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A foldable temporary shelter design

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Abstract
A greater number of populations are in situations of forced displacement due to several factors, including natural and man-made disasters. In the aftermath of such disasters, immediate access to shelter is of the utmost importance. Shelters used after disasters serve as a source of temporary accommodation for a limited period. Depending on needs and requirements, shelter design covers distinct phases such as emergency shelters, temporary/transitional shelters, and permanent construction. Although emergency shelters such as tents provide a first response and meet basic needs, they are only suitable for short-term use because they are not durable. In contrast, temporary/transitional shelters can be used longer than emergency shelters since they are designed to be more robust and resilient. However, it becomes difficult to ensure that such shelters meet basic needs if they are not constructed according to required standards. The use of complex structural systems, materials that do not provide adequate protection from weather conditions, and shelters that cannot be expanded to accommodate larger families are the main problems that need to be addressed. Thus, it is necessary to develop adaptive shelters that can be rapidly assembled, easily transported, and manufactured from robust materials. This study proposes a foldable shelter consisting of eighteen plates that can be folded into a compact form for convenient packing, storage, and transportation. With an area of 9.6 square meters, the foldable shelter can accommodate up to two or three occupants. The proposed shelter is modular in design, allowing for the connection of various modules to create larger areas that can be used for a variety of purposes or to accommodate larger families.

Keywords: foldable shelters, disaster-relief shelters, temporary shelters, folding structures, kinetic structures

1. Introduction
The occurrence of natural and man-made disasters has resulted in the displacement of millions of individuals. The number of people displaced by natural disasters such as earthquakes, floods, and storms, or man-made disasters such as conflicts and violence is increasing and forcing individuals to leave their homes [1-3]. In the aftermath of various disasters, either governments and humanitarian organizations provide temporary shelters to the individuals who lost their houses or makeshift shelters are constructed by displaced people using available materials. However, these shelters often do not meet the users' expectations, as they are unable to provide protection from inclement weather and adapt to changing needs. Moreover, those shelters mostly fail to comply with the technical standards. The majority of existing temporary shelters have deficiencies in terms of habitability, life span, and structural or

technical performance. Moreover, most of them necessitate the use of skilled labor to assemble the shelters, thereby prolonging the installation process.

Depending on the area and the organizations responsible for providing shelter, the types of shelters used after disasters change [4-8]. The nature of the disaster and the duration of the occupants' stay determine the type of shelter that should be used after a disaster. Emergency shelters are designed to be used for a limited period, typically a few weeks, and they are employed to provide temporary housing for individuals who have become homeless as a result of a disaster. In contrast, temporary shelters are preferred for use during the transition period until more permanent structures are built for habitation by affected individuals. Such shelters provide for relatively long periods of stay ranging from weeks to several months. Other forms of shelter, such as transitional shelters, are also designed to provide temporary housing for people to transition from shelter status to more permanent housing. Such shelters can be used for several years and are defined by features such as mobility, upgradability, reusability, recyclability, and resale, which collectively increase the flexibility of the shelters as a form of housing.

Shelter design must meet certain technical and design requirements set by humanitarian organizations. Each individual should be allocated at least 3.5 square meters of space within a shelter unit to provide adequate living, sleeping, and storage areas [4]. Families should be provided with a more spacious environment, typically around 14 square meters, to support the maintenance of daily routines [8]. It is also imperative that basic amenities are provided, including sanitation facilities such as toilets and bathrooms, drainage facilities, and hygiene provisions. These provisions are essential to provide habitable and adequate living conditions for people who have been displaced from their homes.

Although temporary shelters need to be constructed of lightweight materials so that they can be transported when needed, traditional temporary shelters often use prefabricated components that are typically heavy and limited in the number that can be transported at one time. They also lack the flexibility to expand service units or meet other changing spatial requirements. Therefore, adaptive shelters need to be developed for temporary housing that can change with the needs. Adaptability in shelter design can be achieved through the use of kinetic structural systems. By increasing the versatility and effectiveness of temporary shelter solutions, kinetic systems can improve disaster response operations.

