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Emergency Housing Solutions after Earthquakes: Innovative Technologies and Resilience Strategies

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Abstract: The international research project, developed through the collaboration between the University of Chieti and Pescara "G. d'Annunzio" and the École Nationale d'Architecture of Marrakech, aims to explore new strategies for emergency housing, with a focus on technological innovation and the resilience of temporary shelters. The main goal of the research is to define a more efficient housing module for post-earthquake scenarios, based on the analysis of the most advanced international solutions for first-response shelters. This study has made it possible to identify both the strengths and weaknesses of existing proposals, leading to the development of a housing model capable of improving living conditions during emergency phases. The objective is to propose an innovative housing module that not only addresses immediate post-disaster needs but is also adaptable to the specific socio-cultural characteristics of the affected populations. As a result of this work, the "DIVA—Variable Dimension Emergency Shelter" project was developed. This housing model stands out for its ability to adapt to the needs of different emergency phases, offering a versatile and customizable solution that effectively addresses post-earthquake challenges while ensuring respect for cultural specificities and improving quality of life.

Key words: Post-earthquake, housing emergency, emergency shelters, innovative and sustainable technologies, cultural specificities, well-being, experimental housing module.

1. The Marrakech-Safi Earthquake

The 2023 earthquake in Morocco, which occurred during the night of September 8th, was one of the most devastating seismic events in the country's recent history, triggering a large-scale humanitarian crisis with thousands left homeless and severe damage to infrastructure. With a magnitude of 6.8 on the Richter scale, the epicenter was located in the northwestern region along the Atlas Mountains, southwest of Marrakech (Fig. 1) [1].

The earthquake caused widespread destruction, resulting in thousands of deaths and injuries, particularly in the mountainous areas near the epicenter. The most affected provinces were Al-Haouz and Taroudant, but significant damage was also recorded in Marrakech, where buildings in the medina collapsed, and the city walls and mosques in the Jemaa el-Fnaa square were severely impacted [2].

According to official reports issued in the days following the disaster, more than 2,900 people lost their lives, and over 5,000 were injured. The hardest-hit towns and villages were in isolated and hard-to-reach areas. In particular, the remote villages in the High Atlas suffered near-total devastation, with entire communities destroyed. Many people were trapped under rubble, and rescue operations were hampered by the difficult access and lack of adequate infrastructure in these mountainous regions [3].

Roads and bridges were either destroyed or severely damaged, further complicating rescue efforts and the evacuation of people from affected areas.

Many regions were left without electricity or running water, and the destruction of hospitals and schools exacerbated the crisis. Although rescue centers were set up to treat the injured, in many cases, the lack of immediate access to medical care worsened the situation.

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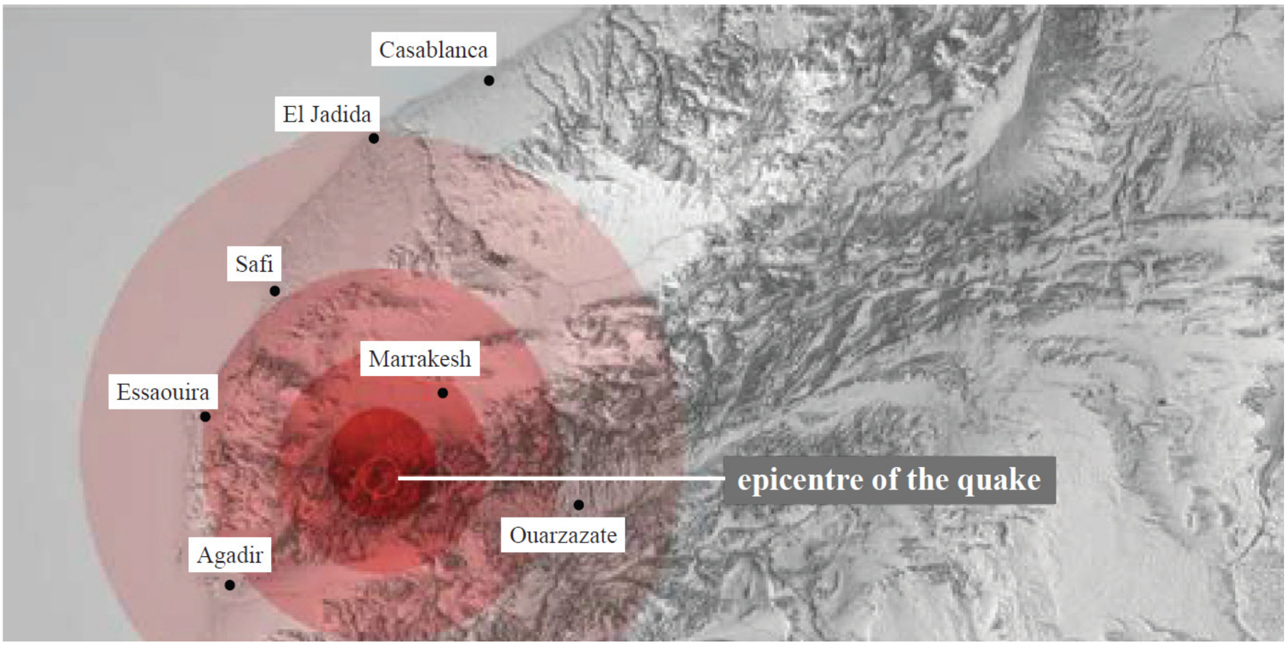

