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Analysis of Kinetic Disaster Relief Shelters and a Novel Adaptive Shelter Proposal

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Abstract

Natural disasters such as earthquakes, wildfires, landslides, and floods displace millions of people worldwide every year. Therefore, temporary shelters should be provided to the people affected by disasters. Generally, conventional shelters such as tents, container-type shelters, and prefabricated structures are used after disasters. However, they do not provide spatial flexibility and adaptability to changing circumstances. Although using kinetic structures in temporary shelter design allows the creation of adaptive systems, the majority of temporary shelters are limited to certain types. This study aims to develop an adaptive disaster relief shelter that can deploy from a compact state to an expanded one to provide not only formal flexibility but also ease of transport and storage. First, it investigates spatial and structural solutions developed for temporary shelters and analyzes to what extent kinetic structural systems provide solutions regarding adaptation to changing circumstances. Based on the findings obtained from the analysis, a novel adaptive shelter composed of scissor linkages and plates has been proposed. The proposed Shelter Module X is adaptive enough, functioning not only as an accommodation unit during distinct sheltering periods but also serving different functions by unit combinations.

Keywords: *Temporary shelters, disaster relief shelters, adaptability, natural disasters, kinetic structures.*

Kinetik Afet Yardım Barınaklarının Analizi ve Yeni Bir Adaptif Barınak Önerisi

Öz

Deprem, orman yangını, toprak kayması ve sel gibi doğal afetler her yıl dünya çapında milyonlarca insanı yerinden etmektedir. Bu nedenle, afetlerden etkilenen insanlara geçici barınaklar sağlanmalıdır. Afetlerden sonra genellikle çadır, konteyner tipi barınaklar ve prefabrik yapılar gibi konvansiyonel barınaklar kullanılmaktadır. Ancak, bunlar mekânsal esneklik ve değişen koşullara uyum sağlayamazlar. Geçici barınak tasarımında kinetik strüktürlerin kullanılması, adaptif sistemlerin oluşturulmasına izin verse de geçici barınakların çoğu belirli tiplerle sınırlıdır. Bu çalışma, kompakt bir konfigürasyondan genişletilmiş bir yapıya geçerek sadece biçimsel esneklik sağlamakla kalmayıp aynı zamanda taşıma ve depolama kolaylığı sunabilen adaptif bir afet yardım barınağı geliştirmeyi amaçlamaktadır. İlk olarak, geçici barınaklar için geliştirilen mekânsal ve yapısal çözümler araştırılmakta ve kinetik yapı sistemlerinin değişen koşullara uyum konusunda ne ölçüde çözüm sağladığı analiz edilmektedir. Analizinden elde edilen bulgulara dayanarak, makaslı bağlantılar ve plak elemanlardan oluşan yeni bir adaptif barınak önerilmiştir. Önerilen Barınak Modülü X, yeterince uyarlanabilir olup küçük değişikliklerle farklı barınma dönemlerinde konaklama birimi olarak kullanılabilir ve aynı zamanda birim kombinasyonlarıyla farklı işlevlere de hizmet edebilir.

Anahtar kelimeler: *Geçici barınaklar, afet yardım barınakları, adaptasyon, doğal afetler, kinetik strüktürler.*

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1. Introduction

Every year, millions of people worldwide are directly affected by disasters, resulting in the loss of their homes, loved ones, and personal belongings. The damage caused by disasters somehow depends on the vulnerability of buildings and the risk reduction policies implemented by governments and organizations. The first 72 hours following a disaster are significant for providing shelter and meeting the immediate needs of the affected individuals. Effective management during this period is essential to prevent secondary disasters in affected areas, safeguard lives, ensure safety, and minimize risks for disaster victims (AFAD, 2011).

Humanitarian organizations and governments strive to provide shelters for immediate use after disasters occur. Due to their affordability, ease of transportation, and quick installation, tent-type shelters are often preferred by organizations, as they can fulfill the immediate demand for thousands of shelters. However, such shelters are convenient for short-term usage. The need for more durable shelter solutions arises because tent-type shelters fail to address the evolving needs of disaster victims who have to reside in temporary shelters for months and even years. Considering the disaster type, location, climate, and the changing user needs over time, the “one size fits all” approach to shelter becomes inadequate and impractical in the subsequent stages of the sheltering process.

The duration of sheltering begins from the moment a disaster occurs and continues until affected individuals are provided with livable, durable, and permanent housing options (Shelter Centre, 2012). The process of disaster response involves a comprehensive recovery approach spanning three inter-connected periods: immediate relief, rehabilitation, and reconstruction (Corsellis & Vitale, 2005).

The immediate relief period entails precautionary measures and actions that are implemented before and after a disaster, intending to minimize the vulnerability of individuals and mitigate potential damages caused by the disaster. Once the immediate needs of the disaster victims have been addressed, the rehabilitation period commences. Its primary goal is to fulfill the needs of the affected people by providing them with temporary shelters and enabling them to continue their daily routines and regain a reasonable standard of living.

In contrast to the temporary solutions provided during the immediate relief and rehabilitation periods, the reconstruction period aims to establish a permanent, robust, and secure living environment for individuals affected by disasters. The process of reconstructing damaged buildings is often lengthy, further prolonged by the requirement of obtaining permits and contracts from municipalities and government authorities (Sey & Tapan, 1987). Therefore, the duration of sheltering can be longer than initially anticipated. As the duration of sheltering extends, there arises a need for diverse types of shelters that encompass varying spatial and technical characteristics to meet the evolving needs of shelter users (Sphere Association, 2018). Emergency shelters are typically employed immediately after disasters, with their usage ideally limited to a few days. On the other hand, temporary shelters should not be occupied for more than six months. Pre-planned vacant sites are generally designated for temporary shelter settlements.

Temporary accommodation refers to a period of extended stay that encompasses emergency, temporary and transitional shelters (Johnson, 2002). Depending on the duration of shelter settlements, temporary shelters can also serve as transitional shelters. In permanent settlements, progressive and core shelters can be used for several months or even years until permanent housing is constructed. Despite being mere rooms rather than fully functional houses, these shelters aim to meet the basic needs of their occupants, enabling them to maintain their everyday lives. In cases where disaster policies and structural systems permit, shelters can be moved to permanent sites. Moreover, they can be upgraded or combined to accommodate larger families.

Temporary shelters used until the construction of permanent dwellings are often unsuitable for long-term usage due to their limited adaptability to different types of disasters, locations, climates, and changing functions. These shelters are generally not upgradeable or reusable, necessitating the use of new shelters after each disaster. For instance, tent-type shelters lack durability against wind loads, fail to provide sufficient thermal insulation and ventilation, and lack privacy, security, and on-site sanitary facilities. The production of tents that can only be used for a few weeks during the sheltering period presents a significant challenge regarding resource consumption and sustainability.

On the other hand, container-type shelters and prefabricated temporary houses offer greater durability compared to tent-type shelters. However, they often lack spatial flexibility for users. Since constructing a large number of container-type shelters or prefabricated houses is time-consuming, manufacturers must carefully plan to produce an adequate supply of shelters. Considering the difficulties experienced after catastrophic disasters and the occurrence of secondary disasters, there is often a need to relocate shelters. This relocation is also necessary for storage or utilization in future disasters. However, it poses logistical challenges as container-type shelters and prefabricated houses are not easily transformable in shape. Transporting only one shelter at a time on a truck increases transportation costs and implementation time accordingly. The use of conventional temporary disaster shelters of this nature can lead to numerous long-term problems for humanitarian organizations and governments, including high costs, storage challenges, transportation limitations, and a lack of adaptability.