The necessity for more adaptable temporary shelters that provide practical, durable, and timely solutions has led to the conclusion that kinetic systems offer superior solutions in the field of temporary shelter design. Therefore, this study proposes a foldable temporary shelter that provides versatility, ease of folding, and portability.

2. Kinetic systems in shelter design

Using kinetic systems in the design of temporary shelters provides several advantages. These include reconfigurability in form, adaptability to changing conditions, flexibility in architectural space, and the ability to be quickly assembled and dismantled. Moreover, they feature modularity, allowing for the combination of multiple shelters to create larger systems.

Although numerous studies on temporary shelters have been conducted by researchers concerning various aspects such as performance, sustainability, habitability, and recyclability [9-12] and many design proposals have been developed by designers, there is a limited study in the existing literature that fully employs kinetic systems in shelter design [13-19]. In the literature on kinetic architecture, as described by [20], two types of kinetic systems are identified: those with variable mobility and those with variable geometry.

The first category encompasses systems that are transported in pieces and subsequently assembled on-site (demountable and relocatable systems) or transported in a complete state, ready for immediate use (portable systems) [21]. Demountable systems are composed of various components including panels, joints, or frames, which are assembled as needed and dismantled into parts for easy transportation. In contrast to demountable systems, relocatable ones comprise larger components that can be relocated at different sites. On the other hand, portable systems are designed to be transported as a single unit, making them suitable for scenarios requiring rapid deployment.

The second category covers kinetic systems that allow significant geometric alterations without necessitating the disassembly of the entire system to move the structure from one location to another. These systems can transform from a compact state to an expanded form. The literature contains several examples of kinetic shelters constructed using a variety of components, including bar elements, scissor linkages, foldable plates, and combinations of scissors and foldable systems [13-19]. Using bar elements or scissor linkages in temporary shelters may present certain deficiencies. The mechanical complexity associated with these structural elements is due to the presence of multiple joints and moving parts. The potential for gaps and joints in their systems may result in a reduction in the resistance of the shelter. Moreover, the use of unsuitable covering materials may also exacerbate these issues. Conversely, foldable plate systems offer enhanced durability, structural stability, and weather resistance. Thus, this study focuses on developing a foldable shelter system.

3. Foldable shelter proposal

A foldable shelter system has been proposed as a potential solution to the sheltering problems. The proposed temporary shelter comprises eighteen plates. The diagram in Figure 1 illustrates the folding principle of the proposed shelter. Except for two rectangular long-side plates, each plate is designed to function with the folding system. Divided into two equal portions, the rectangular plates at the top and bottom fold inwards with the other plates. The triangular plates are positioned along the shelter's short sides; thereby, activating the system. There are four small triangular plates and two large triangular plates on both short sides.

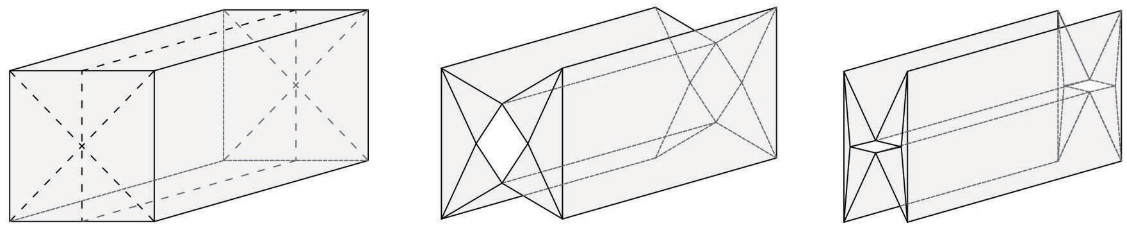

Figure 1: Folding principle

To facilitate the movement of the shelter, larger plates are integrated with the top and bottom plates, enabling the larger sides to be positioned closer together when folding. The configuration of the foldable plates on the system's short side allows for this arrangement. The plates are designed to move inward as the shelter begins to fold. This optimizes the amount of space available inside the shelter. The shelter folds down into a compact state for easy transport and storage. A single pulling force is sufficient to unfold the system despite the overall weight of the system due to its plate components (Figure 2).