Fig. 1 Map of the Morocco earthquake affected areas: the epicentre of the Morocco earthquake started in the Al Haouz region, 44 miles from Marrakesh.

In the most affected areas, traditional Moroccan dwellings made of stone, clay, and raw brick collapsed entirely. While these constructions are well-suited to local climate conditions, they are not designed to withstand earthquakes of such magnitude [4].

Managing the displaced population became one of the primary challenges after the earthquake. Thousands of families were left without homes, and the Moroccan government, along with international organizations, worked to provide temporary shelters. The initial response involved setting up tents provided by the Moroccan Civil Protection and international humanitarian organizations. These shelters were established in both urban areas and remote villages most affected by the disaster [5, 6].

Displacement camps were set up near the most damaged areas, with tents and prefabricated shelters to temporarily house families. Emergency sanitation facilities and stations for the distribution of food and water were also installed in these camps. However, the immediate response faced logistical challenges, especially in rural and mountainous regions, highlighting the need for better preparedness and more resilient infrastructure to handle future emergencies.

Emergency shelters after the earthquake faced several significant challenges. One of the primary issues was the "quality and durability of the structures". In the High Atlas, where the earthquake's impact was greatest, nighttime temperatures can drop drastically, and many temporary shelters, especially tents, did not provide adequate thermal insulation to protect people from the cold, putting vulnerable populations like the elderly and children at further risk (Fig. 2).

Another challenge was the "vulnerability of shelters to weather conditions". Tents, being lightweight and easy to set up, offered insufficient protection against rain and wind, compromising the safety and well-being of the displaced.

There were also "space and overcrowding issues". The tents provided were often too small to accommodate large families, which is common in rural Moroccan areas, forcing many people to live in cramped and inadequate spaces.

Finally, the "prolongation of emergency conditions" became a major concern. As is often the case following disasters, temporary shelters tend to turn into long-term solutions. In the case of Morocco, many people remained in emergency shelters for extended periods due to delays in rebuilding permanent housing. The difficulties encountered in managing emergency shelters after the 2023 earthquake highlighted the need to improve resilience and enhance emergency response capacities, not only in Morocco but in all regions prone to natural disasters [7].

2. International Research Collaboration for Post-earthquake Recovery

The high seismic risk that characterizes both Morocco and Italy has prompted academic institutions from both countries to collaborate in researching solutions for post-earthquake emergencies. One of the most urgent and delicate issues in this context is the provision of temporary housing for displaced populations after natural disasters.

Delivering effective and rapid solutions is crucial, as ensuring safe and adequate shelter in the early emergency phases is essential for preserving human dignity and mitigating the psychological impact of disasters.

