and permanent housing) that has been considered more appropriate to the technological situation in developed countries [17]. After the emergency, the first action is phase 1, which provides immediate shelter for those affected, the so-called 'emergency shelter'. Tents or similar systems are most effective for this purpose. They are easy to erect, easy to transport and inexpensive, but they deteriorate quickly. Their lifespan is usually limited to one year and often does not exceed six months [18].

Subsequently, temporary shelters (phase 2) or temporary housing (phase 3) are set up. Temporary shelter is defined as an enclosure where a family or group can reside immediately after the disaster for a short period and which serves only as accommodation: the provision of food and other basic services are dealt with on a communal basis. Temporary shelter' is defined as housing, usually minimal, but which allows the occupants to resume domestic and

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possibly work activities. Figure 1 shows three examples of these three phases: A standard tent (phase 1), an emergency shelter designed by Shigeru Ban (phase 2) and a temporary dwelling (vivienda mediagua) from Chile, which is a type of prefabricated social housing designed for people who are homeless or have lost their homes due to natural disasters (phase 3) [19].

**Figure 1:** Types of emergency buildings. Emergency shelter, temporary shelter and temporary housing.

For the first phase, the tent solution is undoubtedly the most effective, but due to the short lifespan of the tents, it is not suitable for subsequent phases. For shelters or temporary housing, the solutions point to reconstruction and self-build processes, as the manuals are often oriented towards developing countries.

Moreover, current migrations have shifted the conflict over the housing of displaced populations to developed countries, so that the strategies traditionally proposed by the manuals, such as housing with relatives or self-construction, are of very limited effectiveness as the conditions that make them viable do not exist. It should also be added that much of the accommodation demanded is only temporary, given that the desired destination is another country. Notwithstanding the above, some authors have stressed the importance of prefabrication in these situations as well [20].

Prefabricated construction, or at least technically up-to-date prefabricated construction, has been avoided in emergencies. This may be logical in situations in underdeveloped countries due to lack of technology, transport difficulties, etc., but often the consequence is that refugees in camps may stay in tents for years or in very flimsy constructions made of plastic, self-built, etc., with the resulting lack of comfort and dehumanization. This reasoning must be reversed in developed countries with construction technology in the rise, means of transport, implementation, speed, etc. This will mean adequate standards of quality and comfort. Agencies are suspicious of this type of construction, partly because of cultural inertia and partly because of oversupply: there are innumerable designs, whether from private technicians, universities, agencies, etc. It is common to find activists criticizing these prototypes, often from ideological and non-technical positions. The large container and modular construction companies are often used, as they are practically the only ones capable of responding quickly to a situation that arises. This response has its consequences: lack of adaptation of the solutions to the displaced populations, possible corruption, etc. [21,22]. If there are dysfunctions, it will be necessary to look for weaknesses in the process and improve them, but this does not mean discarding solutions that may be interesting.

The tent system is not suitable in developed countries beyond the first moment of emergency, which should not exceed days or weeks. It is possible to establish settlements, urban and town-planning facilities and prefabricated buildings of sufficient quality, both in terms of habitability and construction quality. The still common view that prefabricated construction is an “under-construction” is today very erroneous and does not correspond to reality [20]. Nor does self-build construction seem to be an option in developed countries: there are technicians, specialists, administrative processes, etc. that can be adapted to the situation, but which cannot be avoided beyond an initial emergency. Agencies also point out that prefabricated housing is expensive. The tent is much cheaper. However, of course, that is in unit cost. If you look at the bigger picture, over 5 years several tents will be needed, which increases the cost and affects the quality of life. On the other hand, tent camps are not acceptable in developed countries, where there are sufficient resources [23]. A prefabricated building can be a home, as the Fukushima case has shown, but a tent will never be. A case in point is the transitional housing built at the initiative of the British government at the end of World War II. This initiative involved the creation of more than 150,000 houses. The cost at the time was around £1,400, more expensive than a traditional brick building, which would be around £1,000. However, many of these houses have remained in use for more than 65 years, although they were not originally expected to have a lifespan of more than 10 years [24].

In situations of natural disaster, where the majority of the population remains in the area, the tent solution does not seem reasonable either, beyond the first instance. This call for prefabrication has a two-pronged approach: on the one hand, it involves the pre-fabrication of construction elements that will be assembled to a greater or lesser degree at the destination (partial or component prefabrication), which is currently unavoidable in developed countries. In addition, the pre- fabrication of shelters that remain stockpiled until their use becomes necessary (total or overall pre-

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fabrication). This second approach proposes the creation of a bank of temporary shelters per country, region or supranational entity that can be easily transferred to the emergency sites. This shelter pool needs to be complemented by other complementary/alternative systems and buildings for common services as necessary. The need for such systems became evident in the crisis on the island of La Palma [25].

Temporary shelters have been the subject of numerous designs using a variety of systems and materials. There are numerous proposals based on the use of panels [26,27], deployable bar structures [28-30], cardboard tube structures [31], and other solutions. Emergency shelters are designed for temporary accommodation in the first period after the tent phase has passed, but can also be useful for accommodation of different groups needed in an emergency situation such as health workers, military, fire-fighters, etc. who in many cases are initially housed in tents. Transitional housing designs have generally been developed along two lines of research. The first type of proposals is based on easily transportable rectangular modules that can be grouped together to achieve larger dwellings to accommodate larger groups or families [32]. A very common type of proposal is based on the reuse of containers. Due to the large number of existing proposals and the storage difficulties they pose, no research has been carried out in our study. Other researchers have focused on proposals for small modules that can be assembled on site and that allow groupings with flexible designs. They have the disadvantage that on-site assembly is more complicated and therefore does not allow immediate action as in other cases [33]. The materials are also very diverse, as are the construction approaches. In some cases, the module is designed from simple elements that are assembled on site, such as the self-built shelter in wood and agglomerated cork panels [34]. Interesting solutions have also been proposed with panels that fold around a central core containing the toilets and unfold to form a complete dwelling [35].