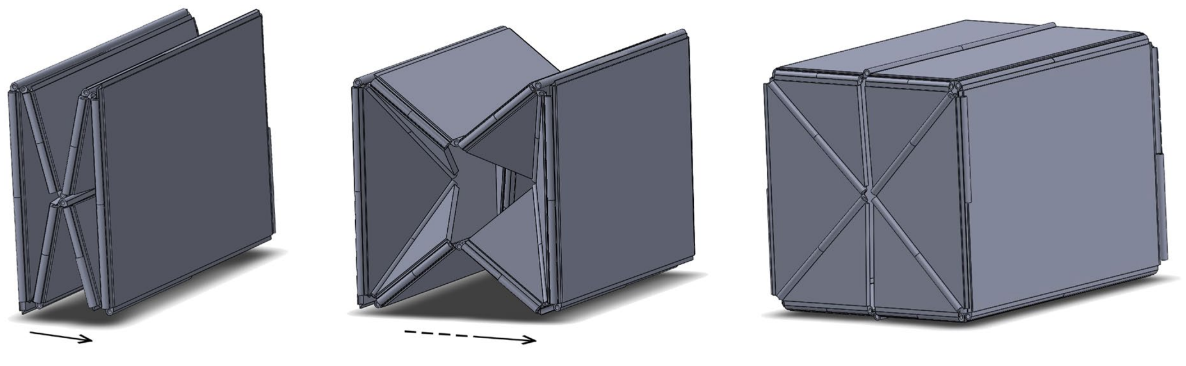

Figure 2: Folding stages of the proposed shelter

Hinge-type connections are employed to allow rotation between the plates of the proposed system about specific axes. The system's considerable weight and size may necessitate the involvement of three to four individuals for transportation. The unfolding of the plates from a single side enables the erection of the shelter to be completed in a relatively short period by a minimum of one or two people. The dimensions of the shelter in its deployed configuration are 260 cm by 400 cm by 270 cm (Figure 3). In its folded configuration, the width decreases to 90cm, allowing for the vertical stacking of six units to be delivered by a truck (Figure 4).

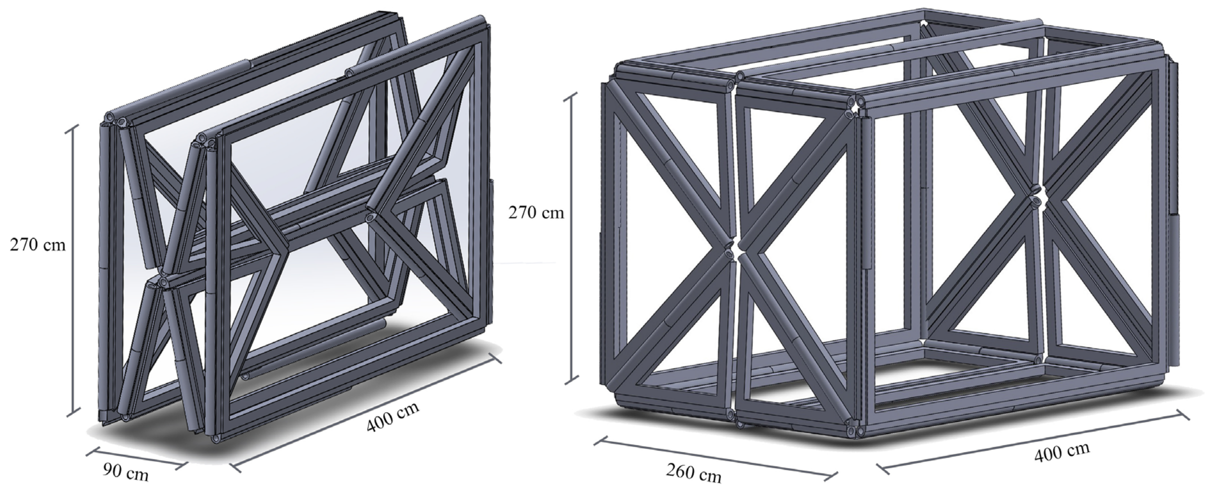

Figure 3: Dimensions of the proposed shelter in folded and unfolded configurations