In the framework of the international collaboration agreement between the University of Chieti and Pescara "G. d'Annunzio", Department of Architecture, and the École Nationale d'Architecture of Marrakech, with the scientific coordination of Prof. Daniela Ladiana and Prof. Tayyibi Abdelghani, a joint research project was launched in December 2023.

The project, titled "Post-earthquake Emergency Housing Solutions: Innovative Technologies and Resilience Strategies" aims to explore new strategies for emergency housing, with a particular focus on technological innovation and resilience [8, 9].

The main objective of the research is to develop proposals for post-earthquake emergency housing solutions based on innovative resilience strategies. The project focuses on the design of housing modules that are not only functional and safe but also respectful of the cultural and social specificities of the affected communities. This approach aims to provide a significant contribution to the design of more efficient and sustainable temporary shelters that can respond quickly and flexibly to the needs of displaced populations [10].

In addition to evaluating traditional solutions, the research seeks to identify the benefits of applying new technologies and advanced materials that can improve the quality of temporary housing. Another goal is to demonstrate the importance of sustainable and modular solutions that can accelerate humanitarian response and facilitate long-term reconstruction.

The research is centered on the issue of emergency housing during the initial stages following a seismic event. This refers to short-term housing solutions that precede the establishment of temporary housing, which typically lasts up to three years and follows immediate emergency shelter until residents can return to their homes.

The first phase of the project involved an assessment of emergency housing solutions adopted in past seismic contexts. Traditional structures, such as tents and prefabricated shelters, were analyzed, with a focus on the shortcomings observed over time: lack of comfort, short lifespan, and poor adaptability to local cultural contexts. Experiences from earthquakes in Italy, Haiti, and other countries have highlighted significant issues, including lack of privacy, inadequate thermal insulation, and vulnerability to weather events [11].

The second phase focused on investigating technological innovations in the field of emergency housing. possibilities for creating more efficient temporary shelters.

Fig. 2 Temporary shelters in Morocco.

Fig. 3 Temporary shelter. Paper Log House by Shigeru Ban.

The introduction of advanced materials and prefabricated technologies has opened new possibilities for creating more efficient temporary shelters. The research analyzed biocomposite materials, modular prefabricated systems, and solutions that ensure greater environmental sustainability. Particular attention was paid to the integration of renewable energy technologies, such as solar panels, and water purification systems to enhance the autonomy and safety of affected communities

The third phase of the research explored the relationship between housing solutions and the cultural and environmental context. An in-depth study was conducted on the compatibility of temporary structures with the needs of local populations, particularly in terms of privacy, accessibility, and internal space distribution. The research also examined strategies to make shelters flexible and adaptable to different socio-cultural contexts, taking into account local traditions and customs [12].

A significant part of the work involved analyzing case studies and successful models, with the aim of identifying innovative projects already implemented in response to natural disasters (Table 1).

Among these, the UNHCR's (United Nations High Commissioner for Refugees) "Better Shelter" project and the modular solutions of architect Shigeru Ban are internationally recognized for their effectiveness in responding to emergencies and their positive impact on community resilience (Fig.3) [13].

These projects provide valuable insights for the research, as they offer concrete examples of how technological innovation can contribute to managing humanitarian crises effectively and sustainably.

In conclusion, the research aimed to develop a clear vision of the most promising technologies in the field of post-earthquake temporary housing, with the goal of understanding how to improve the quality of life during emergency phases.

The ultimate objective is to adopt housing solutions that are safer, more sustainable, and culturally respectful, through the proposal of an innovative technological and environmental model capable of responding to immediate post-disaster needs while adapting to the specific socio-cultural context.

3. Emergency Shelters

Research on emergency housing has focused on developing an innovative experimental module designed to improve living conditions compared to current solutions. After a destructive earthquake, housing response typically unfolds in three main phases: emergency shelters, temporary shelters, and permanent housing. Emergency shelters, often consisting of tents, provide an immediate and very short-term solution, offering temporary shelter during the first few weeks after the disaster. Temporary shelters, on the other hand, are designed to house displaced people for one or two years, before transitioning to permanent housing, which follows established building standards [14, 15].