In most of the cases analysed, the modules are designed to be built on a single floor. The difficulties of finding free land with suitable conditions in developed countries have already been pointed out, which is why solutions that allow groupings in height are always an advantage. This is one of the aspects that has been taken into account in the development of the project and most of the solutions used allow for multi-storey buildings. For practical use, it is considered that the most advantageous groupings are those of two or three levels. Another important aspect that has been taken into account in the project is the design of easily storable and reusable modules. It is an important advantage that the modules can be manufactured prior to the disaster and properly stored in order to be able to respond immediately to the shelter needs of the affected population. Moreover, once the emergency situation is over, the modules should be able to be stored again and reused in similar situations that may occur at a later date.

Another possibility is rapid manufacturing solutions for previously developed dwellings: BIM technologies being used in construction, together with numerical control machinery, can significantly reduce design and construction times, so that there does not even have to be a specific stock of units stored for later use. The IFRC, among other agencies, points out that shelters must be adapted to each specific implementation, and that the necessary characteristics cannot be extrapolated [14]. However, it does seem interesting that these shelters can be relocated, upgraded and reused either in whole or in parts. Moreover, in these aspects' construction technology opens new doors.

## Modular Emergency Buildings Proposed in the CODEMOSCH Project

In the CODEMOSCH research project, various solutions have been studied focusing on phases 2 and 3 according to the Quarantelli classification, the so-called T-shelters, that is, temporary shelters and temporary housing. Six homes have been analysed for emergencies, half of which were built. The three that were left at the project level are included in the type of variable geometry shelters according to the classification of Tosum and Maden [36]. They are the Octógono housing [37], a solution with deployable bar yurts [38] and an emergency shelter with deployable modules of simple scissors [39]. In addition to these proposals, prototypes of the other three have been built (transportable modules assembled in the workshop, transportable modules in pieces and modules with deployable panels) that fall into the group of 'Structures with variable mobility' of the previous authors. Specifically, the first type is classified as "Portable partially relocatable", the second as "Demountable" and the third as "Relocatable".

In the study of emergency shelters, the Octagon shelter has been considered most significant, as the other two are deployable bar structures that have been analysed in other articles. This is a 32 m2 deployable octagonal module capable of accommodating five people. Its folded dimensions are 2.25x 2.25x2.25x2.25 m with an approximate weight of 704 kg, which allows five units to be transported per standard sea container, reducing transport and storage costs. It includes in the package itself the necessary furnishings, such as a table, bunks, cupboard panels, stools, shelves, sink and cooker. Also, rainwater harvesting tanks with a capacity of 250 l (Figure 2). The outer cladding is a double layer of 0.5 mm polypropylene. The interior enclosures are separated by folding curtains of the same material, including a dressing room for women with an interior safety lock (Figure 3). Despite the undoubted interest of the proposal, the budgetary constraints of the project have prevented the construction of a prototype.

Most of the research has focused on transitional housing, for which specific conditions have been set that are considered reasonable in the context of emergencies in developed countries. In what follows, the study will focus on the three modules built as part of the research. The modules designed are in all cases transportable and reusable. A stock of prefabricated dwellings is available, ready to be used as transitional housing in the event of an emergency. The proposed modules can be transported to the emergency area and assembled with simple means. Their dimensions allow them to be transported without the need for special vehicles and in some cases, they can be transported fully assembled, in others in easily assembled pieces and in others folded for transport and unfolded once they are in the camp. Although it is not essential, it is very con-

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venient that the modules can be grouped horizontally and vertically in compact units and preferably on several levels for the reasons indicated above. Of the three proposed modules, two of them can be stacked on several levels and the third is transported with the cover folded, which allows two useful levels to be available. To achieve these objectives, the basic unit is considered to be a rectangle with a maximum width of 2.80 m, which allows its transportation without the need to use special vehicles. These modules can be attached to form larger groupings of various types. Figure 4 shows some of the distributions made with simple modules and Figure 5 shows various groupings of modules that allow for homes with greater accommodation. In the CODEMOSCH project, three types of modules have been designed and built in response to three different manufacturing strategies, the characteristics of which are set out below.

