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RESEARCH ARTICLE

Investigating the Construction of a Post-earthquake Shelter Using the Super Adobe Method in Herat, Afghanistan

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ABSTRACT

Earthquakes, as one of the most destructive natural disasters, have always posed significant challenges to humanity. The construction of temporary housing in post-earthquake conditions is very necessary and should be considered as a life-saving measure. To ensure the safety and health of the people affected by the earthquake, it is necessary to provide solutions for cheap, fast, and safe housing. Construction solutions for cheap and fast housing in times of crisis require the use of earthquake-resistant technologies. Among the types of post-earthquake temporary housing, housing construction using Super Adobe is one of the solutions that speed up the construction process and reduce costs. The purpose of this article is to investigate the need and construction of an emergency shelter using the Super Adobe method after the deadly earthquake in Herat, Afghanistan in 2023. The research paradigm is qualitative and comparative methods and logical analysis have been used in it. In the first part, the types of emergency shelters were compared and the construction of emergency shelters using the Super Adobe method in Herat was evaluated. Then 38 samples made in the Sanjab village of Herat were examined. The results of the research show that according to the geographical, economic, social, physical, and rural conditions of the region, the problems and challenges in the preparation of materials, and the construction of earthquake-resistant shelters, the Super Adobe method is the most suitable option for the construction of emergency shelters in this region. The ability to implement in a short time, the use of local materials, compatibility with the rural context, resistance to cold, heat, and climatic conditions of the region, resistance to earthquakes, low cost, and compatibility with sustainable rural development are the main reasons for the compatibility of this plan with the existing post-earthquake conditions.

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1. Introduction

Earthquakes, as one of the most destructive sudden natural disasters, have always posed a significant challenge to humanity. The need for a robust and efficient system for earthquake preparedness, planning, and rapid response to the needs arising from earthquakes, as well as preventing or minimizing damages to life and providing housing after the earthquake, has always been present. Constructing emergency housing in the aftermath of an earthquake is vital and should be considered as a life-saving and predicted measure. Ensuring the safety and health of earthquake-stricken people requires providing solutions for affordable, rapid, and safe housing. These solutions should not only enhance speed and safety but should also be highly cost-effective.

Construction solutions for affordable and rapid housing in times of crisis require the utilization of modern earthquake-resistant technologies. Building housing using Super Adobe is one such solution that accelerates the construction process and reduces costs. Nowadays, Super Adobe, due to its earthquake-resistant structural properties and ease of procurement and construction, has become a cost-effective solution for emergency housing. Furthermore, the construction of Super Adobe offers additional advantages. Compared to traditional structures, Super Adobe structures and materials are lighter and more easily transportable. This capability empowers authorities to address earthquake emergencies and the basic needs of the community rapidly and efficiently.

The recent earthquake in Herat (October 7 and 11, 2023) severely damaged many rural and remote communities, causing extensive damage to traditional structures and buildings in these villages, rendering them unusable. Most of the villages, far from urban centers, face significant challenges in building and adopting new housing due to high costs and distance from production centers. It was therefore decided to pilot the first Super Adobe structures in this region. After the successful construction of the first sample and the request of the villagers, the construction of 37 Super Adobe structures was planned for households in the village of Sanjab, Herat, Afghanistan. This article describes the construction of these structures in Sanjab village and provides insights into this project and its adaptation and implications for earthquake-prone regions.

2. Research Method

The research paradigm is qualitative, and comparative methods and logical analysis have been used in it. The first part is a document study. It presents different views on the construction of emergency shelters and temporary housing. The main criteria for studying the environmental impact are safety, strength, resistance to earthquakes, resistance to climatic conditions, social and cultural factors, construction cost and efficiency, feasibility, concinnity, compatibility with rural context and traditional houses, sustainability, etc. These qualitative criteria are the most important criteria for evaluating a suitable shelter.