The design of emergency shelters, upon closer inspection, requires more careful attention to balance their short-term nature with the need to provide dignified living conditions. Emergency shelters are often overly basic and should offer better living comfort, with particular attention to thermal insulation, protection from the elements, and privacy, especially considering the extreme climatic conditions to which they may be exposed. These aspects cannot be underestimated, as people may sometimes remain in these shelters longer than the initial phase of the housing crisis [16, 17].

The internal space layout must also ensure good functionality and adaptability to the needs of different family configurations. In addition to practical requirements, it is essential that these shelters be culturally appropriate and integrated into the socio-cultural and environmental context in which they are built. This not only facilitates acceptance and use by the affected communities but also helps maintain a sense of belonging and identity despite the precarious situation [18].

Given Morocco's susceptibility to earthquakes, emergency shelters must be designed to withstand aftershocks following the main event. It is essential to use lightweight yet durable materials capable of withstanding impacts and vibrations. These materials should also be easy to assemble and disassemble, allowing for quick deployment and, if needed, easy removal or relocation of the structures [19].

Another critical factor is Morocco's diverse climate, characterized by significant temperature fluctuations. In desert regions, summer temperatures can reach extreme highs, while mountainous areas experience cold winters. Therefore, shelters must provide good thermal insulation to protect residents from both heat and cold. Additionally, natural ventilation systems are essential to ensure proper air circulation, creating a comfortable indoor environment, particularly in desert areas where overheating is a significant issue [20].

The shelters must also be resistant to adverse weather conditions such as strong winds, heavy rains, and floods, which can occur in Morocco's mountainous or coastal regions. Waterproof and weather-resistant materials are crucial to ensure the safety and durability of the shelters. Given the scarcity of water in many regions, especially in rural and desert areas, it is equally important to integrate rainwater collection and purification systems, offering a sustainable water resource for the affected communities [21].

From a socio-cultural perspective, the design of emergency shelters must respect Moroccan family structures, where extended families and community dynamics play a central role. Privacy is vital, particularly by providing separate spaces for men and women. Modular shelters should allow for a clear distinction between public and private areas, supporting an organization of family life that aligns with traditional practices [22].

To these important characteristics must be added those generally required for shelters in the initial emergency phase:

- Ease of transport and assembly: They are designed to be easily transported and assembled, allowing them to be deployed quickly in disaster-affected areas.
- Rapid installation: They must be set up swiftly at disaster sites to provide safe shelter for those in need.
- Simplicity and functionality: Shelters should be structured simply yet functionally, offering essential living space for displaced individuals.
- Modularity: The design should allow for flexibility in size and configuration, adapting to specific needs and circumstances.
- Constructive reversibility: Shelters should be easily dismantled, enabling quick removal and restoration of the installation site.
- Sustainability: They must be designed with environmental sustainability in mind, using recyclable materials with low environmental impact.

Another important consideration is the inclusion of prayer spaces, as religion plays a crucial role in the lives of many Moroccan communities. Emergency shelters should incorporate areas that can be used for prayer or other religious activities, ensuring the privacy and tranquillity necessary for these essential practices.

From field experiences, including interviews and discussions with individuals affected by seismic events and subsequent housing loss, as well as from the analysis of case studies, essential environmental and technological requirements have been defined for the design of an experimental emergency module. This module must address not only environmental challenges but also the socio-cultural needs of local communities, ensuring solutions that balance durability, comfort, and respect for traditions [23-25].

Table 1 Main emergency shelters in use.

