Foldable Disaster Shelter - An EPS@ISEP 2020 Project

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Abstract. This paper reports the research and design of a foldable disaster shelter for people left homeless due to natural disasters, by a multinational team composed of six students, from six different countries. The team was enrolled in the European Project Semester (EPS), a project-based capstone programme offered by Instituto Superior de Engenharia do Porto (ISEP), to students who have completed at least two years of undergraduate studies. The main objective of the project was to design, simulate and test an ethics and sustainability driven foldable shelter. This goal was pursued by conducting a series of studies to derive the solution requirements, involving a survey on shelter concepts and solutions, a review on worldwide natural disasters, as well as an analysis of the shelter market. The latter led to the definition of a business plan, a marketing strategy, a logo and a brand name. The solution comes with a Web application to help rescue organisations to follow the scheduled maintenance plan and keep track of the deployed units.

Keywords: Collaborative learning · Project-based learning · European Project Semester · Sustainability · Multicultural · Multidisciplinary

1 Introduction

The European Project Semester (EPS) is a one-semester capstone study programme offered by 19 European engineering schools, including Instituto Superior de Engenharia do Porto (ISEP), to 3rd and 4th year engineering, business and product design students. EPS adopts project-based learning and teamwork methodologies to prepare engineering undergraduates to think and act globally,

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with all the necessary skills to face the challenges of today's world economy. This approach fosters the development of complementary skills together with ethics, marketing and sustainability.

The EPS programme provided by ISEP – EPS@ISEP – is a package of 30 European Credit Transfer Units (ECTU) with two thirds of the credits (20 ECTU) assigned to the project module and one third (10 ECTU) to complementary project support modules, comprising Project Management and Team Work (2 ECTU), Marketing and Communication (2 ECTU), Foreign Language (2 ECTU), Energy and Sustainable Development (2 ECTU) and Ethics and Deontology (2 ECTU). Apart Foreign Language, the 2-ECTU modules are project support seminars oriented towards the specificities of each team project [5,6].

In the spring of 2020, a team of six students decided to develop together a safe foldable disaster shelter for people left homeless due to natural disasters. Team members were a Portuguese automotive mechanical engineering student, a Romanian industrial engineering student, a French structural materials engineering student, a Belgian product engineering student, a Dutch physical engineering student and a North Macedonian digital business informatics engineering student. Together, they started by conducting a review on worldwide natural disasters and researching the shelter market, from emergency to animal shelters, in order to support a decision on the type of shelter best suited for the project. This study also aimed to determine in which situations the shelter could be deployed and to specify the desired characteristics, so the product would be able to set itself apart from others and have a meaningful impact on the market. The work done during this phase led to the definition of a business plan, a marketing strategy, a logo and a brand name: SafeBIS (Fig. 1).

Fig. 1. SafeBIS logo

In the design phase of the project, Computer Aided Design (CAD) and Computer Aided Engineering (CAE) tools were used intensively to draw, model, simulate and test virtually the entire prototype of the shelter. The functionality of the prototype was assessed performing simulations with CAD software Solidworks® and CAE software Solidworks® Simulation. A prototype was conceived but, in the end, the team was unable to create a physical prototype of the shelter due to the constraints caused by the COVID-19 pandemic. During the design process, all decisions considered the sustainability and ethical impact of the alternatives at stake.

This paper provides an overview of the learning process the team followed during this project. There are four additional sections: Sect. 2 surveys existing solutions and analyses the related marketing, ethics and sustainability

perspectives; Sect. 3 presents the concept, design and architecture, together with the development and simulation of the proposed solution; Sect. 4 discusses the results of the project; finally, Sect. 5 concludes with a summary of the project and personal student outcomes.

2 Background Studies

The background studies focused on the basic principles that define a shelter, its main functions, existing designs and the possible features and functions that can be added. A brief market survey on related products was done, as well as on applicable standards, together with ethics, marketing and sustainability analyses. This allowed the team to derive SafeBIS's requirements.

2.1 Applicable Standards

To grasp what an emergency shelter should be like, what purposes it must serve, it is necessary to understand what it really is. For that, the United Nations High Commissioner for Refugees (UNHCR) created the Emergency Handbook, a guide to humanitarian responses [9]. The standards presented here represent the minimum set of internationally recognised quantifiable standards applicable throughout all operational stages [2].