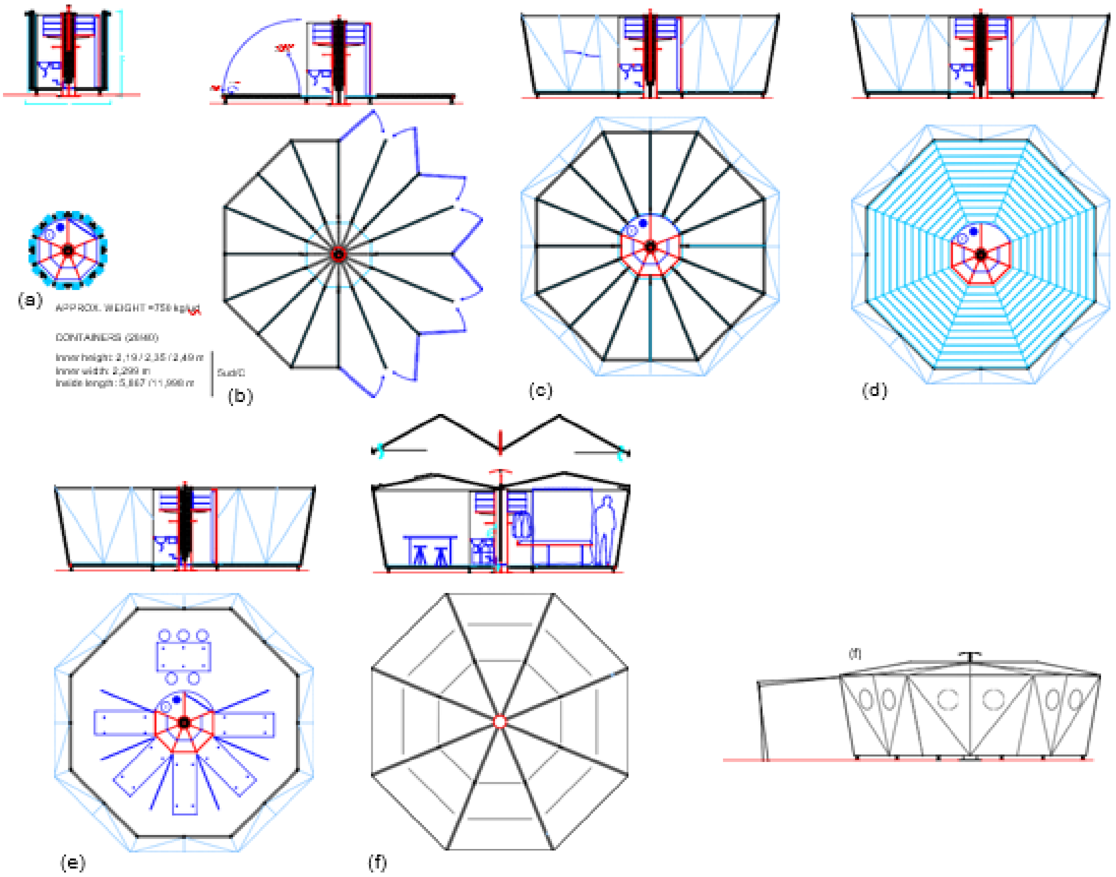

**Figure 2:** Shelter deployment: plan and section views.

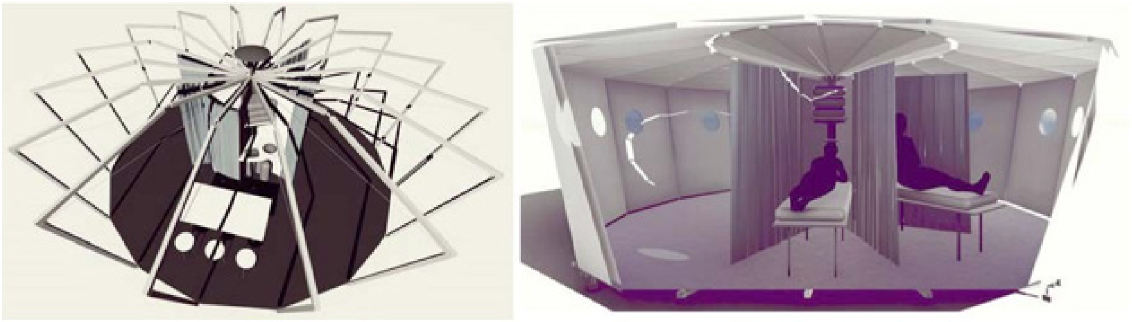

**Figure 3:** Interior view of the module (Joel Cotardo).

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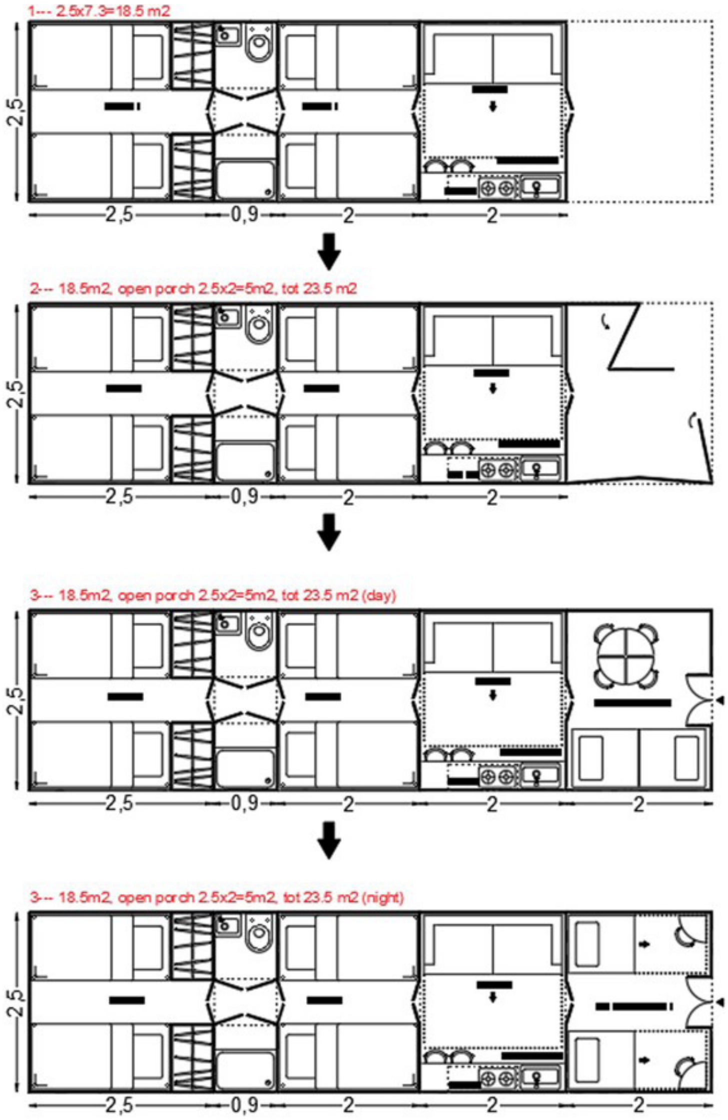