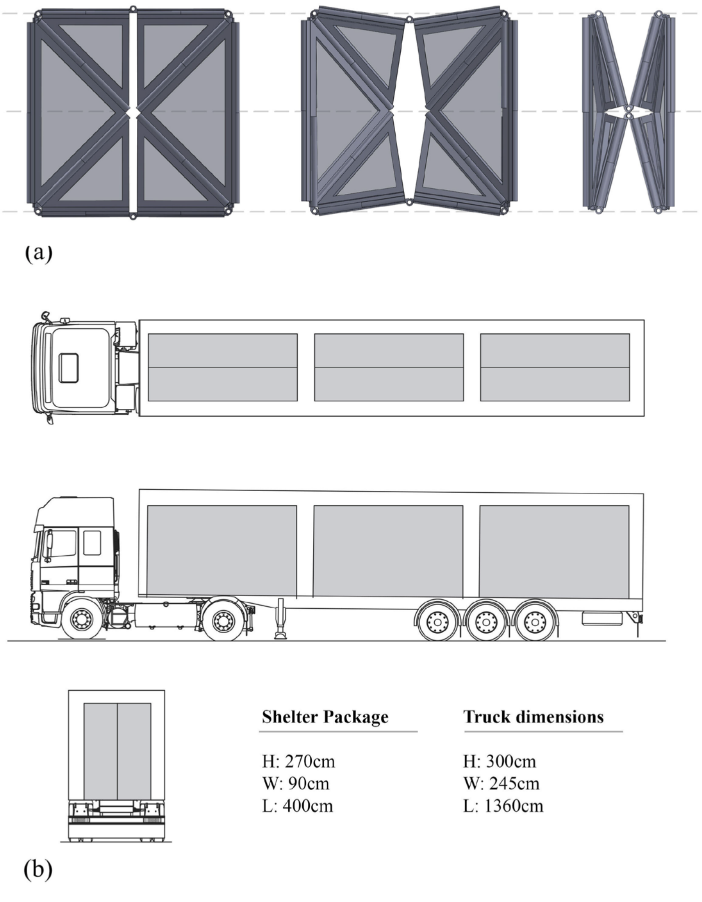

Figure 4: a) Folding process; b) transportation packaging

The foldable shelter has a floor area of 9.6 square meters and a ceiling height of 2.7 meters, allowing for two or three individuals to be accommodated. Once the system is fully deployed, the addition of partitions creates two distinct spaces within the shelter. The unit comprises a dedicated rest area of 6.2 square meters and a bathroom of 3.4 square meters as illustrated in Figure 5. The design is oriented towards functionality with an emphasis on optimizing storage space to accommodate the belongings of shelter occupants.

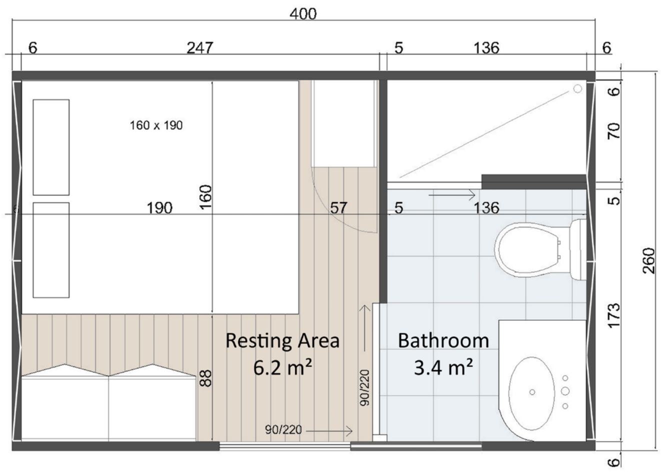

Figure 5: Shelter floor plan

Because the proposed shelter system is modular, several modules can be connected to create larger spaces suitable for larger families or used for different functions. For instance, two modules can be connected at their short sides as demonstrated in Figure 6 to create a dynamic area suitable for families of more than two people. Partitions are used to separate the extended space into resting and living spaces. The partitions slide along the floor and ceiling to provide flexibility and mobility convenience. Incorporating folding furniture into the shelter units increases the available space for various activities such as cooking, working, or playing; thereby improving the functionality for different needs.