Emergency Shelter Standard. According to UNHCR, "a shelter is defined as a habitable covered living space providing a secure and healthy living environment with privacy and dignity". The basic requirements of any shelter are:

- Protection from the elements, space to live and store belongings, privacy, and emotional security;
- Provision of blankets, mats, and tarps;
- Promotion of cultural, social and family roots and, when possible, adoption of local materials;
- Resistant to local seasonal weather patterns;
- Empowerment of refugees by providing the necessary organisational and material support to build their own shelters.

The last requirement helps dwellings to meet the occupant's needs, generating a sense of ownership and self-reliance while reducing costs and construction time considerably. However, it can only be followed if the materials and tools are locally available. Otherwise it is advised that the shelters and/or the necessary materials be brought into the area.

Shelter Design. The design of a shelter must contemplate the following aspects:

- Follow standards regarding the minimum dimensions, which are dependent on the type of climate where the shelter will be deployed;

- Consider the climate and the time people will spend inside the shelter;
- Endure strong winds, heavy rains and snowfall;
- Protect from debris;
- Include protected and heated sanitary and kitchens facilities;
- Protect the human body from heat loss, particularly during sleep;
- Create a living space;
- Maintain a comfortable temperature;

Shelter Solutions. UNHCR [10] presents some other characteristics and concerns to be considered when designing a shelter as well as an *Emergency Shelter Catalogue* [8]. The location will impact the response, therefore, the specific characteristics of an urban shelter differ from those of a rural one. Shelter responses need to be adapted to the local context and climate, cultural practices and habits, local skills, and available construction materials. Rarely one shelter solution fits all the needs of the displaced populations. Table 1 summarises the various settlement options with their most associated shelter solutions.

Table 1. Various settlement options and most associated shelter solutions [10].

Settlement	Most frequently used solutions
Planned and managed camps	Tents; Shelter kit; Plastic sheeting; Transitional/Temporary shelters; Local construction materials
Hosting villages	Shared accommodation or shared property - Plastic sheeting; Shelter kit; Local construction (one room); Cash assistance
Dispersed self-settlement without legal status	Tents; Plastic sheeting; Shelter kit; Cash assistance
Short-term land, house, apartment, or room tenant	Individual or shared accommodation - Cash assistance; Plastic sheeting; Shelter kit; Local construction
Collective centres, non-functional public building, transit centres	One room accommodation - Plastic sheeting; Shelter kit; Local construction (adaptation)

2.2 Related Solutions

The research on shelters included recreational and animal shelters. Recreational shelters, ranging from rooftop or instant tents to inflatable or origami shelters, have characteristics that can be considered for the project:

- The rooftop shelter brings an interesting way to unfold the tent and the possibility to place it on every desired place. However the price is high and the disassembly process requires skills that can only be learned over time. An example of a rooftop shelter is illustrated in Fig. 2a.

– The inflatable shelter has the advantages of being light and easy to repair. However, being forced to stand on flat ground is a downside, as well as requiring a pump to fill it with air. An example of an inflatable shelter is illustrated in Fig. 2b.
– The instant tent is light, quick to set up and easy to repair. However, when choosing the tent spot, the angle and roughness of the terrain must be taken into account as the bottom of the tent is made with only one layer of fabric so changes in terrain are noticeable. An example of an instant tent is illustrated in Fig. 2c.
– Cardborigami is an origami tent that aims to provide long-term shelter for homeless people. The cardboard structure requires no tools to assemble and can be compacted easily and stored. The origami shelter is light as well, besides providing privacy, comfort and protection [3]. As the origami shelter is also heavy weather resistant, this type of shelter brings together the best qualities to be a disaster shelter. An example of the origami shelter is illustrated in Fig. 2d.

(a) Rooftop tent [12]

(b) Inflatable tent [7]

(c) Zomake instant tent [1]

(d) Cardborigami tent [4]

Fig. 2. Recreational shelters

Shelters for animals encompass: (*i*) makeshift shelters - temporary (up to 7 days), low quality, foldable, lighweight and easy to transport; (*ii*) covered areas divided into several smaller spaces by fences; and (*iii*) constructions for pets.