Although various types of temporary shelters exist, most of them fail to meet the universal design standards and technical requirements determined by humanitarian organizations (Sphere Association, 2018; IFRC, 2013). Therefore, adaptive design solutions should be developed in response to changing environmental conditions and user needs. To address this, designers have explored innovative structural systems in recent decades, incorporating kinetic structural systems into their shelter designs. Kinetic structures consist of moving elements that can change their geometric configurations without altering the overall structural integrity of the system. Notably, they offer the distinct advantage of easy assembly and disassembly. They can be relocated to any location in their compact states and may become self-supporting structures when fully deployed or unfolded. These structures have primarily been employed in architecture as temporary structures, retractable roofs, movable bridges, and responsive facades, allowing them to adapt to changing environmental conditions, meet user requirements, and enhance building performance.

Even though kinetic structures provide many advantages, the studies exploring their potential in temporary shelter design are limited (Asefi & Sirus, 2012; TMMOB, 2012; Lee et al., 2013; Extremis Technology, 2014; Mira et al., 2014; Quaglia et al., 2014; Thrall & Quaglia, 2014; Seikaly, 2015; Kawuwa, 2017; TenFold Engineering, 2017; Gomez-Jauregui et al., 2018; Larsen et al., 2018; Alharthi, 2020; Arslan et al., 2021; Pérez-Valcárcel et al., 2021; Lee et al., 2022; Verzoni & Rais-Rohani, 2022). Those studies generally focus on developing new types of shelters. However, there is no systematic study in the literature examining those proposals regarding their kinetic structural systems. In the first stage, this study systematically analyzes kinetic disaster relief shelters based on their structural properties, spatial characteristics, and transportability features. This analysis provides insights into the state-of-the-art in this field and highlights their potential to offer adaptable and flexible solutions. The findings obtained in this stage serve as a comprehensive guide for individuals or organizations interested in developing alternative temporary shelters. Building upon the knowledge gained from the first stage, the second stage of this study introduces a novel adaptive design for disaster relief shelters. This design is specifically developed to overcome the existing problems associated with sheltering. By proposing this adaptive design alternative, this study makes a valuable contribution to the literature. It not only offers a systematic analysis of disaster shelters utilizing kinetic systems but also presents a practical solution that meets the necessary design requirements.

2. Methodology

The methodology employed in this study encompasses a qualitative research approach that combines a critical review of literature on disaster relief shelters with simulation and modeling techniques to develop a kinetic disaster relief shelter (Figure 1).

The initial stage of the study involved a comprehensive review of relevant literature, utilizing bibliographic research to identify design standards and technical requirements for disaster relief shelters. This review also involved the classification of kinetic structural systems based on their kinematic properties and the identification of specific parameters necessary for evaluating the selected shelters. To collect relevant data, a wide range of sources were consulted, including journal and conference papers, books, reports, and websites, accessed through platforms such as Web of Science, Scopus, Google Scholar, and ResearchGate. The study proceeded by examining the characteristics of temporary shelters, living space standards, technical requirements, and design criteria in accordance with temporary shelter standards (Corsellis & Vitale, 2005; Shelter Centre, 2012; AFAD, 2015; Sphere Association, 2018, UNHCR, 2021). Notably, the Sphere Handbook (2018) acknowledged as the preeminent international design standard offering comprehensive and detailed guidelines, played a significant role in formulating the tables and evaluating the shelters. Furthermore, kinetic structural systems used in architecture were classified into two categories regarding their kinematic properties: structures with variable mobility and structures with variable geometry. Each category includes sub-groups with distinct movement and transformation capabilities. The aforementioned characteristics, standards, requirements, and classifications were employed to determine the parameters for selecting and analyzing the kinetic disaster relief shelters. The selected shelters have been analyzed regarding three main categories that are structural properties, spatial characteristics, and transportability features. The analysis findings were presented in Tables to facilitate comparison among the disaster relief shelters employing different types of kinetic structural systems.

The second stage of the methodology focused on 3D modeling techniques to develop a kinetic disaster relief shelter, which enabled the exploration of various configurations and functionalities of the shelter, facilitating an in-depth understanding of its potential adaptability and flexibility. Through this process, the findings from the literature review were utilized to inform the design and implementation of the shelter prototype. An adaptive disaster relief shelter, called *Shelter Module X*, was developed considering the aforementioned design criteria, requirements, and characteristics.

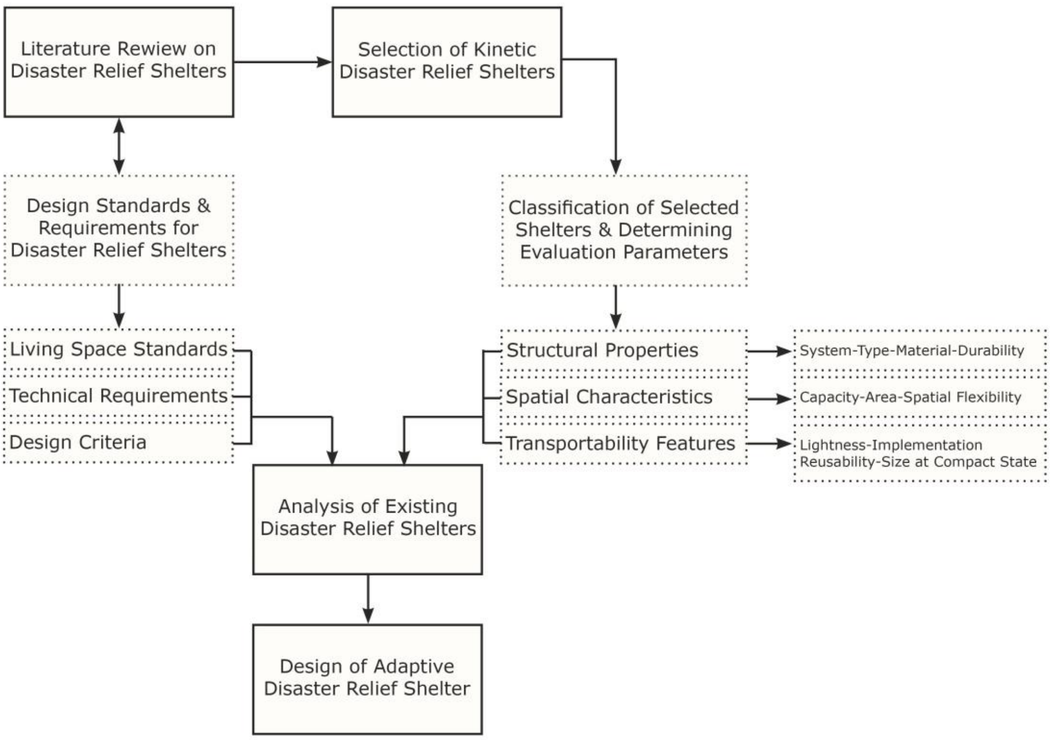


Figure 1. Steps of the research methodology

3. Research Findings, Design Proposal and Discussion

3.1. Characteristics of Temporary Shelters

Temporary shelters can cover the stages in which emergency and transitional shelters are used due to the extended sheltering periods if they meet spatial needs and technical requirements. Unlike emergency shelters, temporary shelters are designed to be used for up to six months and provide essential amenities such as sleeping, bathing, and cooking facilities. In cases where transitional shelters cannot be utilized due to settlement policies, they are referred to as temporary shelters, highlighting the overlapping terminologies used in the context of shelters. However, employing various types of shelters throughout the sheltering process presents more drawbacks than benefits. Each type of shelter possesses distinct spatial and technical characteristics to fulfill specific needs, resulting in increased overall costs. Temporary shelters are expected to be cost-effective, easily constructible, relocatable, and reusable, while transitional shelters should offer rapid upgradeability.