By interviewing several professors and researchers, various criteria for temporary shelters were obtained and classified into eight different categories according to their opinions. These criteria include environmental quality, conformity, efficiency, social and cultural performance, stability, security, and ability to execute. The Analytic Hierarchy Process (AHP) and the Paired Sample Test combination method were used to prioritize and weigh these criteria. For this purpose, the Expert Choice software was used to analyze the data from the questionnaire completed by the professors and researchers. These criteria were then used to compare the types of shelters and to assess the feasibility of constructing shelters using the Super Adobe method in Herat. The second part describes the earthquake situation in Afghanistan and the Hari Rod fault as an active fault. Then, the recent Herat 2023 earthquake and its consequences and challenges were examined. Finally, 38 samples built in the Sanjab village of Herat were examined based on these criteria.

3. Shelter after the Earthquake

Earthquakes are natural disasters that can cause significant damage based on their magnitude and severity. Unfortunately, not much can be done to prevent them, but measures can be taken to minimize their impact. When earthquakes occur, buildings often become unsafe places to live, and immediate action must be taken to rebuild and create shelters. However, this process can take a long time, and until then, victims need temporary housing.

Given the critical role of housing and shelter for humanity, it is essential to anticipate and establish temporary housing for victims of disasters, and this should be a top priority [1]. In disasters, predicting a location for emergency and temporary accommodation is crucial. Without conventional shelter, injured and bereaved individuals are at risk of serious physical, mental, and psychological harm. Failure to make correct and timely predictions in this regard can result in negative and irreparable consequences for current and future generations [2]. When evaluating post-disaster shelter and housing, quality (both construction quality and cultural and climatic suitability), speed, and budget are key considerations [3].

The lack of stability, predictability, and quality in temporary housing may lead to ongoing stress and negative emotions that can contribute to lower life satisfaction. Addressing the living conditions and quality of temporary accommodation is, therefore, crucial to mitigate these negative impacts. By identifying the specific factors that contribute to the discomfort and suffering of people living in temporary accommodation after a disaster and designing targeted interventions to address them, it could be possible to improve the quality of life and well-being of the affected population. The analysis of life satisfaction among displaced individuals housed in temporary accommodations following three strong earthquakes in Italy (Abruzzo in 2009, Emilia in 2012, and Central Italy in 2016—2017) highlights the importance of providing appropriate properties for temporary housing, including privacy, space, thermal and acoustic insulation, lighting, quality materials, and suitable surroundings. Additionally, the location of these accommodations should allow for the resumption of daily activities [4].

Shelter, protection, humble house, shed, or hut, is a primary architectural structure that provides protection from the environment and people can use it, including protection from natural elements such as rain, snow, wind, cold, and heat, or protection from dangers such as war, invasion or accidents. And natural disasters, they take refuge in them. These shelters can be temporary or permanent and are usually made of materials such as wood, metal, plastic, fabric, earth, etc. Shelters are specifically used in times of crisis and emergency, and their main function is to create a safe and temporary environment for people in critical situations to be safe from external dangers in these situations. Therefore, shelter is different in content, form, and function from housing and dwelling. When the shelter becomes an emergency shelter, it is not only a safe place for people in the face of natural crises or accidents, but this action improves safety and reduces the vulnerability of people in the region to provide permanent housing.