**Figure 4:** Solutions with simple modules (Francesca Cetta).

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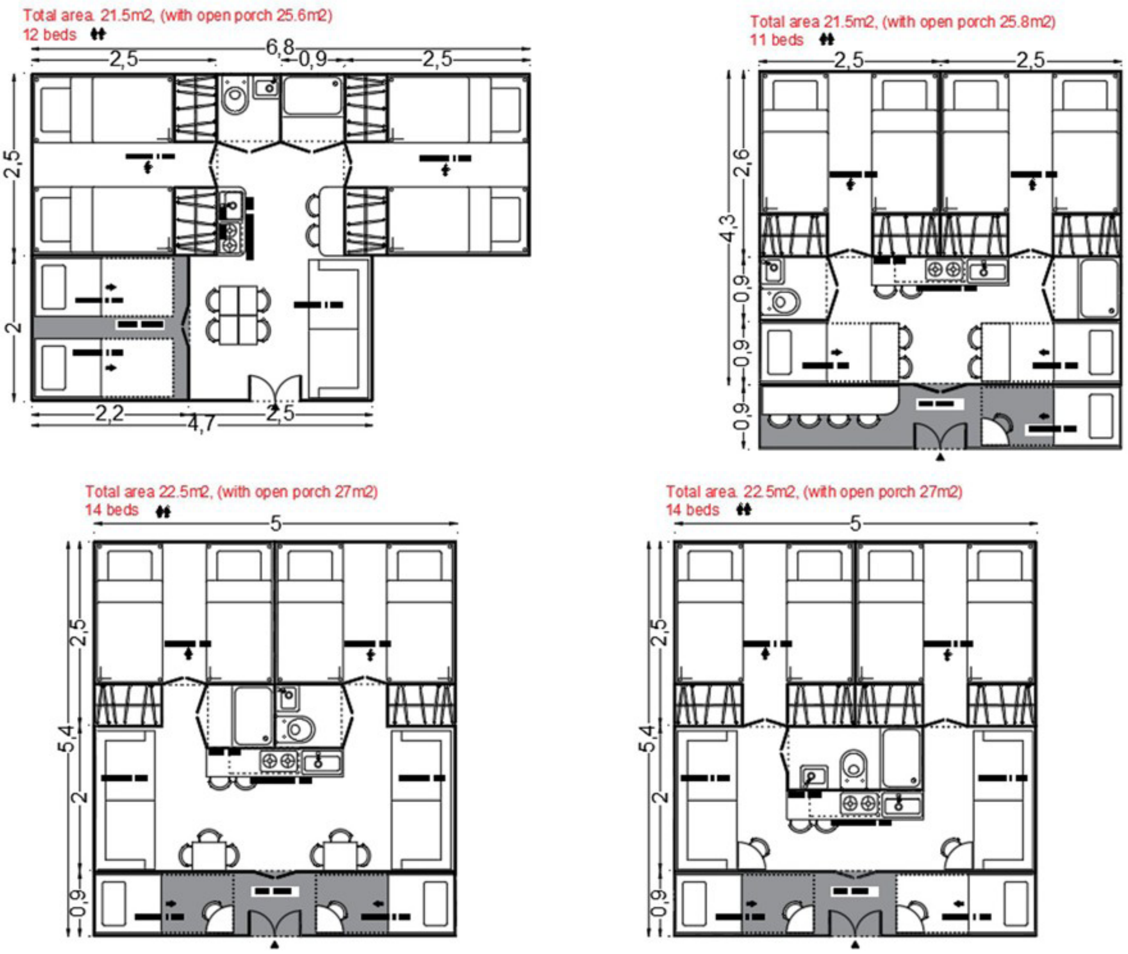

**Figure 5:** Solutions with grouped modules (Francesca Cetta).

### Transportable modules assembled in the workshop (complete prefabrication, but with volume reduction)

First, the possibility of using modules prefabricated entirely in the workshop, capable of being easily transported to the place where they are needed, was studied. This strategy allows a very quick response so that the houses can be ready for use in a few days: the house leaves the workshop fully assembled and equipped and only needs to be connected to the supply networks. Its main disadvantage is that it requires ample space for storage and that transport needs require maximum dimensions fixed by the permitted gauges. Generally, these modules are made up of a dwelling or part of it developed at ground level, which is a strong limitation as it occupies a lot of land. The proposed model is based on a module with a folding roof, so that it can be transported in a more compact form and adjusted to the maximum gauges set by the regulations. By unfolding the roof in its final location, a living space can be created on the upper floor, which increases the housing capacity of the house.

