SOFTENING THE HABITATS
SUSTAINABLE INNOVATION IN MINIMAL MASS STRUCTURES AND LIGHTWEIGHT ARCHITECTURES

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Alessandra Zanelli, Carol Monticelli, Marijke Mollaert, Bernd Stimpfle (Eds.)

Innovative Refugee Shelter Design with Pneumatic Sandwich Structure

Nuerxiati ATAWULA*, Alessandra ZANELLI[a], Carol MONTICELLI[a], Carlotta MAZZOLA[a]

* Politecnico di Milano, Campus Leonardo, piazza Leonardo da Vinci,32 ,20133 Milano, Italy, nuerxiati.atawula@mail.polimi.it

[a] Politecnico di Milano, Architecture, Built Environment and Construction Engineering Department (ABC) Campus Leonardo, via Bonardi 9,20133 Milano, Italy

Abstract

According to the record of United Nations Refugees Agency UNHCR in July, 2018 there are 68.5 million people around the world have been forced to flee from home. This is a huge number of population and they need a new place to live in.

In the present work, a proposal design of refugee shelter that made by "pneumatic sandwich" structure is demonstrated. The main concept of this design is using the pneumatic material to create a pre-fabricated structure. It is a shaped "airbag" that can be folded into very small size for storing and transporting, when it's needed it can be set up by pumping air inside. The compression of the air and the tension of the envelope can support the structure itself. Lightweight timber panels were added to both sides to strengthen it. The main goal of this design is easy transporting and quick assembling. This project aiming to provide a shelter that can be assembled in few minutes, without requiring for any technical skills.

Keywords: softening, lightweight structures, pneumatic structure, sustainability, performance, conceptual design, shelter, refugee camp, manufacturing, quick assembling.

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1. Introduction

1.1 Background Information

There are more displaced persons today than at any other time of the history in the world. Most of these people have been displaced from their homes by persecution, conflict, environmental disasters, and economic strain. By then they need shelters to live in within a very short time span. A shelter is critical for survival, but it also protects users from the extreme weather conditions and some certain natural threats, provides them with a basic sense of security, and a place for our families to interact. And it is impossible to provide them a real house or refugee camp in very short time in that uncertain situation. Shelter is a vital survival mechanism in times of crisis or displacement. It is also key to restoring personal security, self-sufficiency and dignity.

1.2 Layout of text

This report is divided in four main parts. In the first part the reason of this proposal design is explained by the fact of the world's urgent needs for a new type of quick assembling shelters. Since this design is based on the advantages of lightweight structure, the background knowledge about the lightweight structure is shortly introduced.

In the second part, the prototype of this proposal design is described. Then the detailed structural elements and constructing methods are explained. The following part is an evaluation of this proposal design concept. This part includes the cost analysis report, the advantages of the project and possible further developments.

The last part is the conclusion of this whole research. At last the author's own thoughts on this concept is mentioned.

2. Design Concept

In comparison to issues such as food, water and medical care, shelter design and performance is understudied and rarely evaluated, despite it being known that prolonged exposure to extreme thermal conditions can lead to morbidity and mortality.

2.1 The Current State of Shelters

When a natural disaster or conflict took place, thousands of temporary living spaces are needed within a very short time. At the most of time they are provided with a tent. If the time permits, there will be a short construction of harder shelters according to the local climate and available materials. But usually, considering the essence of the situations the needs for shelters exceeds the logistic capacity; consequently, the heavy and bulky refugee tent is abandoned in favor of simple, but more effective, plastic sheeting.

Even these shelters can provide a basic sense of security and a space at as an intermediate and transitional solution, but it cannot give a real safety condition and protection from the vagaries of climate and other unknown danger. Therefore, a new type of shelter is urgently needed for the refugees which can be transported and built in a short time, at the same time provide the basic living conditions that the current shelters cannot. In this case, the ultra-light weight materials and structures are the most probably competent objects that we can seek an answer from.

2.2 The Ultra-Light Weight Materials

For decades the lightweight structures are widely employed in architecture, engineering and building construction and find application in long span roofs for stadiums and exhibition structures; covered shopping malls; entrance structures; signature structures and sculptures as well as shade and environmental protection canopies. Generally, the self-weight of the structure is a small portion of the applied load or generated forces. Lightweight structures often utilize lightweight and high-strength materials as well as advanced technologies for their design and construction.