According to UNDRO (1982), there are eight basic types of post-disaster shelter provision: tents, imported designs, and units, standard designs incorporating indigenous materials, temporary housing, the distribution of materials, core housing, hazard-resistant housing, and accelerating the reconstruction of permanent housing [5]. The post-disaster shelter has broadly been categorized into four phases: emergency shelter, temporary shelter, transitional housing, and permanent housing, but these should not be considered distinct phases with uniformity in timelines across all populations following any one disaster, particularly in low-income environments [3]. After the 2010 earthquake in Haiti, emergency shelters were quickly deployed as a refuge for displaced individuals and families, protecting them from the elements and a sense of security amidst the chaos. Also, according to the definition provided by Daniel Felix and his colleagues, temporary housing, which comes after the emergency and transitional shelter phase, is a place where survivors can stay temporarily, usually for six months to three years, and return to their normal daily activities, and it can be in the form of a prefabricated house, a rented house, etc. Following the 2015 earthquake in Nepal, structures were used as temporary shelters for displaced populations. These shelters are designed to be more robust and durable than emergency tents, providing semi-permanent housing solutions until more permanent structures can be built. Despite having their own space in temporary shelters, people cannot resume their daily lives, so it is impracticable to stay longer in them. The next stage, temporary housing, seems to be the obvious solution to bridge the time gap between temporary shelter and the conclusion of reconstruction works [6]. Temporary housing solutions have the necessary conditions and spaces to allow people to return to their normal activities such as cooking, housekeeping, working, socializing, attending school, etc. Thus, it is a crucial phase because it promotes the return to normalcy in a chaotic [7]. To achieve this goal, the physical space of temporary housing must be in harmony with the cultural, natural, and man-made environment, as well as the ecological, economic, social, political, and community livelihoods [8]. After Hurricane Katrina in 2005, structures were implemented as transitional housing solutions, offering an intermediate step between temporary shelters and permanent homes. The structures offered comfortable living spaces with better amenities, enabling residents to reconstruct their lives while waiting for more permanent housing options. In Pakistan (2010), where recurring floods have displaced millions of people, villages have been established to provide long-term housing solutions.

The economic and environmental questions are also considerable problems of temporary accommodation solutions. The costs of these temporary buildings are usually high, which has been considered a waste of funds owing to the relation between the great investments needed to buy them and their short lifespan [9,10]. The usage of local resources is undoubtedly a better option than the import of solutions [11,12]. If available, local materials are probably culturally and socially more appropriate, as well as more economical, since they are familiar and avoid the high costs that transportation implies. The use of local materials empowers the possibility of involving the local workforce in the erecting works because local people are used to handling them. Local communities often have knowledge and construction skills [13]. Previous studies have found that the first answers to the need for shelter have been provided by survivors [14]. Moreover, the active participation of the victims can be a useful way to restore the sense of pride and neighborhood relationships [15], which is relevant after traumatic disaster events. Increasing social participation helps preserve and maintain historical contexts. It provides a platform for continuing life in rural or urban areas by narrating the past culture and developing new activities [16]. However, not all kinds of community participation can lead to positive outcomes, so, it has to be locally determined [17].

Some indigenous and local construction techniques (Gabion structure and waterproof fabric or Super Adobe) can be more resistant to disasters when compared to some modern building methods [18] since such knowledge has been developed over time and is well adapted to the local environment [19]. Despite the criticism of the new modern ways of production used to build temporary accommodation buildings, and the emphasis on the usage of local resources, it does not mean that innovation has no space in the development of temporary solutions. Properly used, that is to say culturally and locally integrated, innovation and technology may contribute in a useful manner to improve temporary accommodation solutions [20]. Therefore, the design should balance a combination of technological and local ways of construction and materials [21].

According to the studies and reviews, there are various solutions and recommendations for temporary housing and emergency shelters after the earthquake (Table 1).

Table 1. Recommendations to design temporary accommodation buildings.