The company Emsamble, a collaborator in this project, selflessly built an experimental building with the characteristics of an emergency building (Figure 6). It is made up of two modules that were assembled in the workshop with the cover folded to allow it to be transported without the need to use a special vehicle and its design sought to overcome the tube appearance that usually accompanies this type of housing, allowing greater interior space (Figure 7). Due to budgetary limitations, furniture was not included, leaving the module for use as a display. However, an important aspect of the research was to analyse the hygrothermal behaviour in various real radiation incidences, which gives it its unique shape, which may seem whimsical. This shape also made it possible to analyse the problems of resolving knots and encounters beyond a mere prismatic construction, which is probably the most logical and economical shape. This research concluded in 2021 and its results were published in 2024. The building was installed on September 17, 2018 on the A Zapateira campus of the University of A Coruña and its deployment was carried out in one day [40].

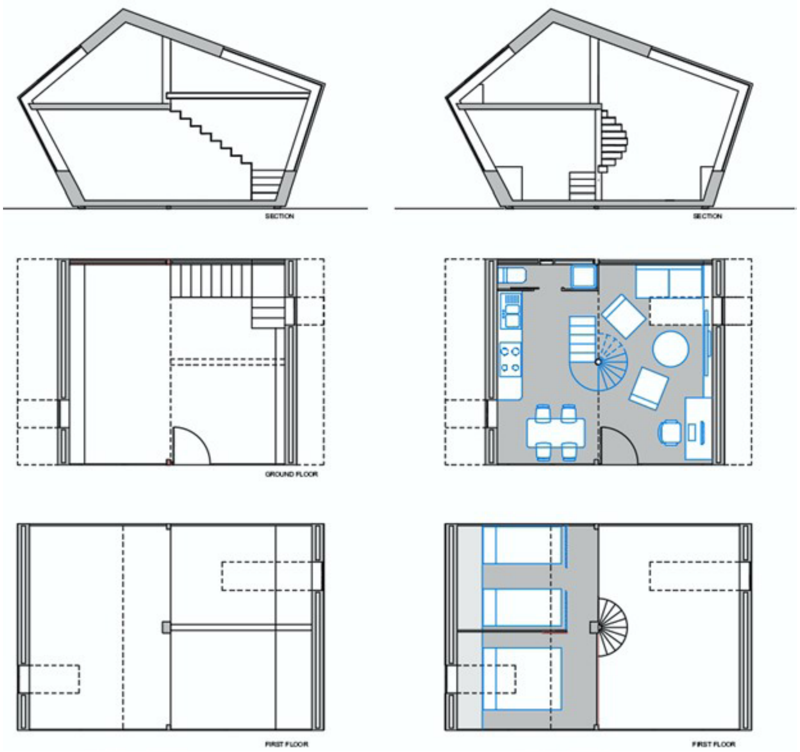

**Figure 6:** Current status of the built prototype and planned accommodation distribution.

**Figure 7:** Module installation phases.

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With the experience obtained in this building, an improved model is proposed that allows better use for emergencies. It is important in the case of transitional housing that the building can accommodate a significant number of people, since the needs usually exceed the response capacity. The designed module allows up to six people to be accommodated in a single module (Figure 8) and up to twelve in a set of two attached modules (Figure 9). In the proposed model, the lighting comes from the front and rear facades and the roof. The party walls are blind, which allows the modules to be grouped in a compact way.