Once temporary shelters have been used for six months, they can undergo various actions to prolong their life cycle, including repairs, relocation to permanent settlements, or expansion to meet additional needs until permanent dwellings are constructed. The literature emphasizes the importance of extending the life cycle of these shelters through measures such as space additions, repairs, reuse in subsequent stages, and relocation to permanent or safer shelter settlements (Arslan, 2007; Askar et al., 2019). Even if temporary shelters are not intended to become permanent houses, they can be upgraded to accommodate different stages of the sheltering period. The incremental transition approach suggests using the same shelter and making minor modifications to meet the evolving needs of shelter users (Wagemann & Moris, 2018). This approach allows for the continued use of the shelter in the same location and habitat, thereby protecting the mental health and comfort of disaster victims (Choi et al, 2020). Furthermore, adopting this approach can lead to reduced costs during the sheltering period compared to the conventional three-phase reconstruction approach, where temporary shelters are used after emergency response until permanent houses are built.

To address the need for adaptability and relocatability, designers and researchers have explored new design solutions for temporary shelters. They have started using kinetic structural systems in temporary shelter designs since they offer formal transformability, spatial flexibility, rapid assembly and disassembly, adaptability to changing conditions, and ease of transportability.

3.2. Analysis of Temporary Shelters

Universal standards, technical requirements, and structural capabilities are prioritized in the selection and evaluation of temporary shelters.

3.2.1. Design standards and technical requirements for temporary shelters

Temporary shelters should be designed considering many parameters to provide habitable living spaces for the people affected by disasters. The living space standards, technical requirements, and design criteria for temporary shelter design are given in Table 1 (Corsellis & Vitale, 2005; Shelter Centre, 2012; AFAD, 2015; Sphere Association, 2018, UNHCR, 2021).

As indicated by the Sphere Association (2018) and UNHCR (2021), the minimum area required for a living space per person in a temporary shelter should be 3.5m^2, excluding dedicated spaces for cooking and bathroom facilities. However, the living space per person should be increased to a range of 4.5m^2 - 5.5m^2 in cold climates, which includes the spaces for cooking, bathing, and sanitation facilities. Temporary shelters should protect the users from extreme weather conditions while providing user comfort through natural ventilation and daylighting the indoor areas. The minimum internal floor-to-ceiling height should be 2m in temporary shelters. However, in hot climates, it should be 2.6m for air circulation. Temporary shelters should also provide privacy, safety, and security, which are essential requirements to maintain daily life for shelter users as much as possible. Moreover, complementary facilities should be considered in and around the shelter because providing designated spaces for cooking, bathing, and sanitary allows people to undertake daily activities. Technical requirements should also be provided, which include fire safety, technical performance, and supplying basic infrastructures and needs. The parameters such as durability, optimal thermal comfort, fire resistance, water resistance, natural ventilation, accessibility, and selection of appropriate materials positively affect the performance of shelters. On the other hand, design criteria include reusability, ease of storage, lightness, cost-effectiveness, rapid erection and dismantling, transportability as well as spatial integrations through spatial flexibility or modularity constitute the principles of designing an adequate temporary shelter.

Table 1. Design standards and technical requirements for temporary disaster shelters

Living Space Standards	***Minimum living space per person***				**$3.5m^2$ in a hot climate excluding space for cooking, bathing, and sanitary**		**$4.5m^2$ - $5.5m^2$ in cold climates including space for cooking, bathing and sanitary**	
	Minimum internal floor-to-ceiling height				2m		2.6m in hot climates	
	Shelter habitability	covered living area	privacy	safety	security	natural lighting	artificial lighting	complementary facilities
Technical Requirements	***Fire safety***	30m firebreaks per built-up 300m in shelter settlements						
	Technical performance	durability	thermal comfort	fire resistance	water resistance	natural ventilation	accessibility	appropriate material selection
	Supplying basic infrastructures and needs	water tanks	sanitary	electricity	bathroom	food supplies	healthcare supplies	
Design Criteria	reusability	flexibility	ease of storage	modularity	lightness	cost-effective	rapid erection & dismantling	transportability

3.2.2. Classification of kinetic structural systems

Kinetic structures can be classified under two main categories as shown in Table 2: structures with variable mobility and structures with variable geometry (Zuk & Clark, 1970; Kronenburg, 2003; Maden, 2019). The first type is divided into three main categories such as demountable, relocatable, and portable. Demountable structures consist of pre-fabricated elements that can be stored in parts, transported as a complete package, and quickly assembled or demounted at the site (Figure 2a). Relocatable structures are composed of transportable modular parts that are generally dry-assembled at the site, whereas portable ones are transported in one piece for instant use (Kronenburg, 2003) (Figures 2b and 2c).

Table 2. Types of kinetic structural systems

Kinetic Structures				
Structures with variable mobility	Demountable Structures	Relocatable Structures	Portable Structures	
Structures with variable geometry	Scissors & Bars Structures	Foldable Plate Structures	Tensegrity Structures	Deformable Structures

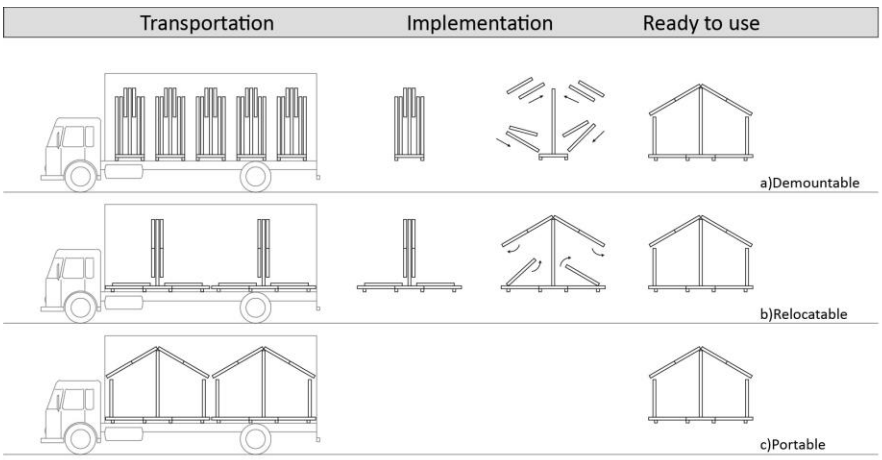


Figure 2. Types of kinetic structures with variable mobility

On the other hand, the second type can be reviewed under four main categories. The first category contains scissors and bar structures. Scissor structures are composed of primary scissor units or loops

(Sarısayın et al., 2022), whereas bar structures can be built using any element. Both types provide advantages regarding transformation, transportation, and storage, but their systems may become complex if they consist of numerous elements and joints. The second category is foldable plate structures composed of plate elements rotating relative to their adjacent plates. The third category covers tensegrity structures composed of bar elements and cables, which are rarely used in kinetic architecture. The fourth category includes deformable structures (e.g., membrane and pneumatic systems) mostly used to cover large spans.

3.2.3. Analysis of selected temporary shelters

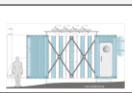
Based on the aforementioned design standards, criteria, technical requirements, and classifications, the selected temporary shelters have been analyzed in three main categories, which are as follows:

- *Structural properties*: system, mobility/movement, material, and durability
- *Spatial characteristics*: capacity, area, and spatial flexibility
- *Transportability features*: lightness, implementation, reusability, and storage

Having mobility in terms of changing location or movement in terms of formal change in the structural systems of temporary shelters is essential since it allows adapting to the evolving conditions and user needs during the sheltering process. Therefore, mobility and movement have been determined as the selection criteria for temporary shelters to be used in the evaluation. The existing literature on the topic has been reviewed, and shelter examples having variable mobility and variable geometry have been chosen, which are proposed by researchers, designers, humanitarian organizations, and engineering companies. Those examples have been analyzed and compared regarding their structural properties, spatial characteristics, and transportability features.