2.2.1 The advantages of the ultra-light weight structures

Ultra-light weight materials are coming with very clear advantages. It's widely regarded as the building material of future. From the view of construction, most of the ultra-light materials can be pre-factored in the factory or other spot, then transported to the site. This saves the cost and reduces the construction time. Meanwhile, ultra-light weight materials, such as membrane, timber, coated textiles and plastic materials have very strong flexibility, which allows designers and engineers to express their ideas in a new level that never seen before.

Moreover, as a light weight material, these materials are easy to transport. Beyond that, from the ecological point of view: ultra-lightweight structures are material-efficient due to the materials strengths are optimally used. Thus, no resources are wasted. At last, after use ultra-light weight structures may usually be disassembled, and their elements are recyclable. Therefore, are superior in meeting the requirement for a sustainable development.

In brief, ultra-light weight structures have the advantages such as:

a. Material saving;
b. Energy saving;
c. Construction cost and time saving;
d. Provide better architectural expressions
e. Improved durability

All these advantages reduce the restriction in architecture design, especially give more possibilities in emergence shelter design. Then could meet the certain demands we are dealing with, such as: fast, light and low cost.

2.2.2 The Sandwich Structures

The merging of different materials to achieve a new material capability is always the best way to develop and optimize a building material. The reinforce concrete is one of the best and the most successful example of merging well-known materials and get a considerable performance. This allows us to have two or more different material's specific performance at once and take the full advantage of them. Using this method in ultra-light weight materials, we have developed the sandwich structures.

Sandwich structures can be classed as composite materials in that they consist of two or more individual components of differing properties which when combined result in a high-performance material. In contrast to monolithic composites - which consist of an intimate mixture of fibers (glass, Kevlar, carbon, metal, etc.) supported within a continuous matrix (e.g. thermoplastic or thermoset resin) - sandwich structures have a discrete structure in which a core material is bonded to, and faced with, a skin material. The skin material usually has a high stiffness, whereas the core typically has high compressive and shear strength. When these are bonded together, this combination gives the sandwich structure a high flexural modulus. This light weight sandwich structure panels have been used in aircraft and space industry, where a low weight is needed in combination with high stiffness.

As mentioned, the advantages of sandwich structural materials are its stiffness and strength on the one side and its light weight on the other side; without increasing the weight dramatically, higher stiffness and strength can be achieved. Also, sandwich constructions function as a thermal insulation or thermal transfer, depending on the materials used. Moreover, the dampening of vibration and noise is another significant benefit provided by core materials.

2.3 The Design Concept

Generally, Pneumatic Structural Systems are structures or buildings that utilize air pressure to ensure its structural integrity. Due to the flexibility and easy to construction, all the pneumatic structures are pre-fabricated in factories and set up by inflating air in a very short time. Therefore, it is the perfect structure for the emergency shelter. However, the skin material usually made from lamented membranes, consequently the pneumatic structures are not puncture-proof and not suitable for extreme climates.

In this case, the concept of pneumatic sandwich structure design is aimed at using the characteristic advantages of the pneumatic structure and, at the same time, give it an external

protection. Arising from this, the pneumatic sandwich structures for refugee shelter is designed as an inflatable air-bag with thin timber panels on the both sides. The core part is a general pneumatic structure which provides the main structural support, and the timber panels will provide an external protection as a skin. Indeed, the timber panels also provides the extra strength and a considerable thermal insulation.