2.3 Marketing

While working on the market/economic analysis, the team broadened its vision and gained a better perspective of the market environment surrounding SafeBIS and emergency shelters. During the demographic analysis, primary and secondary targets were listed. The analysis of historical worldwide data, which shows a rising number of natural and man-induced disasters, involving the destruction of buildings and population relocation [11], indicates both the need and potential demand for disaster response shelters. The SafeBIS brand was defined and strategies were delineated to ensure a strong market entrance. To establish the presence of SafeBIS on the market and reach a large audience, the team decided to explore social media, investing on paid advertising and actively posting materials. Moreover, they created a logo and a website for dissemination and retention of clients. The logo is a reflection of the brand, where the colour orange represents the sense of a warm atmosphere and black of strength (Fig. 1). The honeycomb pattern refers to the shape of the shelters.

The team intends, through social media, to share and connect more easily with clients. A close relationship with clients will help to know what they want, how and where to reach them, consolidating SafeBIS position on the market as a known brand and a trusted company.

2.4 Sustainability

To achieve the highest level of sustainability, each of following pillars must be considered: the environmental, the social and the economical. Considering this approach, SafeBIS will focus on eco-friendly materials and on the adaptation to the local environment.

The selected materials need to be eco-friendly and able to withstand harsh weather circumstances, as this ensures a long life-span for the shelters. The team pursued this by using natural and 100 % recyclable materials, while designing an easy to assemble and disassemble product. The team also focused on using the minimum number of materials and components as possible. The packaging solution is designed to be compact to minimise transportation costs to the disaster areas, allowing 18 shelters to be placed in a single container. Regarding the production of SafeBIS, the team decided to choose solely eco-friendly facilities.

SafeBIS, thus, contributes to two of the United Nations' sustainable development goals: *Good health and well being* and *Sustainable cities and communities.*

2.5 Ethics

The team wanted SafeBIS to comply with ethical and deontological values, ensuring a good reputation for the company and the product. The company's values, strategies and actions influence the perception of the product and its purpose, so operating and applying human laws and requirements is of paramount importance. Concerning Engineering Ethics and the field of applicability, the utmost

concern during the development of the product is with safety, health, and well-being of the public.

Embracing trustworthiness, dependability and punctuality is a priority. From the early beginning of the design till the distribution of SafeBIS shelters, adopting a sustainable strategy and being in accordance with the principles of ethics is essential to ensure the connection between user and product. Regarding the marketing of the product, the team defended the adoption of an honest and transparent attitude towards customers as well as competitors. All aspects, engineering, marketing, sales, environmental must be taken into account in each step of this process. The main contribution of environmental ethics is to find the balance between social, economic, and environmental aspects while always attempting to make sustainable decisions.

2.6 Background Studies Summary

The different types of shelters analysed helped the team to reach a consensus about the essential shelter requirements, such as shape, structure and insulation.

The shape of the disaster shelter was considered the most important characteristic. A honeycomb shape was chosen because it is: (*i*) more efficient regarding the use of space when placing multiple tents; and (*ii*) an aesthetically pleasing organic shape.

A decision was made to build a structure with as few loose components as possible. So techniques like inflation, pipes and a hardshell outer layer were the main options. The final design of the shelter relies on a combination of hardshell and tubes to grant stability as well as foldability.

Regarding the materials for the shell, they need to provide thermal insulation, be relatively lightweight and eco-friendly to manufacture. The team believed that a combination of polymeric materials or fabric was the best choice.

3 Proposed Solution

3.1 Concept

The team's goal was to develop a shelter for people affected by a natural disaster around the equatorial area. The shelter is intended to offer four people a sleeping/living place. An hexagonal shape was chosen so a scaled community could be easily created by connecting several shelters together, allowing large families to live together. The shelter should have a good ventilation and be water resistant to provide a pleasant, temporary living place. The projected average period of use is between two to three weeks. All things considered, the SafeBIS shelter concept is comfortable and safe for users and easy to (dis)assemble, handle and transport for operators due to the integrated folding mechanism.