First, temporary shelters having variable mobility have been examined (Table 3). Demountable shelters occupy less space for storage as they can be dismantled into smaller parts and transported by packing those small parts. However, small structural elements increase the implementation time, labor requirement, and complexity of the structure. In addition, reusing such shelters may cause deformation or damage in structural components and joints; thus, requiring renewal and repair. Because the disadvantages of the conventional type of demountable shelters (e.g., tents, container-type shelters, and prefabricated structures) outweigh their advantages, they have not been included in this evaluation. Two relocatable shelters and two portable shelters have been selected for the analysis. These are the *Shelter Proposal* by Beyatlı (2010), the *Disaster and Emergency Living Facility* by AFAD (2015), the *Portable Shelter Proposal* by Uçar (2015), and the *Portable Post-disaster Home Proposal* by Dialameh (2017), accordingly.

Table 3. Temporary shelters have variable mobility

PROJECTS		STRUCTURAL PROPERTIES				SPATIAL CHARACTERISTICS			TRANSPORTABILITY FEATURES			
NAME	EXTERNAL VIEW	SYSTEM	TYPE	MATERIAL	DURABILITY	CAPACITY	AREA	SPATIAL FLEXIBILITY	LIGHTNESS	IMPLEMENTATION	REUSABILITY	SIZE AT COMPACT STATE
Beyatlı - Shelter Proposal 2010		Container structure w/ steel expansion solution	RELOCATABLE	Steel, PVC panels, textile	Materials are durable but cannot be assured time	2 people	10sqm	YES: Units can be combined	Heavy	< 1 hour by 1 person	YES	One unit package = 280x233x240cm
AFAD - Disaster and Emergency Living Facility 2015		Modular system with insulated plates and tensioning belt	RELOCATABLE	Polyurethane plates in walls and roof, fiberglass and polyester in pallet floor w/ adjustable legs and covering plates	> 1 year	1 person	3.5sqm	YES: Modules can be combined	Lightweight	20 mins by 3 people	YES	As one module package Not specified size 12 modules can be carried in one truck
Uçar - Portable Shelter Proposal 2015		Container structure w/ steel expansion solution	PORTABLE	Steel, PVC panels	Materials are durable but cannot be assured time	4 people	18sqm	YES: Expands by changing dimensions of scissors & panels	Heavy	2 mins by 2 people	YES	One unit package = 120x650x270cm
Dialameh - Portable Post-disaster Home Proposal 2017		Steel frames, wooden beams, plywood panels	PORTABLE	Steel, wood, plywood	Materials are durable but cannot be assured time	4 people	20sqm	YES: Expandable units	Heavy	2 mins by 1-2 people	YES	One unit package = 215x350x280cm

The *Shelter Proposal* is a relocatable container structure designed which reuse waste materials as components and use new materials only for the scissor-like elements (Beyatlı, 2010). Unlike conventional container-type disaster shelters, it occupies less space in its compact configuration than a container since it is expandable. The shelter is composed of scissor-like elements and panels, and it can be stored in parts and assembled at the site. Therefore, it is easier to transport and store the shelter than the other conventional container-type shelters. In this shelter, PVC panels and accordion textile material are used for walls and roofs, and steel is used for structural elements and adjustable legs. Using the waste container structure makes it cost-effective and provides material savings. Having a 10m2 living area for two people, the *Shelter Proposal* is spatially flexible since it allows combining two units from the sides of the shelter.

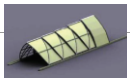
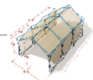
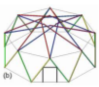
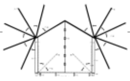
The *Disaster and Emergency Living Facility* has a modular system consisting of polyurethane plates used for walls and roof, fiberglass and polyester for the slab, and it has a tension belt to increase structural durability. Its adjustable legs allow the shelter to keep flat and to be used even on sloping terrain. The wheels under its adjustable legs make it easier to move for implementation, which can be locked via latches on its wheels to keep the shelter in place. One of the modules of the shelter is 3.5m^2, which equals the minimum area for the living space standard per person. However, it can be expanded by module additions because its slab is designed like a pallet.

Both of the examined relocatable shelters are durable enough to be used for more than one year and meet the technical requirements of fire and water resistance, thermal comfort, daylighting, and natural ventilation. They can be implemented rapidly. The *Shelter Proposal* can be implemented in less than one hour by one person, whereas the *Disaster and Emergency Living Facility* can be assembled in 20 minutes by three people. Multiple shelters can be transported on trucks. Considering their sizes, it can be said that they may provide habitable living environments for users for long-term use.

The *Portable Shelter Proposal* developed by Uçar is a container-type structure composed of scissor-like elements and PVC panels as in the relocatable shelter designed by Beyatlı. This shelter has more expansion capability, and it can be transported in one piece in its compact state. It occupies less space for storage. In the *Portable Post-Disaster Home*, steel and wooden frames are used for the structural components, and plywood panels are used for the walls. Wooden beams are preferred on the slab and walls to reduce the shelter cost, whereas steel frames are used for the shelter skeleton. Both selected portable shelters are durable enough to be used for more than one year. The *Portable Shelter Proposal* meets all technical requirements, while the *Portable Post-Disaster Home* meets the requirements except fire resistance. When the living areas are compared, it is seen that the *Portable Shelter Proposal* provides 18m^2 for four people while the *Portable Post-Disaster Home* has 20m^2. Although these portable shelters are heavy, their implementation takes 2 minutes by one or two people since they can be expanded by just pulling one side of the shelter to make it ready for use.

After examining the shelter examples having variable mobility, the temporary shelters having the capability of changing their geometries have been analyzed (Table 4). The search for adaptive structural solutions to store, assemble, and transport shelters has led designers to develop temporary shelters that can transform their shapes from compact shapes to expanded forms. Features such as lightness, flexibility, rapid erection and dismantling, reusability, ease of storage, and transportability can be accomplished using kinetic systems in shelter design. For the evaluation, six deployable temporary shelters have been selected, which are the *Weaving Home Shelter* by Seikaly (2015), the *Transformable Shelter* by Asefi & Sirus (2012), the *Gable Roof,* and the *Deployable Yurt* by Pérez-Valcárcel et al. (2021), the *Deployable Scissor Arch* by Mira et al. (2014), the *TF-64* by TenFold Engineering (2017). Also, foldable examples such as the *Hush Shelter-2* by Extremis Technology (2014) and the *Disaster Shelter* by TMMOB Ankara (Union of Chambers of Turkish Engineers and Architects, Ankara Branch; 2012) have been examined.

Table 4. Temporary shelters having variable geometry

PROJECTS		STRUCTURAL PROPERTIES				SPATIAL CHARACTERISTICS			TRANSPORTABILITY FEATURES			
NAME		SYSTEM	TYPE	MATERIAL	DURABILITY	CAPACITY	AREA	SPATIAL FLEXIBILITY	LIGHTNESS	IMPLEMENTATION	REUSABILITY	SIZE AT COMPACT STATE
Seikaly Weaving a Home Shelter 2015		Deformable self-deploying system	DEFORMABLE	Fabric & plastic members	-	3 people	20sqm	YES: Modules can be combined	Lightweight	Easy to assemble, no time specified	YES	Fully folded unit No size specified
Asefi & Sirus Transformable Shelter Proposal 2012		Steel frame w/ sliding mechanism	SCISSOR & FOLDABLE PLATE	Steel frames & curved plates	-	-	50sqm	YES: Modular and can be combined	Lightweight	< 1 hour by 2 people	YES	Compact modular units No size specified
Valcárcel et al. Gable Roof Proposal 2021		Deployable cylindrical vaults with reciprocal scissor linkages	SCISSOR	Aluminum tubes, fabric	-	-	73sqm	YES: Units can be combined and deploy together	Lightweight	Easy to assemble, no time specified	YES	As kit of parts or modules No size specified
Valcárcel et al. Deployable Yurt Proposal 2021		Reciprocal structures w/ triangular frames	BAR	Aluminum tubes, sloping pillars	-	-	76sqm	YES: Modules can be combined	Lightweight	Easy to assemble, no time specified	YES	As one compact module - No size specified 24-30 modules can be carried in one truck
Mira et al. Deployable Scissor Arch Proposal 2014		Scissor arch	SCISSOR	Aluminum, membrane	-	4 people	14sqm	YES: Units can be expanded & transformed	Lightweight	2 hours by 3 people	YES	Fully folded unit No size specified
TenFold Engineering TF64 2017		Modular, self-deploying system	SCISSOR & FOLDABLE PLATE	Steel, insulated panels	> 1 year	6 people	68sqm	YES: Units can be combined, expandable units	Heavy	In minutes by one person	YES	10.4sqm compact unit
Extremis Technology Hush Shelter-2 2014		Foldable plates w/ hinges	FOLDABLE PLATE	Wooden insulated walls	> 1 year	-	19sqm	YES: Units can be combined	Heavy	2 hours by one person	YES	Compact folded unit No size specified
TMMOB Disaster Shelter 2012		Foldable plates & panels w/ hinges	FOLDABLE PLATE	MDF plates, panels & L-shaped water-protective components w/ white lacquer coating	> 1 year	2 people	~9sqm	YES: Panels can be removed & another unit can be combined w/ hinges	Lightweight & has wheels to carry	< 1 hour by one person	YES	As one compact module = 30x300x260cm 45 modules can be carried in one truck