Source	Recommendations
Omidhar, et al. *(2007)*	Protection against heat, cold, wind, and rain; Stabilizing and maintaining the boundaries of the house of ownership and misappropriation of property; Building and renewing social organization; Creating psychological security and private environment; Determining an address to receive services (medical services, food, etc.); Accommodation of people within the limits of access to work.
Nikrvan Monfared (2007)	Having a specific identity in terms of general, technical, and functional differences; Considering different areas with the needs of users; Prefabricated production and light, resistant, and stable; Use of existing and local materials in construction; Lightness and applicability of forces with simple technical skills; Considering factors that affect comforts such as climate and culture on the one hand, and meeting the conditions related to lighting, heating, and cooling, on the other hand.
Corsellis & Vitale (2005)	Corsellis & Vitale having adequate privacy and security; Durable and resistant housing; Having proper lighting and heating network and ventilation; Appropriate infrastructure prices including water services; To consider health and environmental management facilities and wastes and the effects of cultural identity.
Bamanian and Bakhtiarian (2013)	High construction speed; Low volume weight value in the pre-erection state; Easy storage conditions in the warehouse; Easy transport ability, the few species and the number of transshipments; Simple implementation with the need to little technical skill, the possibility of expansion in the future, presentation, and implementation for various areas; Prefabrication of the foundation and other parts, the possibility of replacement of parts; Use available solvents.
Bahraini and Akhundi (2000)	Against heat, cold, wind, and rain; Storing furniture and keeping what remains of the disaster safe; Stabilization and maintenance of house boundaries; Creating psychological security in the private environment.
Lindell et al. *(2007)*	High manufacturing speed; Low weight and volume in storage mode; The ability to easily establish transfers in terms of variety and number in minimal mode; The ability to develop in the future, the possibility of replacing parts; Prefabrication of the foundation of the building, simplicity of connection and alignment.
Falahi (2007)	Using local technology; Paying for shipping; Suitability in terms of safety, culture, and climate; Participation of the injured in the establishment; Justice in the equal distribution of temporary accommodation among the victims; Giving importance to local and indigenous architectural and landscaping standards.
Sartipy Pur (2011)	|Capable of carrying vans and deploying the series in different conditions; Use of appropriate structures; Ease of production, ease of installation, and simple details compatible with the environment, climate, and weather.
Behzadfar (2005)	Protection against heat and cold; Attention to the size of the tents with the size of the household; Suitability of the type of tents to the culture and lifestyle of the victims (urban or rural); Establishing temporary accommodation near the previous place of residence of the victims.
Johnson Cassidy (2007)	Offers a comfortable level of quality of life in temporary accommodation that meets the prevailing standards of living; Low price; The possibility of building a series of low-cost housing with the culture of the victims; To be possible to use; Easy removal and non-polluting temporary housing.

Source: Hart, K. [22].

Although many solutions have been proposed for temporary shelters, some problems seem to persist. These problems arise mainly from misunderstandings and misconceptions about post-disaster situations and local contexts. The combination of crisis, pressure, and lack of resources has led to unsuccessful options and decisions, and the strategies implemented have been culturally and locally inappropriate, resulting in economically and environmentally unsustainable outcomes.

To mitigate these problems, it is first necessary to have prepared and appropriate strategies and solutions in advance, rather than thinking about them after an accident occurs. Second, local resources and plans should be prioritized over imported and off-the-shelf solutions. Finally, more attention should be paid to people-oriented solutions rather than bureaucratic and administrative work.

4. Super Adobe

In the aftermath of an earthquake, temporary shelter is critical for displaced people. All over the world, many construction systems have been used for temporary accommodation after natural disasters and earthquakes, the most important of which are: Dome houses, Air supported structures, Super Adobe, Flat pack shelters, Hexagonal shelters, Gabion structures, and Waterproof fabric, combined structure of canopies and tents. When selecting and constructing shelters, it is important to consider various factors such as the type of crisis, shelter strength, and stability, security, implementation speed and ability, available facilities and resources, compatibility with geographical, native, and climatic conditions, as well as cost of implementation and responsiveness to local needs. Among the various types of emergency shelters used worldwide during times of crisis, the most suitable options for temporary to permanent accommodation are Super Adobe, gabion, and waterproof fabric structures. Table 2 shows the comparison between temporary housing construction systems.