	**ShelterBox.** An international non-profit organization that distributes emergency kits containing tents and essential survival equipment. The tents are durable and designed to offer protection from adverse weather conditions. The kit also includes blankets, stoves, cooking utensils, and water purification systems. It is used in disaster-stricken areas like earthquakes, hurricanes, and conflicts in more than 100 countries.
	**Better Shelter (IKEA Foundation & UNHCR).** A prefab shelter, easy to assemble, designed by the IKEA Foundation in collaboration with UNHCR. This shelter is modular, durable, and includes a solar panel to provide lighting. It features a steel structure with water- and wind-resistant panels. The estimated lifespan is about 3 years, and it can be disassembled and transported easily and be used in various emergency contexts.
	**IRC (International Red Cross) Tents.** The IRC distributes tents specifically designed for emergency situations, intended to respond quickly to earthquakes or other natural disasters. These tents are easy to transport and set up, providing basic shelter for displaced families or individuals. They are weather-resistant for a short period. Used during emergencies in various parts of the world, such as the 2010 Haiti earthquake and the 2015 Nepal earthquake.
	**HabiHut.** A prefabricated shelter designed for quick assembly, with particular attention to water access and hygiene. It is modular, durable, and can be used as a home or a community service structure. It includes a rainwater collection system. Used in Kenya and other parts of Africa for communities affected by drought or natural disasters.
	**Exo Shelter (Reaction Housing).** Designed to be quickly deployed in disaster-stricken areas, the Exo Shelter is a modular solution with a rigid, lightweight structure. Each module consists of a rigid plastic frame, easy to stack and transport. It provides safe, durable, and thermally insulated housing. Used in emergency situations like earthquakes and hurricanes, its compact and flexible design enable a fast response.

4. DIVA (Emergency Shelter with Variable Dimensions)

After the analysis phase, developed by the two schools, which led to the identification of important requirements forming the basis for design choices, the research culminated in the definition of a prefabricated housing model. This model was designed to accelerate and simplify the setup phase of emergency shelters, while also ensuring a higher degree of privacy and comfort compared to current solutions widely used in the international context.

The goal of addressing the socio-cultural needs of local communities led to the creation of a flexible shelter, capable of adapting to different living situations and family configurations. The project is based on a modular shelter, available in various sizes, with the possibility of being customized according to the specific space and privacy needs of displaced families. This modular approach allows not only meeting practical shelter needs but also addressing the socio-cultural requirements that are essential to preserving the dignity and well-being of communities affected by natural disasters.

The modular shelter can be conceived in different configurations, with living units of variable lengths that can be adapted according to family size (Fig. 4). Larger families require more living space, and the modular system allows for the extension of the shelter to provide more spacious accommodation. Inside, the shelter can be divided into separate compartments using curtains or lightweight panels, creating a distinction between public and private spaces, and offering some degree of privacy for family members. This is particularly important in cultural contexts where privacy between men and women or between generations is a fundamental aspect of daily life.

Additionally, the shelter is designed to be easily adaptable to local climatic conditions. In regions like Morocco, for instance, the temperature fluctuations between day and night can be significant, and the shelter must provide adequate thermal insulation to protect its inhabitants from both the extreme daytime heat in summer and the cold of winter nights, particularly in desert and mountainous areas. To address this issue, the materials used must be lightweight yet resistant to weather conditions.

The integration of natural ventilation systems is essential to maintaining a comfortable indoor microclimate, especially in areas where heat can become unbearable.

Another essential design element is sustainability. The shelter must be built using recyclable and low-impact materials. This not only reduces the environmental footprint but also ensures greater durability and ease of dismantling and transportation. The shelter's reversible construction allows for quick disassembly once the emergency is over, facilitating the restoration of the installation site without damaging the surrounding environment. This is a crucial aspect in the post-crisis phases, as it aids in the return to normalcy without leaving invasive traces on the territory.

From a technological perspective, DIVA was designed to integrate innovative solutions that improve the quality of life for its inhabitants during the emergency phase. These include solar panels for providing low-cost renewable energy, systems for collecting and purifying rainwater to ensure water autonomy in areas where water supply is limited, and the use of fire-resistant materials to enhance safety. These technologies not only meet the immediate needs of families but also represent a step towards greater community resilience, in line with environmental sustainability principles.

DIVA modules can be transported to the disaster site, placed in designated areas, and assembled and activated by non-expert personnel through simple and quick operations, which consist of positioning the base pallets and placing the coverings over the pre-set structure.

The module consists of two interconnected parts: a fixed, rigid section and a mobile section that unfolds accordion-style (Fig.5-6).

The rigid part, a service block 1.5 m deep, serves as the container for the extendable, mobile section during transport; the extendable part, once deployed over the base platforms, forms the living area.

The rigid part, fully prefabricated, is made of welded steel box profiles, with cladding of honeycomb aluminium panels bolted to the structure, and insulation made of rock wool and cork.