**Figure 8:** Proposal with simple modules.

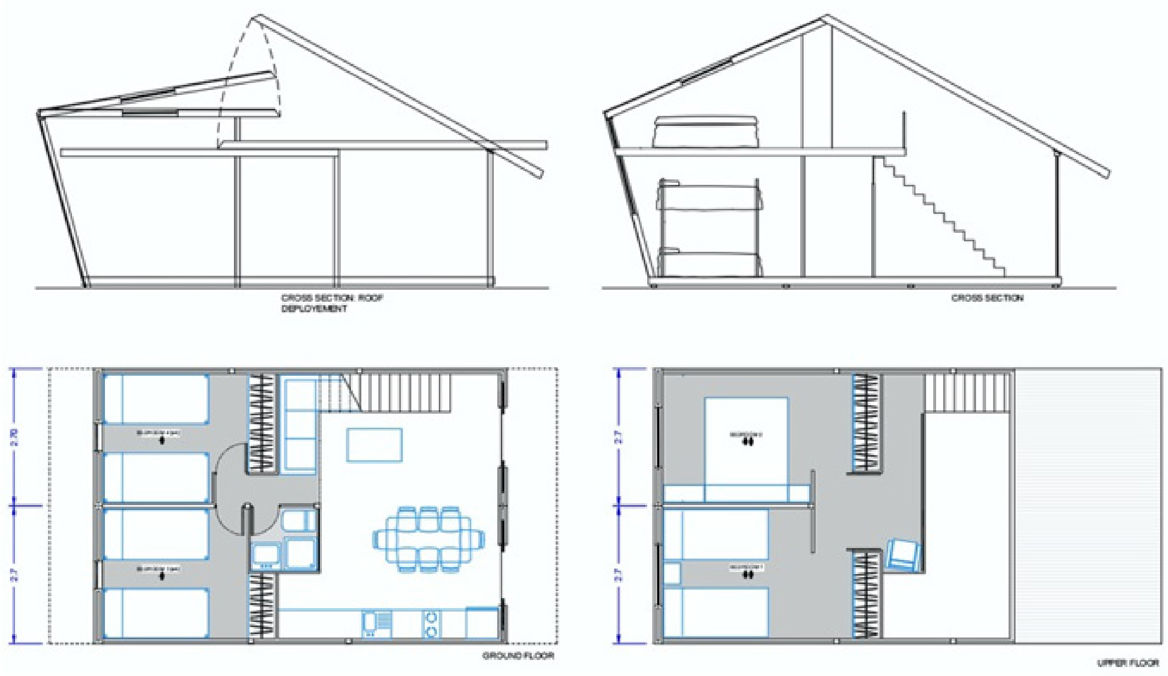

**Figure 9:** Proposal with two attached modules, forming a house.

## Transportable modules in pieces (prefabrication of component elements)

The second type of modules that has been analysed is the case of modules that can be decomposed into pieces that can be transported and assembled on site. In this case, for the modules to be useful as emergency housing, it is necessary that they can be assembled on site in a simple way, with reduced auxiliary means and by personnel who do not have prior training. This system is especially useful when it can be assembled by the users themselves.

For this purpose, a module has been designed and built for a minimum emergency housing consisting of a module 2.86 m wide and 6.38 meters long. It has a bedroom with capacity for four people in two bunk beds, a small bathroom and a kitchen area and a living room in which a folding bed can be arranged for another two people, so the total capacity of the module could reach up to the six people (Figure 10). As the module is transported in pieces, it does not have the clearance limitations of the other two modules analysed, so larger homes can be designed. The small dimensions of this prototype are due to the budgetary limitations of the project.

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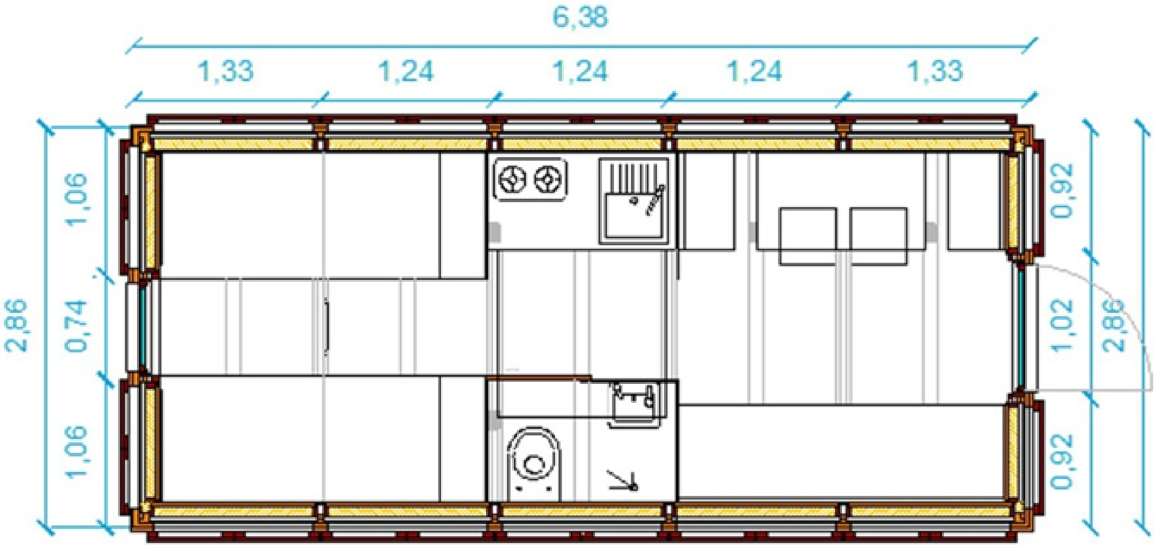

**Figure 10:** Module plan.

Its construction was carried out through an industrialized system, the UBUILD [41]. The system is based on the use of prefabricated wooden pieces made using a numerical control machine and assembled on site. The system solves joints with direct splices, without using hardware. The only tool necessary is a screwdriver, preferably an electric one, which can be supplied with the pieces. The building is assembled by direct fitting of parts and screwing them together, so the module can be assembled by two people in two days, although the most desirable thing is to have four people who could assemble it in one day. It does not require auxiliary means for assembly, except for a small scaffolding that must be provided for safety and that can be reused for other modules. The assembly is transported by lorry and it is convenient that it has a small crane to unload the packages of parts, which are of the appropriate size to be handled by two people.

**Figure 11:** Module assembly phases.

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The main advantage of this system is that the manufacturing instructions can be used in all types of numerical control machines. In an emergency situation, factories close to the affected area could receive manufacturing instructions and proceed as quickly as possible. By having the pieces available, the affected people could assemble the emergency building themselves. The built module was made in this way [42]. The manufacturing of the parts was carried out on numerical control machines in accordance with the instructions provided by the UBUILD Company. The pieces were transported by lorry to their location and the building was installed on January 24, 2020 on the A Zapateira campus of the University of A Coruña. In this case, it was installed on an existing slab so the foundation was not necessary, which in any case is very shallow, given its low weight. Its construction was carried out in one day, although some finishes had to be completed the next day (Figure 11). This finishing phase allows thermal adjustment and customization of solutions. The prototype includes several envelope configurations, allowing for a suitable adaptation to the climate of the site.

## Deployable panel modules (complete prefabrication)

The third type of modules analysed is a system of deployable buildings. Our team has carried out extensive research into deployable bar structures, but we have also studied deployable systems made up of rigid sheets, which in this case have resulted in the design of a module for emergency housing. This system has several advantages. It can be manufactured in the workshop, which allows a more precise construction, as it is foldable it can be transported in a very compact way and its installation and use can be carried out very quickly. The basic idea is a container in which the facades are folded towards the roof, the side walls are folded in the form of a gusset and the interior partitions are folded towards the floor, where a space is left to contain them (Figure 12).