The Super Adobe structure is a form of soil architecture invented and developed by Engineer Nader Khalili, founder of Cal-Earth Institute. Super Adobe is a form of earth bag construction that uses layered long fabric tubes or bags filled with soil to form a compression structure. The basic construction method entails filling sandbags with earth's sand and laying them in a circular pattern. The circles created are tied near the top to form a dome. Barbed wire is laid between these circles to prevent the sandbags from moving and give them earthquake-resisting power. Hence, these materials used for war (sandbags and barbed wire) were finally used for peaceful goals, mixing traditional earth architecture with global safety requirements [22]. Super Adobe structures can be built quickly and provide strong shelter while more permanent solutions are developed or existing infrastructure is repaired. These structures are relatively easy to construct using locally available materials such as earth and sandbags, making them cost-effective and accessible in disaster-stricken areas. They're a viable solution for temporary housing because they're earthquake-resistant and can withstand some seismic activity. They're also environmentally friendly because they use natural materials. The main advantages of using Super Adobe include its flexible form, fast construction, thermal comfort, energy efficiency, low cost, structural strength, self-supporting capability for up to two floors, low maintenance, and the use of recyclable and reusable resources [23].

The system is particularly suitable for providing shelter for a short period of 5–10 years. It is cheap and allows buildings to be quickly elevated by inhabited caves with little training. Each shelter is made up of one central, circular space for the roof and some additional spaces for cooking and sanitary services. This system is highly flexible and efficient. The materials used to make traditional sun-dried bricks for prosperity are not always available. Even these inhabitants do not always have the time or space to make these blocks and store them. With the technique of filling bags directly from the land and empowering them with barbed wire, almost any land can be used to create a shelter, keeping in mind that building speed is much faster. Structures are used as a temporary solution or they last longer by adding a layer of mud or another finishing material. Additional supplements, such as ovens and animal shelters, can also be provided to create a more permanent status. The shelter itself can be expanded or minimized according to individual needs. The technology can also be used for building infrastructures such as roads, retaining walls, and landscaping elements [24].

Soil bags increase resistance to flooding and fire, and the large walls also act as thermal insulation. Depending on the soil characteristics in the area, stabilizers such as cement, lime, or asphalt emulsion may be added. The adobe structures are designed in a dome shape. In addition to the windows, there are small openings in the roof. This design allows the structures to be heated by sunlight in the winter and act as windbreaks in the summer, cooling the air inside.

Table 2. Comparison between temporary housing construction systems.