In the mezzanine area above the sanitary facilities, there is a small tank to supply water to the washbasin, while the toilet requires no water supply, as it uses a small incinerator to dispose of waste, with maintenance limited to emptying a bag of ashes. Finally, on one side of the roof, there is a thermal panel that allows part of the water in the tank to be heated and used in the bathroom.

The extendable part, which allows the unit to expand and contract, consists of a series of wooden portals, spacer elements, and protective, waterproofing covers made from a combination of rip stop nylon on the outside and reflective polyester on the inside. The extension mechanism is facilitated by wheels at the base of the portals and X-shaped connecting elements that link the portals in sequence.

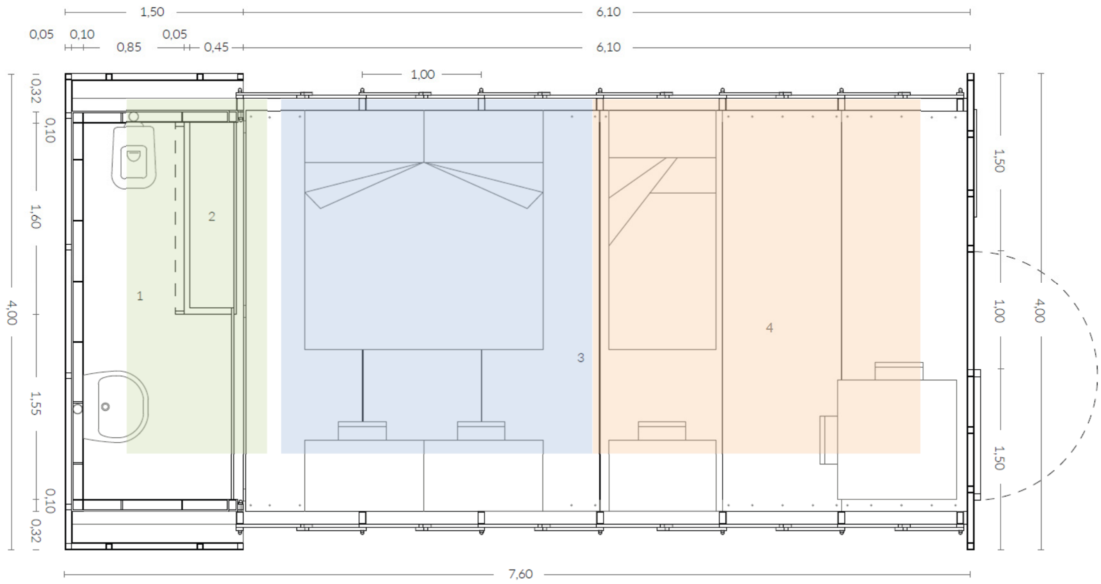

Fig. 4 DIVA—Emergency shelter with variable dimensions. Plan of the basic module.
1—Bathroom, 2—wardrobe, container, 3—night accommodation, 4—day accommodation.

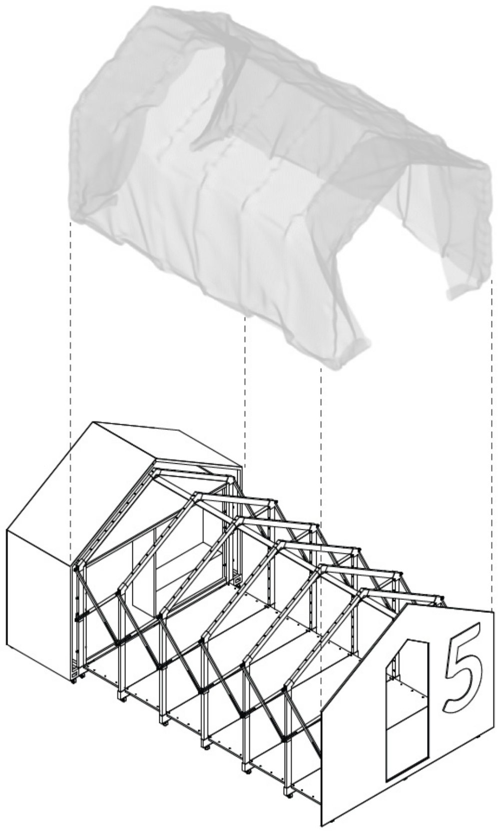

Fig. 5 DIVA—Axonometric view of components.