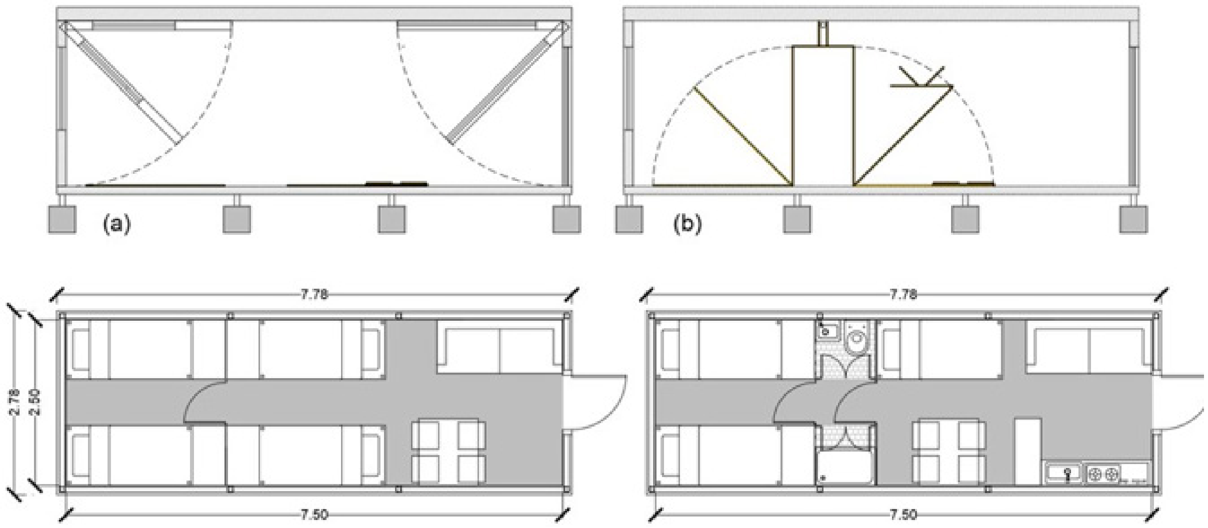

**Figure 12:** Plan and section of the module with the deployment system of the internal partitions.

The building can consist of two or three modules that are deployed successively forming groups of several floors, which in turn can be grouped to have common access to the upper floors. Access to the house is through a corridor with a railing that is initially folded and is deployed after unfolding the upper module. Each module is transported with its section of corridor, which is screwed together when coupling them. The module is arranged on the previously levelled foundation. Once seated, the cover is hoisted. Then the end walls are deployed from the inside. The building was installed on September 29, 2020 on the same A Zapateira campus and the deployment process lasted about two hours (Figure 13). On October 2, 2020, Hurricane "Alex" entered in Galicia with winds of up to 88 km/h, and since then there have been several episodes of even stronger winds. In all cases, the module resisted perfectly without any damage.

As indicated, groups of two and even three modules can be deployed. Figure 14 shows the deployment system. First, the module package is placed on the foundation and fixed to it. Lifting with the crane, the upper module is deployed at ground level, including the corridor and railing area of the upper floor. At this moment and at ground level, the interior partitions are deployed, the furniture is placed and the facilities of said floor are connected. Next, the lower floor is deployed and the connection to the facilities is subsequently concluded. The most operational thing is the joint lifting of three modules joined horizontally which, when separated from the adjacent groups by means of stairs, allow easy access and adapt to the ground levels. Given the lightness of the modules, a normal crane is capable of lifting a set of up to three groups of modules at the same time, simplifying assembly tasks. A similar lifting system, but using jacks instead of a crane, was successfully developed in a previous research project [43,44].

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**Figure 13:** Module deployment phases.

## Clustering of modules

In all cases, it has been planned that the modules can be grouped. The importance of reducing the space necessary for the installation of emergency housing in the expected environment of developed countries has already been discussed, where there are always serious problems in obtaining adequate land for the installation of a camp. In all cases, systems based on rectangular modules have been used in which the lighting and ventilation openings are located on both sides to allow the modules to be attached to others, forming more compact clustering. In the first case studied, the modules have an inclined roof, not allowing their grouping in height (Figure 15). On the other hand, in the other two cases the modules can be grouped into two or even three levels (Figures 16 & 17). The studies carried out advice that the grouping be limited to three levels, since greater heights would be difficult to access without elevators and on the other hand, the effects of wind would seriously penalize the foundations. It is considered that the most appropriate would be clustering on two levels.

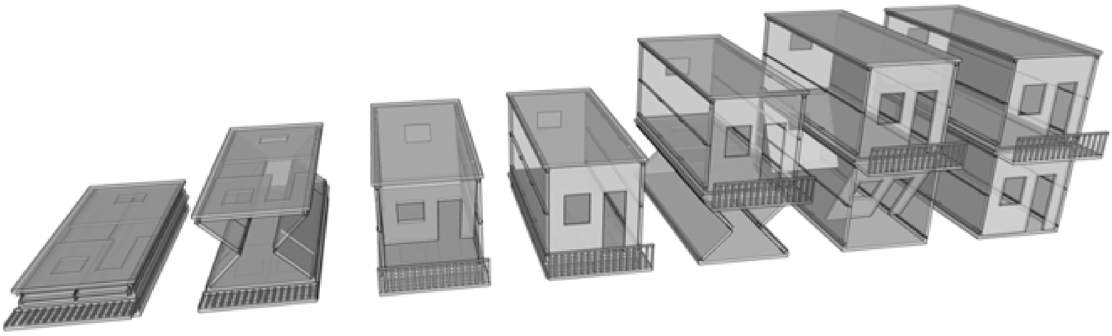

**Figure 14:** Deployment scheme of a set of two modules stacked vertically.

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**Figure 15:** Clustering of type 1 modules (Joel Cotardo).