3.2 Design

To meet the requirements of the UNHCR, a minimum living area of 14 m^2 is needed to shelter four people, as every person requires a minimum area of 3.5 m^2. Moreover, the shelter should withstand a maximum internal load of 780 kg and winds up to 75 km/h.

The folding structure is made of aluminium square profiles of $50 \times 50\,mm^2$ and the walls and ceiling of the cocoon are in cotton fabric. The floor has a lower layer in aluminium sandwich panel and a top layer in cork to create a pleasant and homely atmosphere. The hexagonal outer structure has a 16.3 m^2 area, with 2.56 m edges, 5.11 m maximum width, 2.85 m maximum height and 0.3 m height legs. The living cocoon offers a 14.3 m^2 area with a 4.7 m width and 2.30 m height. When folded in the storage container, the shelter has a 1.22 m width, 4.39 m length and 0.73 m height. The structure weighs 75 kg, the fabric 30 kg, the floor 72 kg and the cork layer 10 kg, totalling 187 kg. Figure 3 shows a full view of the shelter model.

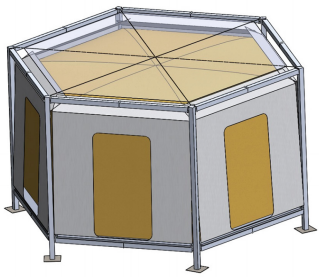
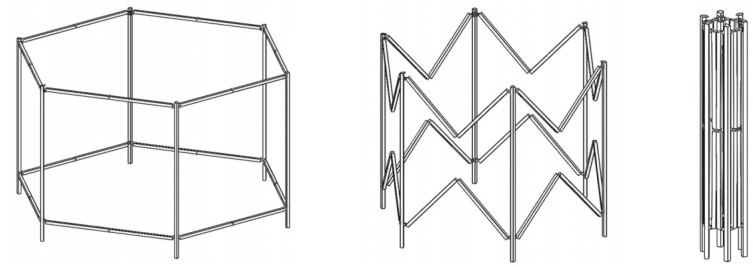


Fig. 3. Shelter model

Structure. The structure of the shelter was designed using Solidworks® CAD software and consists of six vertical columns, combined with foldable roof and bottom substructures. When pushing the vertical columns together, the shelter is compacted so it can be transported easy. When pulling the columns away from each other, a strong hexagonal shaped structure is deployed. The structure is reinforced with three steel cables, each cable connecting one top corner to the opposite top corner, helping maintain the integrity of the structure. The resulting system is easy to (un)fold and has no loose parts. Figure 4 illustrates the folding mechanism.

Thermal Protection and Ventilation. The thermal protection is deemed an essential requirement for equatorial areas, where shelters will be placed, due to extreme high temperatures, heavy rain falls and humidity. To address this issues, the shelter's design includes:



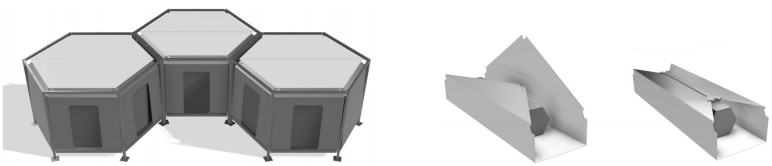
(a) (b) (c)

Fig. 4. Folding mechanism

- supports to maintain the floor elevated, so no water enters the shelter, and provide adequate ventilation underneath.
- a two-layered cocoon design, made of two types of cotton fabric, where the outer layer is waterproof. This design allows fresh air to flow between both layers, keeping the interior cool.
- a mesh fabric on the inner layer of the doors and window for ventilation. The users should open the outer layer and keep the inner layer closed.

Modularity. As the main objective was to design a shelter for large families to stay together, a honeycomb shape was chosen for the design of the shelters. This shape makes it possible to connect multiple shelters and create a community. Every shelter features three doors, which can be used to connect with other shelters. This is accomplished by using an extendable piece of fabric to connect two shelters together. Figure 5a illustrates the connection of three shelters.

Packaging. An innovative packaging solution was conceived by using the floor as a storage box for the remaining shelter parts. To transform the floor into a storage box, the floor splits in five parts which are able to fold as they are all connected to each other through designed hinges. This way, SafeBIS becomes very easy to transport, reducing costs and the impact on the environment. The storage container is shown in Fig. 5b.