The *Weaving Home Shelter* has a deformable structure and is composed of structural fabric with plastic members. Being capable of folding itself across a central axis, the shelter has operable windows that can control air circulation. There is a space for the water collector that supplies electrical energy for the waving action of the shelter. The shelter has a 20m^2 living space for three people, but it can be expanded by combining units. It is lightweight due to its materiality, easy to assemble, and can be stored as folded. Also, this shelter meets all technical requirements.

The *Transformable Shelter* has scissor and foldable plate structures composed of steel-framed modules with a sliding mechanism. The shelter is easy to assemble, store, and transport due to its lightweight structural system. It can be assembled by two people in less than an hour. Having a sliding mechanism, the shelter provides variable geometries changing the configurations only along the horizontal direction. The shelter can cover 50m^2 by expanding, which allows it to be used for various functions.

The *Gable Roof* is composed of reciprocal scissor linkages, whereas the *Deployable Yurt* has reciprocal bar structures. The *Deployable Scissor Arch* is comprised of polar scissor units, and the shelter is covered by a fabric membrane. These three examples demonstrate the structural investigations and possible applications of scissor linkages and bar structures in shelter design proposals. The designers of these structures explored the structural limits of the proposed mechanisms and conducted several analyses for durability. Because such structures are durable and provide ease of storage, transportation, and implementation, they are promising for further applications even if technical requirements have not been accomplished yet. Since these shelters can cover large spaces, they are adequate even for larger families, although the designers did not mention the number of occupants. The *Gable Roof* covers 73m^2, which can be expanded on both horizontal sides of the shelter. Likewise, the *Deployable Yurt* encloses 76m^2 thanks to its reciprocal scissor structures. Compared to these shelters, the *Deployable Scissor Arch* is smaller since it covers only 14m^2 and serves four people. However, larger spaces can be covered with module combinations. These three structures provide various geometric configurations and can be used as temporary shelters in the long term. Even though these examples are composed of scissor mechanisms or bar structures, they do not require professional assistance to assemble the structures. The *Deployable Scissor Arch* can be assembled in 2 hours by three people.

The *TF-64* is another deployable example composed of a steel structure and insulated foldable plates that are used for walls, roofs, and slabs. Its height can be changed thanks to its adjustable steel legs. The *TF-64* needs electrical power for deployment, which is provided by solar panels and batteries attached to the system. The deployment of the whole structure takes minutes. Covering an area of 68m^2, this shelter provides living space for six people. It covers 10.4 m^2 in its compact state. Thanks to its expandable feature, the units can be combined for space additions to meet the spatial needs of shelter users.

The *Hush Shelter-2* and the *Disaster Shelter* have foldable wooden plates that are connected by rotating hinges. The *Hush Shelter-2* may require fieldwork and cannot be fully folded. It can be unfolded in 2 hours by one person if the foundation is ready for the shelter. Otherwise, it may take more than 2 hours. On the other hand, the *Disaster Shelter* does not require fieldwork thanks to its adjustable legs, which allow the shelter to be used even on sloping terrain. Although the shelter is heavy, the adjustable legs make the shelter easy to move and relocate. Since the shelter has wheels, they can be locked when placed. The slab and roof of the *Disaster Shelter* are also foldable, which makes the shelter more compact. The shelter has L-shaped elements placed above the roof and wall intersection to prevent water leaks. Both examined foldable shelters are durable and easy to store and transport because they can remain in their compact foldable states while transporting. These shelters are spatially flexible, but they can be extended only if new units are added by removing the side panels from the shelter.

3.3. Design Proposal: Shelter Module X

Providing lightness, protection from changing environmental conditions, ease of transport and storage, and quick installation by users have been aimed while designing *Shelter Module X*. The proposed shelter has a deployable system consisting of scissor linkages and insulated foldable plates, which covers 17.88 m^2 when unfolded from the compact state to expanded form (Figure 3).

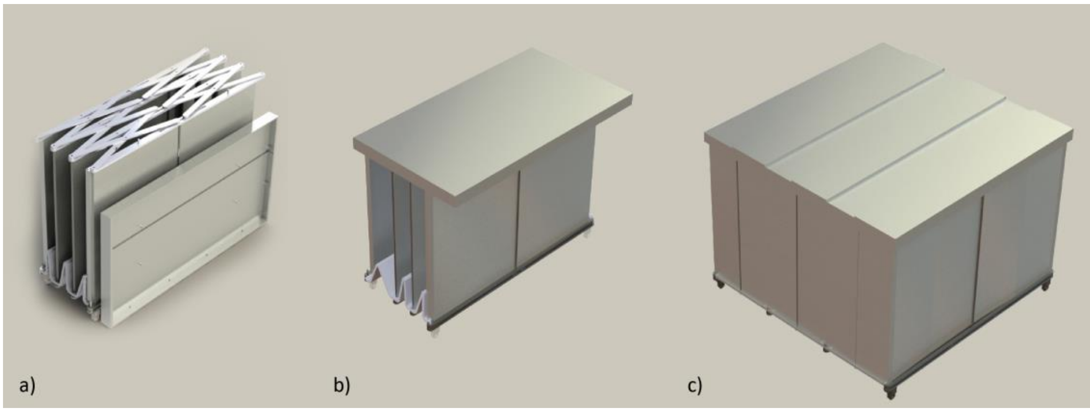


Figure 3. Deployment stages of the *Shelter Module X*: a) compact state; b) half deployed state; c) expanded form

The *Shelter Module X* is composed of twelve translational scissor units that are connected with revolute joints. Six are positioned at the bottom (Figure 4a), while the remaining ones are located at the top (Figure 4b). The scissor elements play a crucial role in controlling the movement of the plates as they are connected to the side plates. By sliding the scissor-like elements along the slots on the side plates, the deployable system starts moving and expanding. Simultaneous deployment occurs for the plates positioned on the sides, top and bottom, excluding those aligned with the *y*-direction (the longer sides of the unit) (Figures 4a and 4c). These plates are temporarily fixed to the scissor elements, but they are designed to be bifold for storage (Figure 4b). The side plates lying on the *x*-direction fold into the shelter, optimizing space utilization. The side plates along both *x*- and *y*-directions are connected at the corner by concealed cross hinges that enable rotation of the plates (Figures 4b and 4d). These hinges remain completely invisible when the plates are unfolded. The slab folds vertically within the shelter and is supported by horizontal rods and vertical pins (Figures 3b and 4b), which engage with stationary plates located between the scissor elements. The roof encloses the shelter structure, featuring eaves and a sliding mechanism that enables its width to be reduced by half (Figure 4c).