3. Concept Development

3.1 The Prototype

As it mentioned above, after the design of an innovational pneumatic sandwich structure, a suitable form applied on this structure to shape a shelter. As a result, the prototype of the shelter is a foldable rectangular unit in a transportable size. (Fig 1) The size of the main structure is 1.5m x 2m x 11.2cm. After unfolded there will be 4 sandwich panels connected. It simply needs to be inflated air in the "airbag" and set up to the designed shape. Then insert the base component in the main structure and fill up with soil. At last, use the enhancing pipes and straps to stabilize it. Two of these components creates one whole shelter with 3mx3m inner space. (Fig 2)

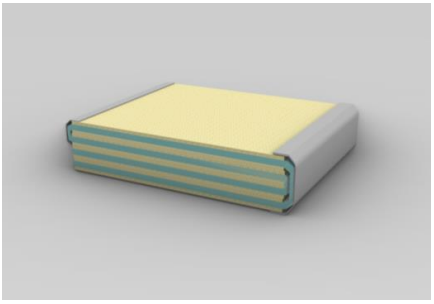

Figure 1: The folded shelter

Figure 2: The fully installed shelter

3.2 Structural Detail

3.2.1 The Main Wall

The main wall and roof part are designed as an integrated component. It has four parts connected together and all of these parts designed in same material and in same size (1.5m x 2m x 2cm). The Pneumatic material is around 1cm thick without air. And the plywood panels outside are 9mm thick.

One different design of this proposal from general pneumatic tent is this “airbag” core designed as air mattress which means it only requires air inflating once and seal the air cock, does not require continuous air pumping. And the inflating can be done by a simple hand pump or any other inflator. To strength the structure and reduce the onsite construction, there

are two extra flexible canvas part deigned as built-in prefabricated portion of the main structure. They are the triangle canvas including a plastic window and the underlying connection between the two walls. The installation step of the main structure is: first, unfold the structure and expand it to the designed shape. Second, when it is completely unfolded then start to pump air. After it got the required amount of air pressure that can hold the structure. It will become a stabilized structure when it's fully filled with air. (fig 3)

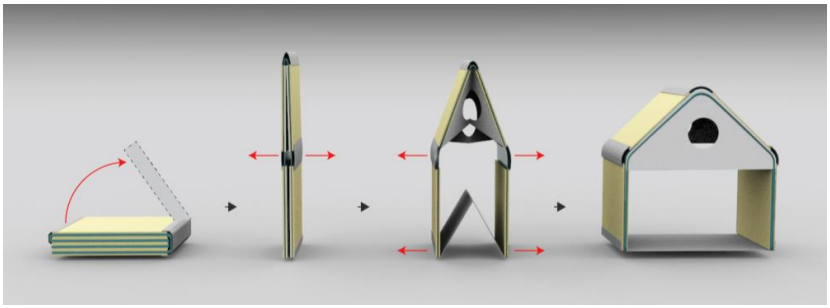

Figure 3: The main structure installation steps.

3.2.2 The Base

The base is designed as a unique component. It's similar to the main part as a sandwich structure. But unlike the main part, this one is a canvas tank and it can be filled with water, soil or sand according to the available source of the site surroundings.

The size of the empty base component is 1.5m × 3m × 3.4cm. It can be folded to 1.5m × 1.5m × 6cm size for preserving and transporting. When it is filled the full size will be 1.5m × 3m × 20cm. The volume is 0.9m^3. If it is filled with water, the weight will be 900kg, if it is filled with soil or sand the weight will be around 1.5t. Therefore, it is heavy enough to hold the whole structure fixed on the ground. (Fig 4)

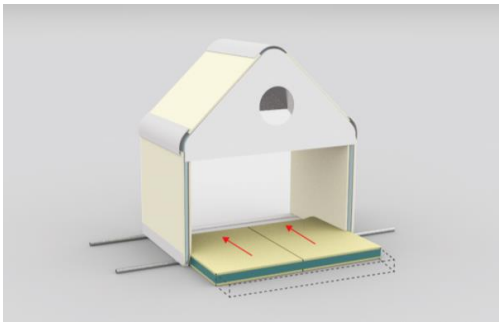

Figure 4: The base installation

3.2.3 The Structural Enhancement Pipe

Even the proposed pneumatic structure can hold the main structures and the self-weight, but due to the unstable shape of the shelter, there is extra structural elements needed to preserve the shelter from horizontal load, such as wind.

The proposal pipes are designed with lightweight aluminum. To make sure it is easy to package and transported with the other components, the pipes are designed as an extendable unit. One end of the pipe can be screwed in to another one's different ending. The original size of the pipe is 1.3 meter. Before the base is filled, extend the pipes by connecting four of them, and put under the base. There will be a notch under the main structure to hold the pipes as well. After the whole structure installed, the pipes will be fixed on the ground by the weight of the shelter. Then use straps to tie the pipes through the designed hole on the end to the strap holder joints (fig 5) on the upper part of the wall. These units can provide an enhanced bearing capacity for horizontal loads. (fig 6).