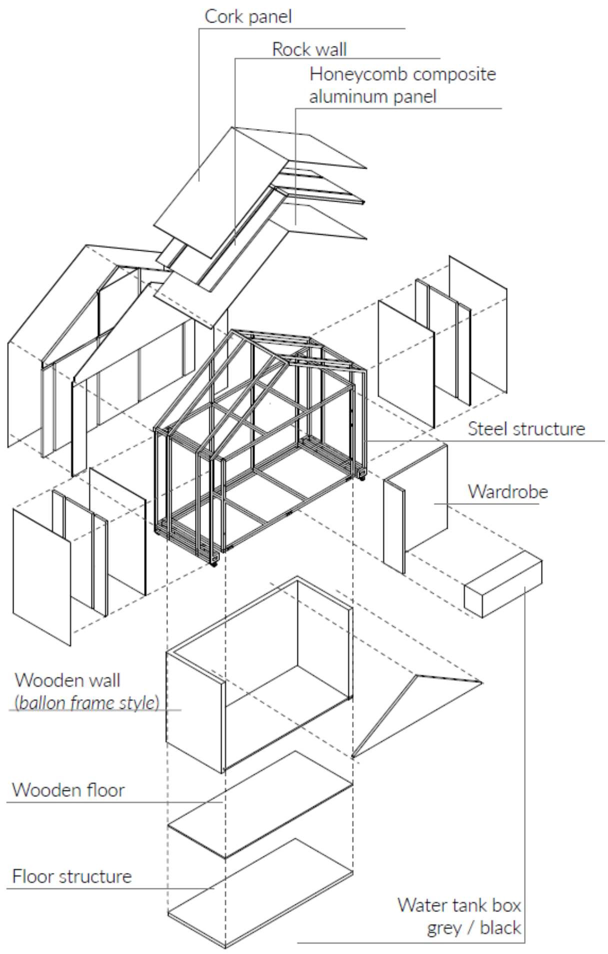

Fig. 6 DIVA—Axonometric view of the a service block.

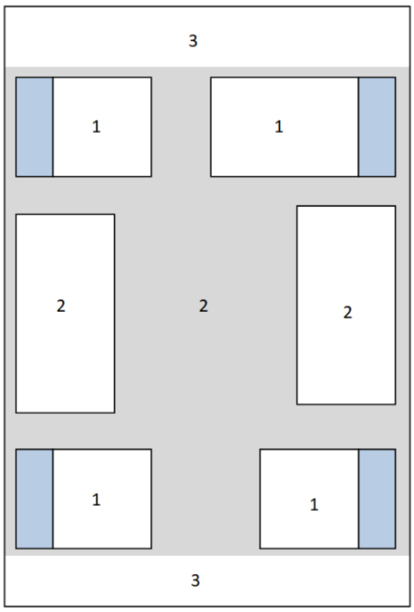

Fig. 7 Central space settlement model realized with DIVA. 1—residential unit, 2—relationship space, 3—street.

After full extension, these can be locked to ensure the stability of the configuration. The wooden flooring between the portals further guarantees their spacing. The structure's assembly is completed by connecting magnetic LED (Light Emitting Diode) rods along the roof ridge, providing internal lighting at night.

The ability to combine multiple modules makes this type of shelter particularly versatile. Each module can be used individually for small families or combined with others to create larger spaces for extended family groups. This system allows for great flexibility in terms of space configuration and offers a dynamic and customizable response to different housing needs (Fig.7). Additionally, modularity enables easier maintenance and the possibility of extending living spaces, if necessary, during the evolution of the emergency.

5. Conclusions

The collaboration between academic institutions in Morocco and Italy marks an important step in research on post-earthquake housing solutions. The adoption of innovative technologies represents a promising approach to improving living conditions for displaced people. This research not only contributes to a more effective emergency response but also to building greater resilience in communities exposed to seismic risk.

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