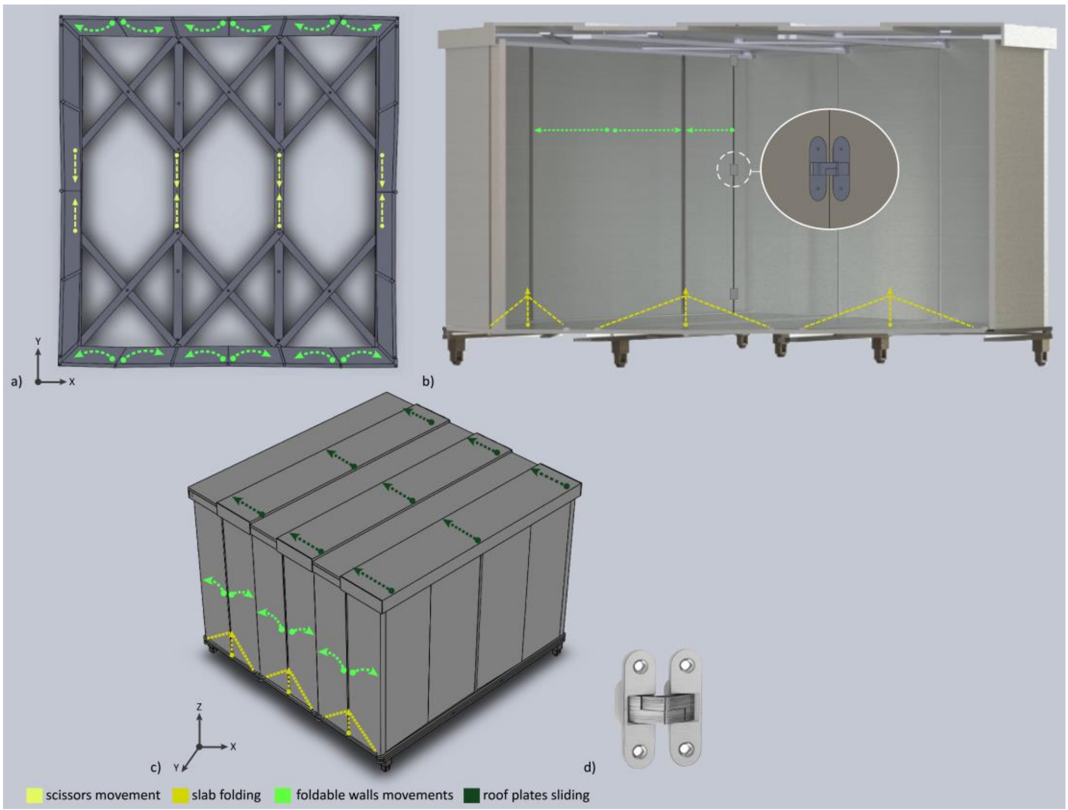


Figure 4. Movement diagram of the shelter components

The system's deployability enables the unit to be folded into a compact bundle, offering ease of transport and storage. The *Shelter Module X* can be transported on a truck either in a fully folded state by detaching the roof plates and wheels or in a demounted state. Three shelters can be transported on a truck in their fully folded configurations as shown in Figure 5a. The size of the shelter reduces by almost one-third, and it occupies an area of 6.44 m^2 (1.52m x 4.24m). On the other hand, each component of the shelter can be packed with its corresponding carrier rods, allowing for easy storage. Dismantling the components offers a relocatable option that enables the transportation of up to six shelters on a truck at once (Figure 5b). The dimensions of the shelter package measure 230x450x140cm. To facilitate relocation and adaptability to uneven terrain, the shelter is equipped with wheels and adjustable legs (Figure 6). These wheels can be attached to the shelter before movement or during the placement of the shelter on the ground. With a height adjustment range between 24cm and 32cm, it is preferable to select a relatively smooth terrain, although the wheels can accommodate variations in ground elevation. Moreover, the wheels can be locked to securely position the shelter and provide protection against flood. Thanks to these wheels, users can swiftly open the shelter and commence usage. Otherwise, the process may take longer due to the physical effort and weight of the components.

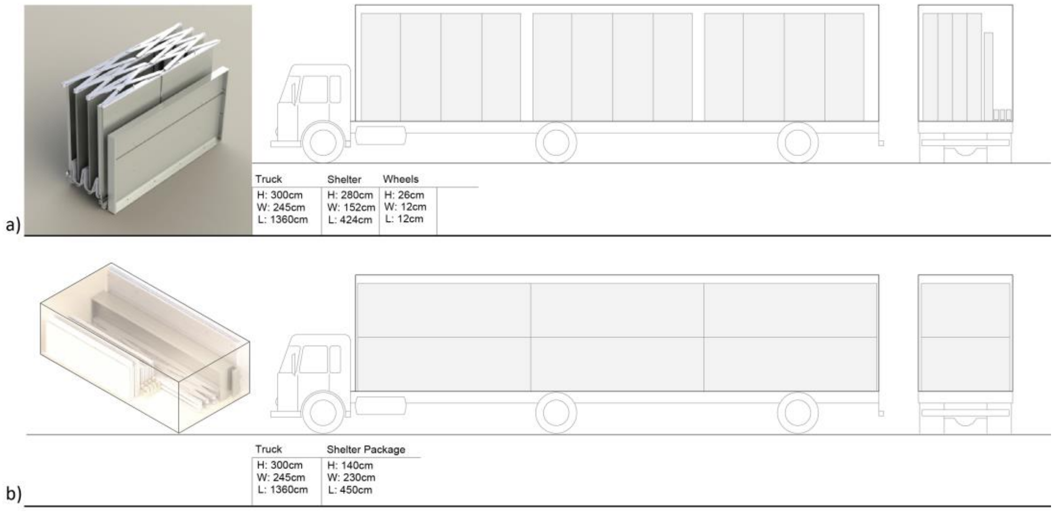


Figure 5. Transportation of the *Shelter Module X*: a) fully folded state; b) demounted state

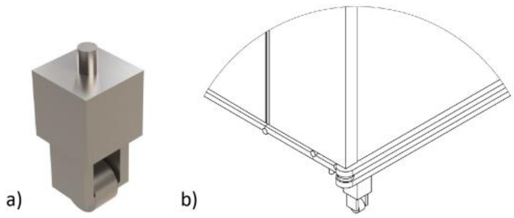


Figure 6. Wheel and connection detail

Disaster relief shelters should provide a minimum of 4.5 m^2 of living space according to universal design requirements and guidelines for temporary disaster shelters, including the bathroom and kitchen. The *Shelter Module X* encompasses a bathroom, a kitchen equipped with essential amenities, foldable tables, and chairs, a living room that includes functional work areas with foldable furniture, and a bedroom suitable for two occupants (Figure 7a). Because it covers an area of 17.88 m^2, the proposed shelter can meet users' basic needs for longer use and accommodate up to four individuals when the living room doubles as a sleeping area (Figure 7b). The *Shelter Module X* has slim windows positioned to not only provide cross ventilation and privacy but also allow in natural light (Figure 8a). The design of the shelter takes into consideration changing conditions to ensure habitable and sustainable spaces (Figure 8b). To enhance user comfort and adaptability within these compact environments, foldable furniture and doors are used. Sliding doors are employed to optimize space utilization, while the exterior door is designed as a double-leaf door for practicality.

