Abstract

The FlexHab project of Alta Scuola Politecnica aims to study an application solution for the MadFlex (developed by Composite Research s.r.l.). It is a composite material panel, with a layered structure, basically a sandwich-like structure. Thanks to its innovative mechanical feature, the panel is flexible, even rollable, on one side, while it is absolutely crushproof on the other. The preliminary analysis of different fields of application has shown how the potential of MadFlex is addressed in the critical context of disaster management, for the construction of emergency shelters. In the Italian context, the "Recovery period" is conventionally split into "Medium-term supplementary reconstruction sub-period" and "Definitive reconstruction sub-period", in which shelter solutions are wooden houses, containers and SAE. The FlexHab project proposes a solution able to eliminate the first sub-period and to significantly reduce the overall timing of the "Recovery period”. Crucial elements of the research are the interface with an innovative material with no applications and any technical tradition, and the conception of a constructive and technical system coherent both with it and with the specific requirements of the emergency shelters topic (adaptability to different weather conditions, reversibility, high performance, easy to transport, easy to storage, sustainability, affordability, flexibility and modularity). The objective of FlexHab is to conceive a shelter solution both for the private market and for a revolution of the disaster management processes, combining the requirements of comfort, flexibility, smart technical solutions and life cycle sustainability.

Keywords: emergency shelter, lightweight structure, composite material, innovation, performance, comfort, sustainability, modularity

DOI: 10.30448/ts2019.3245.37

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Peer-review under responsibility of the TensiNet Association
1. Introduction

The FlexHab project investigates a possible field of application for a new composite material, the MadFlex, and develops a specific construction technology regarding flexible housing solutions. The material has been developed by Composite Research srl.

Some crucial points of the research are how to approach an innovative material with no existing applications and to define a constructive and technical system consistently with the materials’ properties and with the specific requirements of the emergency shelters’ topic.

The preliminary analysis carried out, concerning the different possible fields of application, has shown how the potential of MadFlex is addressed to the critical context of disaster management and can be efficiently deployed in the construction of emergency shelters. In the Italian context, the “Recovery period” is conventionally split into “Medium-term supplementary reconstruction sub-period” and “Definitive reconstruction sub-period”, in which shelter solutions are wooden houses, containers and SAEs (Soluzioni Abitative in Emergenza meaning “emergency housing solutions”). The FlexHab project proposes a solution able to eliminate the first sub-period and to significantly reduce the overall timing of the “Recovery period”.

2. Project description

The project is concentrated on creating a technology push for a new material. The MadFlex (PCT WO2016120785 A1) is a lightweight asymmetric composite material panel, having a sandwich-like structure. It exhibits a two-order-of-magnitude difference in bending stiffness, depending on the direction of the applied bending moment, thanks to a reversible buckling phenomenon of one of its skins: it is flexible, even rollable, on the one side, while it is rigid like a traditional sandwich panel on the other one. In addition, the foam core confers to the MadFlex good insulation properties.

The design and the development of a novel flexible habitat starting from the potentialities of the new material face a multiplicity of research needs which has been integrated into a systemic approach and organized in four main steps:

1. The requirements identification: at the material / building component / habitat level. The new material is tested and its characterization orients the right matching with a set of technical requirements for adaptive structures and flexible skins;
2. The form + structure integrated design process: supported by advanced form-finding design tools and performance-based modelling tools;
3. The experimental phase, where a first demonstrator of the new adaptive skin is installed and tested to validate the behaviour of the new habitat and to optimize its final design;
4. The study of different application of the novel habitat solutions and the evaluation of social, economic and environmental impact by using multi-criteria analysis, Life Cycle Cost (LCC) and Life Cycle Assessment (LCA).

Figure 1: The two-order-of-magnitude difference in bending stiffness of the MadFlex.

The goal of the FlexHab project is then to design and develop a novel flexible habitat starting from the potentialities of the MadFlex. The main objectives are:

• Apply a multi-functional, flexible, “aeronautics-derived” composite material (MadFlex) to figure out futuristic habitat solutions;
• Improve a revolutionary approach to the building system introducing an innovative technology;
• Envision an innovative building skin, seamless and integrated with the structure, considering the industrial production requirements.;
• Satisfy user needs through an economical and social sustainable solution;
• Investigate performances and the economic feasibility of a basic adaptive habitat.