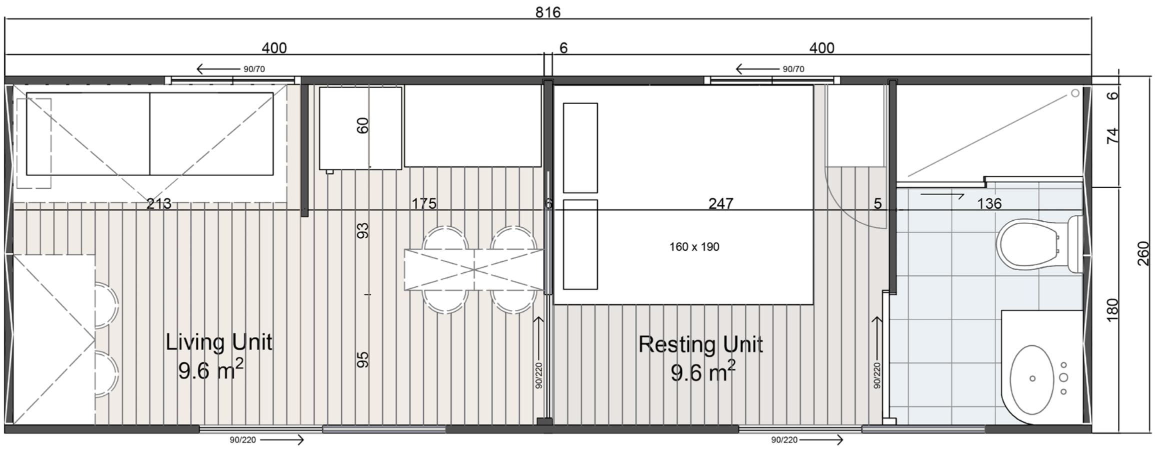

Figure 6: Alternative floor plan for the combination of two shelter modules

The proposed foldable shelter has a longer lifespan due to its robust construction, whereas conventional temporary shelters are designed to be used for a maximum of six months under normal circumstances. The plates of the shelter are constructed of insulated materials and designed for repeated use in different climates and locations, ensuring their adaptability and longevity.

4. Conclusion

The frequency of natural and man-made disasters has increased in recent years, contributing to the increase in the number of individuals who have been forced to leave their homes. In the aftermath of these occurrences, there is a greater need for temporary shelters, but traditional forms of such shelters are unable to adequately meet the demands. This has prompted the development of creative design ideas for those shelters.

Kinetic designs have gained recognition in the field of shelter design due to their capacity to adapt to changing circumstances. Researchers and designers have proposed a variety of temporary shelter types. Among these, portable shelters are a particularly practical choice due to their ready-to-use nature. However, they are relatively heavy and have a significant logistical disadvantage in comparison to other types that can be transported in pieces. In contrast, relocatable and demountable shelters require less space than portable shelters because they can be dismantled with relative ease. This capability provides the extra advantage of enabling the transportation of numerous units simultaneously. However, they necessitate the involvement of a professional workforce and a lengthy assembly process. Consequently, there persists a requirement for the development of adaptive solutions in this field.

In this study, a foldable temporary shelter has been proposed as a potential solution to the shortcomings of existing shelters. Since the proposed foldable shelter has a simple mechanism, it can be claimed that it provides a practical alternative to the complex shelters currently in use. Moreover, its modular design consisting of foldable plates allows for the formation of diverse unit combinations to accommodate varying circumstances and requirements.

Acknowledgments

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