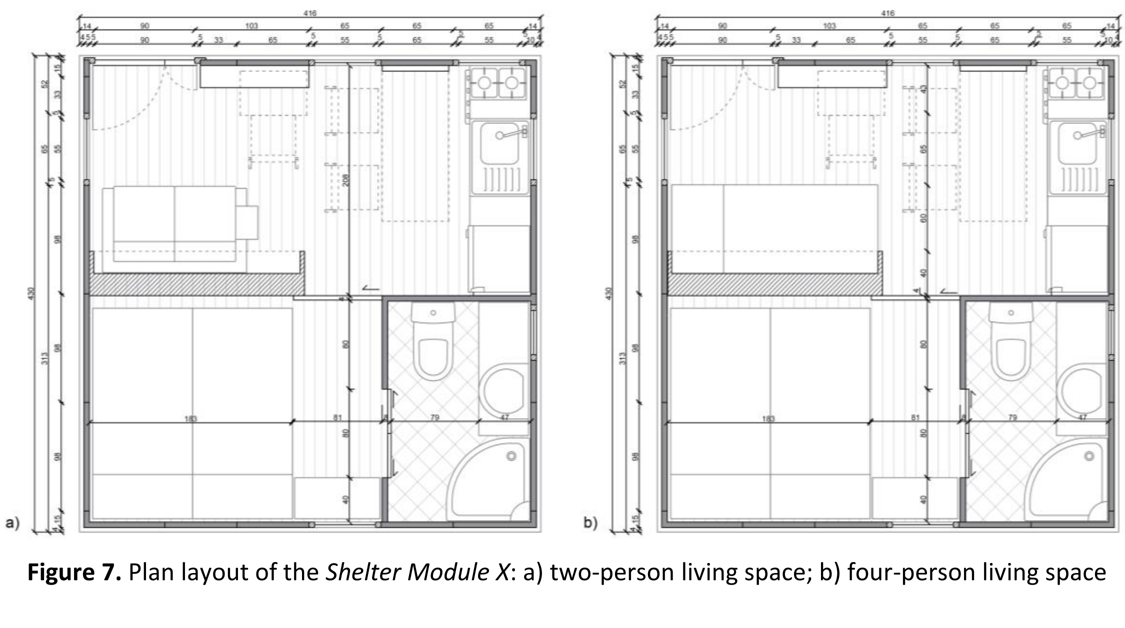


Figure 7. Plan layout of the *Shelter Module X*: a) two-person living space; b) four-person living space

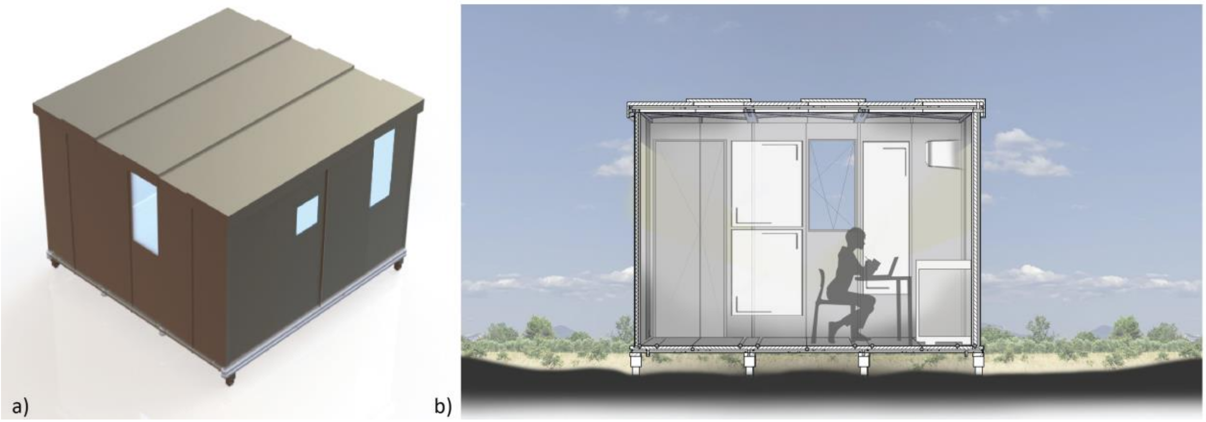


Figure 8. a) 3D view; b) sectional perspective view

Even though the proposed *Shelter Module X* is designed to serve as a temporary shelter that is suitable for long-term use since it features a kitchen and bathroom area, it can also be used as an emergency shelter by excluding the service unit (kitchen and bathroom). Because the system is adaptive, the number of scissor linkages in the system can be changed. Rather than using three scissor units in each row (i.e., a 3x2 type module), two scissor units can be used to generate a smaller module (2x2 type module) that covers an area of $12m^2$, which can accommodate two people during emergency periods (Figure 9a). The proposed *Shelter Module X* is adaptive enough to develop alternative solutions by offering module combinations to accommodate larger families or diverse functions (Figures 9c-9g). Those solutions incorporate the creation of common open areas to enhance the overall habitability of the sheltering area.

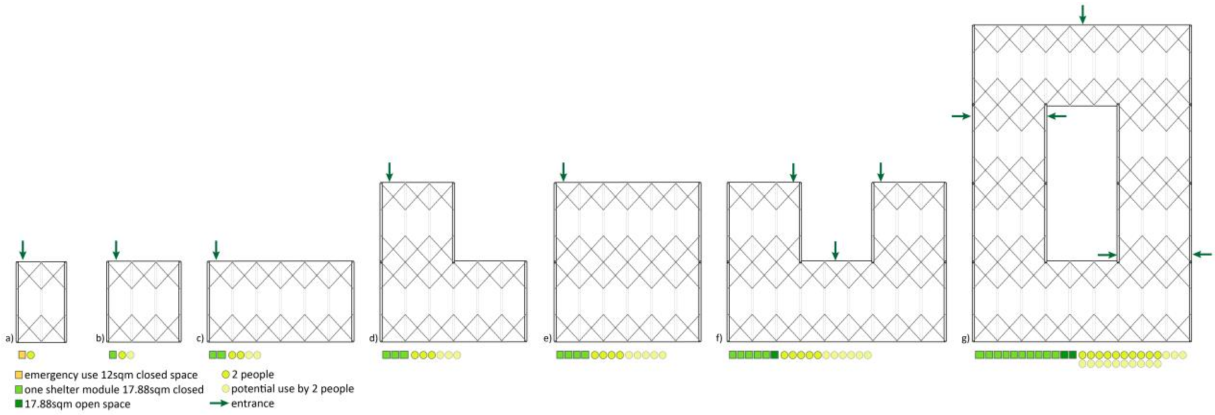


Figure 9. Alternative module combination diagrams

3.4. Discussion

It is crucial for temporary shelters to adhere to universal standards and possess adaptability and flexibility, as they may be deployed in diverse locations, climates, and cultural contexts as well as in response to various types of disasters. However, conventional-type temporary shelters often lack reusability and adaptability. Most of them cannot be rapidly assembled and necessitate the involvement of skilled professionals for construction. Moreover, they have disadvantages regarding storage and transportation, as they cannot be easily folded into compact states and occupy a significant amount of space.

The examined disaster relief shelters in this study have various structural systems providing advantages in terms of adaptation to spatial, functional, or environmental changes. The analysis shows that the selected temporary shelters having variable mobility provide significant advantages since they can be relocated when needed. This mobility enables shelters to be moved within the shelter settlement or to safer and permanent zones during the sheltering period. Using relocatable and portable shelters brings multiple advantages, including cost reduction, ease of transportation and storage, and the elimination of the need for extensive workforce or fieldwork during implementation.

The examples given in Table 3 are adaptive and flexible enough to meet the changing needs of the users. Moreover, these shelters demonstrate durability in withstanding changing weather conditions and can be implemented easily in less than one hour by one or two people. Furthermore, they occupy less space compared to conventional-type shelters when in their compact configurations.

On the other hand, temporary shelters having variable geometry are more flexible in shape control and can be compacted when relocation is necessary. That means more shelters can be transported on a truck at once. Compact shelters can rapidly be expanded in minutes by the users without the need for professional assistance or extensive fieldwork. Their structural systems, including adjustable legs, enable placement on various terrain and slopes without requiring significant land improvement. Among the examples of temporary shelters, scissors, and foldable ones are promising in terms of the advantages they provide. It is crucial to keep the mechanisms used in such shelters as simple as possible while also ensuring that the components are lightweight for ease of transportation. Nevertheless, durable materials should be chosen, considering the potential for extended usage beyond the initially intended timeframe. The majority of the temporary shelters in Table 4 are lightweight and can be rapidly erected or dismantled within minutes when needed, whereas the relocatable shelters in Table 3 may require more time for assembly. However, their compact design allows for multiple units to be transported on a truck, maximizing efficiency in large-scale implementations. This advantage enables the rapid deployment of thousands of shelters within a short timeframe, addressing the urgent shelter needs of disaster-affected populations.