**Figure 16:** Clustering of type 2 modules (Joel Cotardo).

## Results and Discussion

The main result of the research carried out was to demonstrate the viability of the proposed solutions (Figure 18). In all cases, the prototypes were installed very quickly and with reduced auxiliary means. In fact, the cranes used were those of the trucks used in transportation. The designed modules have some common characteristics. The enclosures are formed in all cases by trans ventilated facades with an interior wall of OSB board with an intermediate insulator and an exterior sheet that differs in the three prototypes. In the first case, it is solved with plastic sheets, in the second with a 20mm marine-type phenolic plywood board, with external Viroc sheets, a panel made up of a mixture of wood particles and cement, called Cement Bonded Particle Board (CBPB).) and in the third with

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ribbed metal sheets. Thermal analyses have been carried out in all cases that indicate that sufficient insulation can be achieved for the intended use and location. The floor in the first module was made in the workshop with a concrete slab, which added significant weight. To avoid this, in the other two cases, the flooring was made with an OSB board, but it was found that it was not suitable due to its difficulty in cleaning. Because of this, future research is analysing the possibility of using other lightweight materials, but more resistant to wear and easier to clean. One option that is being evaluated is the use of Superpan Tech, a structural board from the commercial FINSA, composed of wood fibber faces and an interior of agglomerated wood particles that allows the application of different wear-resistant coatings.

**Figure 17:** Clustering of type 3 modules (Joel Cotardo).

**Figure 18:** Set of built modules.

In the first module, the inclined roof was made with the same materials as the enclosure, adding a waterproofing textile sheet. In the other two prototypes, the flat roof was resolved with a 5 mm thick polybutylene PVC textile sheet reinforced with fiberglass stretched over a rigid frame. In all three cases, the system has worked correctly considering that they are located in a city with high rainfall. In all cases, the foundations were very small, except for the wooden prototype that was installed on an already existing slab. In the other two modules, the installation was carried out on small concrete cubes, which were made by making small excavations and filling them with concrete. In reality, the only work that had to be done carefully was the levelling of the supports. During the course of the research, various studies were carried out on ballast anchors that are sufficient for the actions transmitted by the designed modules.

## Conclusions

Modular transitional housing, partially or completely prefabricated, constitutes a valid solution for accommodation needs in emergency situations in developed countries, but to do so they must meet a series of conditions. It is necessary that they be cheap, since in general, the available resources are usually scarce and it is necessary in an emergency to care for the largest number of victims possible. It is also necessary that they be easily transportable without the need for special vehicles and they can be installed very quickly. One of the critical points of the fields is usually the layout of the facilities, which for reasons of efficiency and speed it is advisable that they be superficial or, where appropriate, very shallowly buried. Therefore, the modules must be designed to be separated from the ground, which allows the passage of said facilities. In general, this type of modules may have higher costs than other solutions, but if storage and reuse problems are adequately resolved, the module can be used in successive emergencies, allowing for rapid amortization of the initial costs. The results obtained allow us to affirm that the designed modules meet these conditions.

In the case of Type 1 modules, the home may be transported once the workshop has been completely assembled with all the necessary equipment to quickly come into operation, providing an immediate response to the needs of those affected. Its design allows prefabrication with all control guarantees and an adequate design allows repetitive manufacturing, reducing costs. On the other hand, the folding cover allows the usable surface and volume to be significantly increased. In the case of Type 2 modules, their main advantage consists of digital manufacturing, which allows parts to be machined quickly and the participation of workshops close to the affected area to which the data can be sent very easily, that allow machining. Also interesting is the capacity of the module to be able to form groups that allow better use of the available land.

In the case of Type 3 modules, their main advantage is foldability. The entire module can be folded including all facades and interior partitions. This allows for a particularly compact module in such a way that the requirement for storage space is reduced and in addition, in a standard transport, up to a set of five modules can be carried to the emergency area at the same time. It is even possible to transport a set of up to six modules hanging from a helicopter, in extremely urgent situations. Its assembly is especially quick and it can be ready for habitation in just one day. As in the previous case, the modules can be grouped into compact sets. The tests carried out have made it possible to verify the effectiveness of these modules in a reasonable period. It has been confirmed that no water leaks appear, despite being located in a very rainy area with a humid Atlantic climate. The structures and foundations have resisted perfectly even in situations of very intense winds, as has been noted. The temperature and humidity measurements of the modules have demonstrated patterns that respond to the theoretical calculations carried out, which ensure the habitability conditions necessary for their use in the anticipated emergencies. While it is considered that the modules designed can be an appropriate response to emergency situations, it is clear that they can by no means be unique and exclusive solutions. What is really important, is to have a stock of ready-to-use modules that can and must respond to various types. This is necessary both to avoid settlement monotony and to be able to respond to a wider range of situations of the affected population. The ability to respond with a wide variety of shelter types is the most desirable option.

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## Conflict of Interest

There is no financial interest or conflict of interest.

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