	Dome structure	Wind structure	Super Adobe	Flat structure	Hexagonal structure	Gabion structure and waterproof fabric	Combined structure of shed and tent
Installation dimensions	3.7*3.7 with thickness of 175 mm	Variable	Variable	3*3 or 3*4	3*3	Variable	3*3*2.7
Approximate weight	450 kg	According to variable dimensions	According to variable dimensions	Approximately 160 to 350 kg	1000 kg	According to variable dimensions	300 kg
Material	Expandable polystyrene	Variable	Sack, wire, and soil	Waterproof tarpaulin, fiberglass, sandwich panel	Steel and rigid foam insulation	Gabion, steel and tarpaulin	Steel and fiberglass
Installation method	Prefabricated parts	According to variable numbers	Local workforce	Prefabricated parts	Prefabricated parts	Local workforce	Prefabricated parts
Necessary tools	The production parts are produced in the desired workshop and connected quickly on the site	The production parts are produced in the desired workshop and connected quickly on the site	Shovel	The production parts are produced in the desired workshop and connected quickly on the site	The production parts are produced in the desired workshop and connected quickly on the site	Semi-heavy vehicles	The production parts are produced in the desired workshop and connected quickly on the site
Environmental conditions	It can be used in all conditions	limited	It can be used in all environments	It can be used in all environments	It can be used in all environments	It can be used in all environments	It can be used in all environments
Useful life	In the open environment up to 30 years and in hot areas up to 20 years	From 6 months to a year	Due to the insulation at the end of the work, it has a long service life	3 to 6 years	10 years	Due to insulation, it has a high useful life at the end	5 years
Warehouse conditions	Chemicals do not require closed storage, but require safe conditions	It requires closed storage	No special conditions are required	No special conditions are required	No special conditions are required	No special conditions are required	No special conditions are required
Shipping method	Can be transported everywhere by container	Easy	Build on site	Can be transported everywhere by container	Can be transported everywhere by container	Easy	Can be transported everywhere by container
Advantages	No penetration of moisture into this material High compressive and mechanical resistance Long life It is very light compared to other materials Fast and convenient production in a modular way Optimal energy consumption Limited heat exchange	Being multi-purpose Can be used in different sizes and openings Variation in shape and design Fast installation	Ease of construction and no need for technology Low volume before installation Long life High thermal resistance Fast and convenient production in a modular way High resistance to earthquakes Quick setup	No penetration of moisture into this material Low volume before installation Decent lifespan It is very light Fast and convenient modular production Water collection Quick setup Beauty Interchangeability of parts	No penetration of moisture into this material Low volume before installation Decent lifespan Create different shapes Fast and convenient production modularly Water collection Quick setup	Ease of construction and no need for technology Low volume before installation Long life High thermal resistance Fast and convenient production High resistance to earthquakes Quick setup Fast mass production capability	Absence Moisture penetration into this material Low volume before installation Good longevity compared to other materials very light Fast and convenient production Modular faceplate Water collection Quick setup
Used	Japan - Permanent settlement in rural areas	America	Pakistan, Bangladesh, India	Ethiopia, Syria, Iraq	Türkiye and Jordan	-------	Türkiye, Italy
Source	Tang, 2009	, Huang 2015	Khalili,1986	Abaka, 2014	FEMA, 2012	UNHCR, 2015	Todmi, 2010

Source: Shaw, R. [19].

5. Seismic Hazard of Earthquake in Afghanistan

As one of the earthquake-prone regions of the world, Afghanistan has always faced the challenges of earthquakes and their devastating effects. In this country, which is located in the heart of Asia, many of its residents are always exposed to the dangers of earthquakes. Afghanistan is located on the active Alpine–Himalayan orogenic belt formed in response to interactions between the Indian, Eurasian, and Arabian plates [25]. The collision boundary of the Indian, Eurasian, and Arabian plates is in adjacent Pakistan and Iran in the east and south of Afghanistan, respectively [26].

The literature contains evidence and suggestions that 10 large Afghan faults are seismically active. The Chaman fault has by far the most evidence of seismic activity. It is part of the western margin of the transpressional plate boundary between Eurasia and India. After the Chaman fault, the Darvaz fault has the most evidence of recent slip. The north-striking part of the fault is partly in Tajikistan but mostly in Afghanistan. The Hari Rod fault has a striking geomorphic expression on satellite images. Other active faults are the Andarab Fault, the Darafshan Fault, the Sarobi Fault, the Central Badakhsan Fault, the Alburz Marmul Fault, and the Panjshir Fault, which are active according to the results of earthquake concentration and microearthquake studies [27]. Afghanistan's tectonic regions and active faults are shown in Figure 1.

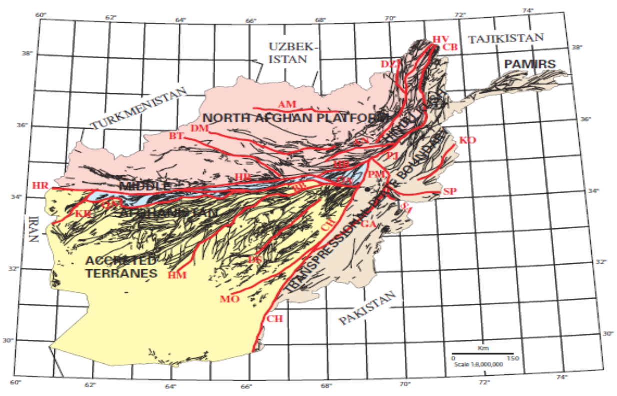

Figure 1. Tectonic regions of Afghanistan: Pink, North Afghan platform. Blue, Middle Afghanistan. Yellow, terranes that were accreted to the platform. Tan, left-lateral transgressional plate boundary between the Indian and Eurasian plates.