The lightweight and compact nature of temporary shelters necessitates the careful integration of insulation solutions with structural systems without significantly increasing the weight or implementation time. Deployable temporary shelters composed of scissor-like and bar elements require using flexible or rigid covering materials to create enclosed living spaces. Designers of such structures generally focus on mechanism design and disregard the covering material, but it should be integrated with the system. Because the covering material is not the primary issue, insulation may become a challenge in these shelters. On the other hand, foldable structures are more advantageous since insulated panels can be used as part of the foldable system. This integration ensures that the insulation is incorporated seamlessly without compromising functionality or adding excessive weight to the shelter.

In the case of the proposed *Shelter Module X*, careful attention has been given to several features. The scissor linkages and insulated folding panels have been designed in a way that they do not block each other during the opening and closing processes. This consideration ensures smooth operation while maintaining insulation properties. Furthermore, the design takes into account the importance of minimizing additional weight, ensuring that the shelter remains lightweight and portable without compromising on insulation capabilities.

The multi-phased sheltering process, which covers emergency shelters, transitional shelters, and permanent reconstruction, requires the use of different shelter types until permanent dwellings are built. Tents are mostly employed during the immediate relief period, whereas container-type shelters are used during the rehabilitation period. Despite their cost-effectiveness, they have many deficiencies such as poor thermal insulation, limited privacy, inflexibility, and instability. Thus, they are not convenient for long-term usage. Despite their durability, container-type shelters are not cost-effective, and only one shelter can be transported on a truck due to its size. Moreover, they are heavy and not adaptive enough to respond to changing user needs and conditions.

On the other hand, temporary shelters having mobility and movement provide many advantages compared to those conventional types, encompassing not only adaptability to changing circumstances but also reduced implementation time and overall cost. Using multiple shelter types in the periods of immediate relief and rehabilitation such as tents and containers increases the overall cost spent for sheltering. However, with the development of efficient design solutions, kinetic disaster relief shelters have the potential to fulfill the criteria, standards, and requirements of both periods. They can even serve as permanent shelters due to their inherent ability to be relocated, upgraded, and reused. At this point, a question arises: can temporary kinetic disaster shelters evolve into long-lasting solutions? The answer lies in their inherent flexibility and adaptability.

Because the energy crisis and limited resources led designers to develop sustainable and energy-efficient design solutions, more adaptive and flexible alternatives have been proposed in recent years not only in building and façade designs but also in the realm of temporary shelters. Kinetic disaster relief shelters can offer many benefits, from ease of storage, transportation, and implementation to spatial flexibility and adaptability. One notable benefit of kinetic shelters is their potential for multiple uses in various disaster scenarios, mitigating the need for continuous shelter production. Kinetic shelters might be more economical than three-stage sheltering which requires using different types of shelters. In addition, they can yield time and energy savings since their ease of assembly, disassembly, and transportation significantly reduces the time and effort required for implementation. Another advantage lies in the potential transformation of kinetic disaster shelters into permanent dwellings. By repurposing these shelters as long-term housing solutions, they can help prevent land waste and urban sprawl, while also reducing construction costs.

Taking the aforementioned factors into consideration, the development of a modular shelter can offer a viable solution for disaster relief shelters. Because the *Shelter Module X* is designed to be both easily transportable and expandable, it allows for adaptability to varying shelter durations and changing conditions. Implementing the *Shelter Module* X does not require extensive fieldwork or professional assistance. However, in cases where a combination of diverse modules is needed, professionals may need to assemble them on-site or prior to their arrival at the shelter settlement to ensure a smooth deployment process. For long-term usage, the proposed design can be converted into a permanent dwelling by enclosing the entire structure, reinforcing the insulated panels, and securely attaching them to the scissor elements. This transformation would necessitate the creation of a foundation, which could be achieved by improving the shelter's land, increasing its elevation, and removing the wheels. By following these steps and making the appropriate modifications, the *Shelter Module X* can transition from a temporary shelter to a durable and functional permanent dwelling. This adaptation allows for the longevity of the shelter, ensuring its suitability for long-term usage and providing a sustainable solution for displaced individuals or communities.

4. Conclusion and Suggestions

The need for shelters persists as long as the displacement resulting from disasters continues. The duration of sheltering depends on many factors such as the type of disaster, the extent of damage to the built environment, and the number of people affected. Even though sheltering is commonly perceived as a temporary solution, its duration is not always limited to a specific timeframe, as indicated in the existing literature. In fact, the construction of permanent housing can be delayed, leading to sheltering periods that can extend for years. During this extended period, the inadequacy of disaster shelters becomes apparent, and the living conditions can become unbearable for occupants. These shelters are designed with a temporary mindset, meaning to serve for no more than six months. As a result, they often fail to address the changing needs, locations, climates, and diverse user requirements, thus exacerbating the universal challenge of sheltering.

Acknowledging the potential changes in user types and needs over the extended sheltering period is crucial (e.g. children may enroll in school, and the number of patients or newborns may increase). Therefore, it becomes much more important to adapt to evolving circumstances and user needs. Designers must prioritize the quality of life within shelters, aiming to support the mental and physical well-being of the people affected by disasters and enable them to continue their daily routines such as work, study, rest, and recreation. In shelter settlements where people must live in temporary shelters until permanent dwellings are built, it is essential to incorporate common areas that foster social interaction. Moreover, there is also a need to provide service units, administrative facilities, and healthcare centers within the shelter settlements. Therefore, design solutions should cover creating large communal areas for such needs by either proposing large-scale units or combining small units to form larger spaces.

Because finding adaptive and flexible shelter solutions remains a priority, humanitarian organizations, engineering companies, researchers, and designers continue developing alternative design solutions. To respond to the changing needs and spatial requirements over time, interdisciplinary studies can be conducted. As new structural solutions are developed, the deficiencies in the existing design solutions of the temporary shelters can be solved. Kinetic structural systems can be a good solution in temporary shelter design since they offer not only structural and spatial improvement but also more adaptive and habitable living environments. Among the examples of disaster relief shelters, those having deployable and foldable systems are promising regarding adaptability and flexibility since they may provide alternative spatial arrangements for larger units and settlements.

The *Shelter Module X* offers a range of benefits, including spatial flexibility, modularity, adaptability to changing needs, and the creation of a habitable living environment throughout the sheltering period. However, most of the studies in the literature dealing with temporary shelters primarily focus on system development. Many studies highlight demountable or complex systems that are typically not user-friendly when it comes to installation. Emphasizing ease of assembly can be a key consideration for facilitating quick installations during the immediate relief period. In addition to system development, temporary shelter design should also concentrate on spatial arrangements and enhancing user comfort within and around the shelter. Further research is needed to develop more adaptive solutions for both individual shelter units and entire settlement settlements. In particular, the design proposal can be further enhanced by considering the implementation time and required workforce for both relocatable and demountable options. In the case of the relocatable option, the connection of plates and scissor linkages need to be explored to enable installation by non-professionals. Likewise, demountable options need to be designed and evaluated, taking into account the necessary workforce and time required for both professional and non-professional assemblies.

As the existing studies on kinetic disaster relief shelters are limited in scope, there is a significant gap in the literature regarding their potential for further development. Therefore, conducting a systematic review of such shelters to reveal their potential for further development and presenting a design proposal in this study will not only fill the gap but also contribute valuable insights to the field. This study can serve as a guide for further studies in this field.

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Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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