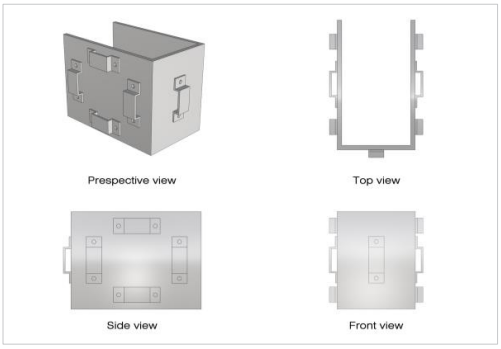

Figure 5: The joint detail

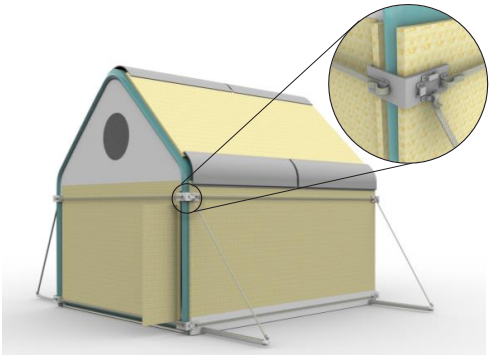

Figure 6: The enhancement structures

3.2.4 The Front and Rear Wall

By using the aforementioned components, a shelter can be completed, yet not enough privities and protections are provided. To improve the protection, there are two more components designed, using the same material- pneumatic sandwich panels. Both components are in the same size, but the front wall have a simple door that made by a thicker plywood panel.

The installation of these walls also designed as simple as possible. After all the structures installed, the walls can be inflated and tied with straps to the main structure and the base.

4. Concept Evaluation and Further Development

4.1 Cost Analysis

According to the proposal requirements and used materials, a preliminary market (cost) analyzing is made. Due to the most part of this proposal designed as a prefabricated whole unit, the fabrication cost will be the main cost of the project. Considering the main advantage of this proposal is easy installation and it can be set up by only 1~2 users themselves and all the necessary tools will be provided with the kit, then the construction cost is not involved. Because of wide geographical suitability of this proposal shelter, the certain location of the users is not defined. For this reason, the transportation cost is also not considered in this report.

In the view of fact that the lower price is one of the main demands of a refuge shelter, this cost analysis took place in the developing countries such as India and China which having the lower production cost. In extra they can provide inexpensive and convenient mass numbers of product transportation to all over the world by sea. The following cost report (Table1) is based on the lowest price collected from the manufacturers:

Table 1: Cost list of one kit

Item	Dimension	Quantity	Price of one unit	Total price
Inflatable Pneumatic Tent	1.5m×3m *	1	35 €/m^2	157.5 €
Plywood Panel	1.5m×2m×9mm	12	173.5€/ m^3	56.25 €
Strap Holder Joints	20cm×15cm×12cm	8	2.8€/Pieces	22.4 €
Connecting Canvas Unit 1	1.5m×20cm	6	9€/m^2	16.2 €
Connecting Canvas Unit 2	1.5m×3.2m	1	9€/m^2	43.2 €
Foldable Canvas Tank (Base)	1.5m×3m×20cm	1	35€/ m^3	31.5 €
Plywood Panel (Base)	1.5m×1.5m×12mm	4	193.5 €/m^3	20.8 €
Lightweight Aluminum Pipe	1.3m, Ø3cm; 0.894kg	8	4.4 €/kg	31.46 €
Strap	3.2m×3cm	10	0.8 €/m	25.6 €
Total				404.91 €

And we need two of this kit to build one shelter; After a fully cost data collecting and analyzing, the total price of this project is estimated approximately 820€ (Transportation not included). There is a list of comparison with other shelters on the market:

Table 2: Cost comparison with the other shelters on the market:

The Project	Type	Size (W×L×H)	Cost
UNHCR framed tent	Non-Pneumatic	4.15m×4m×2.4m	612€
Ikea better shelter	Non-Pneumatic	5.68 m×3.32m	1150€
PNEU-TEX by Ferrino	Pneumatic	5.1m×5.1m	6600€
FSI DAT Series Pneumatic Shelter	Pneumatic	2.13m×2.13m×2.4m	4327€
This Proposal	Pneumatic	3m×3m×2.3	820€

From this comparison we can see that, the pneumatic shelters on the market are extremely expensive that cannot be widely used as a refugee shelter. This market analysis shows that this project has an obvious advantage on cost. Due to the large number of shelters are needed and most of them provided by non-governmental humanitarian foundations and organizations, the low cost certainly is one of the main considerations of refugee sheltering projects.

4.2 The Advantages of The Project

This proposal shelter has several advantages, such as foldable unit, easy to package and transport, easy installation and suitable to various geographic and climatic conditions. At last but not least, this proposal shelter requires relatively low production cost.

Because it is a pneumatic structure, before inflated with air, the whole structure will be in a considerable small size. And the foldable design makes it small and flat panels. This will provide convenience for packaging and transporting. Even a large number of shelters can be piled up to stock or transportation without damaging the shelter and occupying large spaces.

The feature of pneumatic structure makes the shelter very easy to set up. Due to the design of the main structure as a whole unit, it just requires filling air with an inflator or a pump. Even one person can install the shelter without special construction skills.

Because of the moveable base and anchor design, the shelter has a very good compatibility to the various geographic featured areas, such as deserts, forests and grasslands, even some hard ground surfaces. What is more is that, due to the prosperities of pneumatic sandwich structure, this shelter has a good thermal insulation. It can provide relatively comfortable living condition in a hot or cold climate.

4.3 The Further Possibilities

Generally, refugee camps evolve during the time. After settled down and have through sometimes, the users will take some changes according to their daily needs or cultural habits. And what can be expected is the demands of the location that depended on climate and

geographical factors of the place, will drive the further developing or evolution of the shelters. This proposal design allows certain kind of later developing on the shelter. Here are some further development possibilities listed:

However, this proposal project designed as a component unit, it provides more easy way to enlarge or extend the space by merging or connecting more components. As the original shelter is designed to create a 3m x 3m space by connecting two of the components, it allows to create a longer space by connecting more components together. This will provide larger shelter or other service spaces such as temporary classrooms or stock house.

For a long-term use of the shelter as a housing, there is also the possibility to install solar panels on the roof. The original slope roof provides perfect angle and space for the solar panels. And the solar panels can improve the condition of the shelter by providing energy supply.

There is another creative development possibility for a hot climate area. Since the main structure of this shelter is pneumatic structure that needs to inflate air in it, there is also a possibility that fill certain amount of water in the lower part of the wall to get a considerable thermal insulation and a cooling effect. Of course, this concept only suitable in the area that have rich of water resource.

5. Conclusion

Lightweight materials and structures have been used for shelter and refuge housing for decades. The recent developments of new materials and light weight structures are providing more and more possibilities for improving the construction techniques and qualities of the emergency relief and housing.

This work also demonstrates that the innovative development of existing material possibly provides an improved feature for designing and construction processes. The development of this pneumatic sandwich structure started from the demands of the emergency housing, to ensure that the final outcome will satisfy the users and the demands. Among the development of this proposal project, different type of prototypes was considered for providing a better result and more practicability.

From a personal perspective, this proposal concept of a new pneumatic sandwich structure can have a good result in the expected time. The development and use of the pneumatic sandwich structure will provide more effective and efficient solution to the emergency shelter design. It is also possible to expand the use of this structure to other field of housing or temporary building. As a sum up even some most part of this paper is demonstrating the design of proposal shelter however the main purpose of so work is proposing the idea of pneumatic sandwich structure concept and the possible advantages it can provide, especially the

possibilities of providing a new and efficient way shelter design to meet the demands of some mass number of refugees around the world. Therefore, the prototype of this proposal concept may not be the best one but developing it could provide more practical use of pneumatic sandwich structure. The aim of the project is very clear, and its potential outcome in real development is very promising. I was highly motivated to work in this concept.

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