(a) Modular shelter (b) Folded packaged shelter

Fig. 5. SafeBIS features

Tracking Website. To make the communication process between SafeBIS and the shelter owners more efficient, the team concluded that the best way was to create a website with a back-end database, for shelter owners to share information on their shelters. This information can only be accessed through authentication by the system administrator and the shelter owner.

3.3 Development

Due to the COVID-19 pandemic, this section describes the work developed by the team in order to simulate SafeBIS. ISEP closed on March 12th and team members returned to their home countries, making it impossible to build a proof of concept prototype.

Simulation Tests. To ensure that the final design withstands the load requirements due to the weight of the occupants and their belongings, numerical simulations using the finite element method were performed with Solidworks™ Simulation® CAE software. Several iterations were performed, enabling a reduction of the total weight of the structure and the floor, while maintaining an adequate safety factor. Figure 6 shows the simulation of the structure. The numerical simulations identified the hinges, connecting the columns of the foldable structure, as weak points. To address this issue, several models of hinges were designed and numerically simulated until they passed the aforementioned tests.

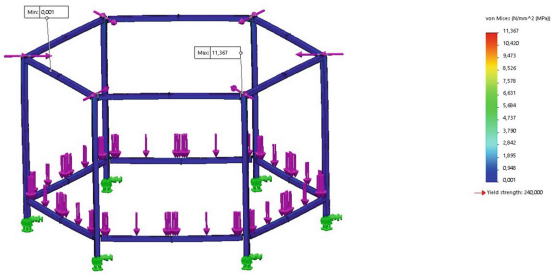


Fig. 6. Numerical simulation of the structure

4 Discussion

4.1 Simulations

The mechanical behaviour of the structure when subjected to the weight of its occupants and their belongings was numerically simulated. Additionally, according to UNHCR requirements, a family tent for hot climates must be able to withstand the effect of 75 km/h winds, be strongly attached to the ground and tensioned without any damages. The team was unable to do this simulation as the software used is not ideal to simulate fabric behaviour, so further development should address this issue.

4.2 Prototype

Due to restrictions caused by the COVID-19 pandemic, it was not possible to make a 1:1 scale prototype. The team created a scale model to get a better perception of the looks and operation of SafeBIS, but several limitations persisted. Namely, it was impossible to test if: (*i*) the cotton cocoon stays inside the structure while folding the shelter to its compacted configuration; (*ii*) the compacted configuration of the structure and cocoon fit perfectly in the storage box; and (*iii*) the proposed ventilation scheme maintains a pleasant internal temperature.

Future work should then include building a 1:1 scale prototype to check the listed limitations.

5 Conclusion

5.1 Project Outcomes

The team embraced the challenge of creating a successful business based on providing safe temporary shelters. To pursue this goal, team members created: (*i*) a marketing plan to promote the product to target people and organisations; (*ii*) a detailed business plan to specify logistics, costs and funding, supplies, and target consumers; (*iii*) an ethical and sustainability driven design for a packaged foldable shelter; (*iv*) a website with a back-end database; and (*iv*) multiple simulations to refine the design.

Another outcome of EPS@ISEP was the learning experience gained by team members by working together in the design of a solution to a real problem, in a multidisciplinary, multicultural environment. In the end, an excellent domain of soft skills was evident in the coordination of the work, despite having been done mainly online due to the COVID-19 pandemic. Each member of the team developed communication, negotiation, and collaboration skills, while contributing and consolidating his/her previous knowledge and acquired knowledge in other disciplines, such as marketing and sustainability.

5.2 Personal Outcomes

Team members unanimously agree that the EPS@ISEP was a very enriching experience not just for personal development but also for their future professional careers. Regarding personal outcomes, the opinion of team members was very positive. This can be illustrated by the following testimony:

– "*It was the biggest challenge ever thrown at me! Working with a bigger group than what I am used to and, as a plus, developing a product of which I knew nothing about was interesting to say the least. It was a lot of fun and invigorating, but also somewhat frustrating at times. Throwing in a global pandemic in the mix made it extra interesting. But overall, it was an experience that I would happily do again!*" – Eduardo.

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