3. Problem understanding and opportunities exploring

The MadFlex is a composite material panel with a layered structure. The uniqueness of the MadFlex consists in its mechanical feature: the panel of MadFlex is flexible, even rollable, on the one side, while it is crushproof on the other. Investigating the possible scenarios where MadFlex properties could be determinant to perform a revolution inside the market, emerged
that the Emergency Shelter field was the most suitable to develop new innovative solutions. In fact, in the Emergency field the more relevant requirements are transportability (MadFlex is rollable and lightweight), constructability (MadFlex is lightweight and could be equipped in the production phase), performances (MadFlex has good thermal and mechanical performances), and customizability (MadFlex could be customized with many different finishings).

Looking for possible stakeholders involved in the Italian scenario and analyzing their needs, the main requirements have been outlined. Victims of calamitous events demand an increasing of comfort and quality of life inside the emergency shelters as well a more user-friendly solution closer to their houses. Institutions as the government and the Protezione Civile department require a decreasing of costs and time of the solution and an increasing of performances and social sustainability within the Recovery period. Finally stakeholders interested in trade, production and advertising of the FlexHab proposal are looking for the competitiveness of the project solution, that must be more sustainable, in terms of cost and social impact, of the existing ones.

In Italy, the Recovery period is conventionally split in different phases to which correspond different emergency housing solution. Firstly, temporary shelters as containers and wooden houses are used to provide an immediate aid; nevertheless, they are not positively evaluated by the population because of the lack of comfort and security. Meanwhile, SAEs (meaning

Figure 2: The emergency management process, Current situation applied in Italy and FlexHab innovative scenario.
“emergency housing solutions”) are built to host the disaster victims. They are well appreciated because of their tendency to look like as permanent houses, but, on the other hand, they are available too far from the catastrophic event. The FlexHab project introduces a solution able to eliminate the first sub-period, and consequently to change the nature of the Recovery period in the field of costs, time and social impact.

The MadFlex can be efficiently deployed in the construction of emergency shelters in the critical context of disaster management, thanks to many peculiarities intrinsic in the material, such as being flexible and rollable on one side, and stiff and crushproof on the other. It allows both an easy and efficient transportation/stock, and a rigid livable skin. Then one of the main assets was to design a shelter that would be easily stocked in a FlexHab kit that, as for common tents kits, is easy to transport, built and dismantled for future uses. Moreover, conversely to many composite materials, MadFlex can be moulded and accessorized in a continuous flow process, saving up to 50% of the cost spent with a warming process and meanwhile, addressing constructive needs as introduction of joints, during the production phase. Facing the emergency shelter issues, low cost and easy and fast implementation are fundamental requirements. As a consequence, modularity becomes a smart answer to fit industrial production necessities as well for the settlement and the architectural composition of the artefact. Furthermore, from an energetic point of view, it has good thermal and acoustic performances in relation to its thickness guaranteeing good thermal level of comfort for the shelter.

4. Project features

4.1. Innovativeness

The shelter’s design embraces, in single solution, the technology of the tent, easy and fast to deploy, and the “archetype” of the house, as a private and human scaled space. The goal of the design is to provide a just-in-time housing shelter being easy and fast to assemble, in order to avoid the need of temporary shelters as containers and temporary houses as SAEs. As a consequence of its being rollable and lightweight, meanwhile preserving its mechanical and physical performances, the MadFlex, in terms of transportation, is more competitive than the majority of construction materials available on the market. This was a further proof to start envisioning an innovative emergency shelter, easily folded into a FlexHab kit that, as for common tents equipment, is easy to transport, built and dismantle for future uses.

Analyzing the competitive solutions on the market and mostly looking into the Italian scenario, two emergency habitat solutions are deployed. Firstly the big emergency tents, then containers and other temporary shelters are used to provide an immediate aid, usually not positively
evaluated considering the temporality of the alienating situation. Afterwards, SAEs are built to host the disaster victims; even if they are quite well appreciated thanks to their homely look, they arrive too late from the emergency break.

The FlexHab kit ensures a just-in-time deployment, while its peculiar design, made possible by Madflex flexibility, reminds the archetype of the house, making it more likely to be appreciated by the users. The main feature of our design is the irregular pentagonal shape of the shelter. This asymmetry is conceived to allow, on each side, a different function as services, light and furniture with a high freedom for a user-based customization. Moreover, the pentagonal design, coming from the use of the modular Madflex panels, enables to set up the whole envelope through a single construction gesture. The shelter entrance is defined by a threshold, symbol of privacy and ownership. The interior space is composed by modules of 1.5 m that can be easily assembled in different combinations, adapting the shelter to the hosting group or family.