Source: Santos, D.M. and Beirão, J.N. [24].

A comprehensive earthquake catalogue is a critical input for reliable probabilistic seismic hazard analysis. Figure 2 shows the earthquake data for the years 2000 to 2016.

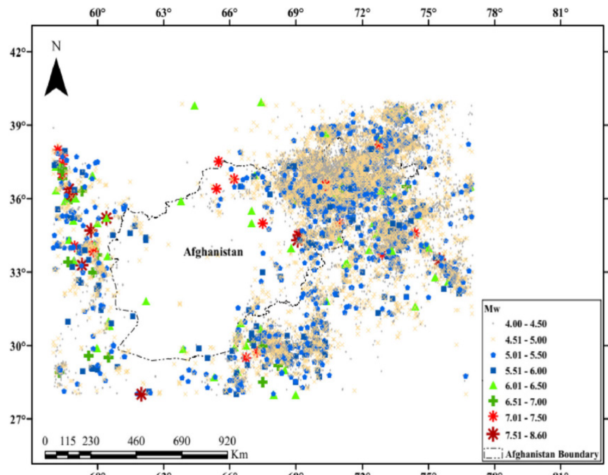

Figure 2. Homogenized earthquake catalogue of Afghanistan.

Source: Santos, D.M. and Beirão, J.N. [23].

Afghanistan's geography and active tectonic forces present challenges to earthquake preparedness and response. The country's diverse topography, including mountainous areas and vulnerable urban areas, as well as remote and disadvantaged areas, requires appropriate strategies to address the unique risks associated with seismic activity. Throughout its history, Afghanistan has experienced several destructive earthquakes, each leaving its mark on the landscape and society. These seismic events have shaped the understanding of earthquake hazards and emphasized the importance of developing strategies to mitigate their effects. Investments in early warning systems, public awareness campaigns, the development of earthquake-resistant structures, the establishment of well-equipped relief agencies, the design and construction of shelters for victims, and the management of environmental conditions can be essential components of a comprehensive approach to reducing the impact of earthquakes.

The Super Adobe method is now being used in Canada, Mexico, Brazil, Chile, Iran, India, Siberia, and Thailand, as well as in the U.S. The Super Adobe system has shown great potential in applications such as earthquake resistance, flood control, erosion control, stream bank stabilization, slope and embankment stabilization, landslide protection, and infrastructure [28]. It is constructed using long propylene earth bags, barbed wire, and soil found on the site, following the native architectural methods of many regions of the world while adhering to global safety requirements and California earthquake standards.

While building a roof using adobe may seem simple, it is crucial to prioritize the structural integrity of the structure. To ensure this, engineering concepts such as base isolation and pullback are utilized in the design of these shelters. Long coils of sandbags provide compressive (vertical) strength, while barbed wire provides tensile (horizontal) reinforcement. The success of the tested prototypes for California's seismic codes and the resulting approvals can be attributed to the following principles: Super Adobe techniques allow the construction of a monolithic structural system built entirely of earth in curved shapes. The sandbags, because of their flexibility, allow the construction of curved surfaces. When using single and double curvature shells arch, vaults, domes, and apse the majority of conventional roofing systems can be eliminated. Single and double curvature compression shells transfer their stresses along the surface of the structure and not from elements like column and beam-type buildings. Dead load and live load stresses are transferred to the bearing soil and spread evenly along the perimeter of a dome or bearing wall. The base of a dome or bearing wall distributes the load of the structure over a much larger area. A dome or load-bearing wall built on a floating foundation, with the base-isolated by a layer of gravel or sand, provides the ideal seismic-resistant structure [29]. Super Adobe structures have been constructed in various countries as emergency or temporary shelters and have proven to be earthquake-resistant, remaining in good condition for several years.