The shelter is equipped with basic services as kitchen and a soundproofed bathroom. Natural and artificial lights and interior spaces are carefully designed to fit man and its daily activities. The structure supporting the Madflex is designed on the whole length with wooden supports for extra furniture, allowing the customizability of the spaces. All those features allow FlexHab a valuable competitor in the market, able to supply both medium term and definitive reconstruction sub-period solutions.

Figure 3: Different modular configurations of the shelter and transversal section definition.
Figure 4: Rendering and plans of the shelter interiors depending on daily activities.
4.2. Technical soundness

Composite materials are usually produced with long and expensive techniques as wet/hand lay-up to shape composites on a predesigned mold. MadFlex can be produced through different industrial processes. It can be molded with a high cost warming process, or with a continuous flow process at 50% less cost. Furthermore, during that process, it can be easily accessorized to be further implemented and joined with other materials or MadFlex panels. Facing the emergency shelter issues, low cost as easy and fast implementation are fundamental requirements. Therefore, a continuous flow process was considered as a constraint for the whole design, that allows the production of panels of 1,5 m width and unlimited length, justifying the choice to introduce modularity to fit industrial production necessities. Furthermore, the issue of fast assemble of MadFlex panels is faced through the implementation of specific joints and polycarbonate windows straightly during the industrial production process. Between possible joints’ alternatives, it has been selected the most suitable for fast and simple employment, avoiding the necessity of specialized craftsmanship. To fix the MadFlex to the structure specific “socks” are implemented, made of the same strong material of MadFlex panels. These “sock joints” create a circular void to be inserted through the metal cables connecting each structural wooden frame. The MadFlex panels are afterwards joined through an high resistance and waterproof zip. As a result, no specialized craftsmanship, specific tools or heavy machineries are needed: MadFlex is the component with the easiest and fastest implementation of all the shelter and of any other envelope solution used in the market.

4.3. Feasibility

The level of feasibility of the solution has been verified from multiple points of view. The chosen Madflex configuration has been tested to verify its mechanical and thermal characteristics by Composite Research srl. Moreover, the durability to fold and unfold actions is already been tested and proved by the startup. Without any finishing touch the solution wouldn’t be user friendly and probably not accepted by the disaster victims, because of its alienating aspect. To overcome this constraint and provide an adequate aesthetic touch to the shelter, an exterior and inner finishing is applied and tested. The construction feasibility is proved with an intermediate model that have been built in scale 1:15. A mock-up real scale prototype and a whole shelter model at 1:20 scale has been also built to verify the feasibility of the construction process. They have been useful tools to verify and adapt technical solutions during an integrated and heuristic design phase. Further verifications regarding transportation issues have been carry out, designing the whole arrangement of the FlexHab kit in a standard shipping container. Each container is able to host a total of 6 FlexHab modules of 1,5 m, the equivalent of two shelter for two persons each, or a whole shelter for eight/ten people, including services and furnitures. One of the main goals of the project is to ensure that the solution is economically sustainable.
to guaranty competitiveness facing other solutions in the market. SAEs and solutions realized with traditional methods cost 1000 euro/m². A preliminary costs’ survey on which all the construction elements as well as furnitures and services has been carried out, clarifying the sustainability of the solution. The whole shelter costs around 950 euro/m². This amount would probably decrease if the price of several objects and system would be purchased on large scale.

Figure 5: Technical transversal section focusing on the main interfaces.
Figure 6: 1:1 Prototype - Overview and detail of the “sock guide”.
5. Conclusion

The FlexHab project proposes an efficient solution to manage the “Recovery period”. This revolutionary impact on the disaster management is allowed by the integration of the tent technology, as an easy and fast solution to deploy, with the home archetype, as private and human scaled space, in a unique FLEXible HABitat. “Flex” stands as flexible, since the initial point for the project has been the innovative material of MadFlex and its main peculiarity. Its morphology mirrors some of the potentialities of the materials. “Flexible” is referred both to the material’s behavior and to the internal space’s conception: in fact the design of the furnitures, integrated in the structure, allows for a different arrangement of the living areas according to day-times and night-times. “Hab” refers to habitat, the space of domesticity, a new and starting living fulcrum to heal the loss of a house.

Thanks to the pentagonal modular design and innovative joints introduced in the production phase, the whole envelope can be set up through a single construction gesture. No specialized craftsmanship, avoiding the need of specific tools and heavy machineries: only a complete “kit” with assembly instructions and technical support would be provided.

Figure 7: 1:20 Prototype - Final solution

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