6. Herat Earthquakes and Construction of a Post-earthquake Shelter

Herat is one of the western provinces of Afghanistan, which has always been vulnerable to earthquakes due to its location in a seismically active region. Earthquakes in this region are the result of complex tectonic activity on the southern and eastern margins of the Indian and Arabian plates. Herat has experienced strong earthquakes in the past, causing severe damage to the infrastructure and population of the region. These earthquakes have affected not only the people but also the urban and rural structures of Herat, necessitating seismic safety measures and inevitable reconstruction.

The October 11, 2023, M 6.3 earthquake near Herat, Afghanistan, occurred as a result of thrust faulting at shallow depths near the westernmost end of the Hindu Kush mountain range. This earthquake was preceded by two magnitude 6.3 earthquakes that occurred four days earlier. All three earthquakes occurred on east-west striking faults that dip either to the north or south. The earthquakes occurred within the Eurasian Plate in an intracontinental mountain belt. Earthquakes in western and central Afghanistan are primarily influenced by the northward motion of the Arabian plate relative to the Eurasian plate. Since 1920, eight other earthquakes of magnitude 6 or greater have occurred within 250 km of the October 7 earthquake, all within Iran [30].

A total of 11585 people (1655 families) were affected by this earthquake [31]. More than 2400 people were killed in this earthquake in Afghanistan, the deadliest tremors to hit the quake-prone mountainous country in years [32]. There was a critical need for shelter repair assistance and transitional shelters as 73 percent of houses in 320 villages have been severely damaged or destroyed, with more moderate damage in the remaining villages [26].

Following the Herat earthquake and subsequent aftershocks, many villages in the region were destroyed, leaving many residents homeless and causing significant loss of life. With winter approaching, there was an urgent need to construct emergency shelters in the affected areas. The Herat region and its rural areas face multifaceted challenges. These challenges include:

- **Environmental Challenges:**
  - The region experiences strong winds, commonly referred to as the 'black wind', which can make tent relief efforts unstable and ineffective.
  - Due to the ruggedness of the area and the considerable distance between villages and urban areas, providing insulated conex boxes in large numbers and transporting them to remote rural areas is challenging and costly.
  - Constructing emergency shelters using durable materials, such as steel and concrete, presents challenges due to the lack of necessary facilities, high costs, and the need for skilled personnel to meet technical specifications.
  - Building houses and shelters without considering the region's climate, geography, available natural resources, and physical structure of the village can disrupt the environmental balance.
- **Cultural Challenges:**
  - Following an earthquake, residents may be reluctant to leave their damaged homes and property due to concerns for their belongings, livestock, and gardens. This desire to remain in the same location can hinder relocation efforts.
  - Rural residents in earthquake-prone areas typically reject shelters that do not align with their local lifestyle and functional requirements.
- **Conformity Challenges:**
  - Shelters must be functional, harmonious, and aesthetically pleasing to the residents.
  - Structures that are not modular or do not allow for quick assembly and the ability to expand or connect to other structures can hinder the efficiency of assisting processes.
- **Efficiency Challenges:**
  - Due to inclement weather, winter, and strong winds, constructing shelters has become difficult and even impossible.
  - The limited availability of materials and economic constraints in the region also restrict the selection of cost-effective solutions for shelters.

- **Stability Challenges:**
  - Existing shelters may be compromised by environmental factors, which could result in their collapse under strong winds or seismic activity.
  - Rural inhabitants are at risk of falling debris from earthquake-damaged buildings.
- **Social Challenges:**
  - Proper management and disposal of earthquake victims' corpses has not been completed, leaving the affected residents in a state of psychological shock.
  - The construction of permanent housing may be delayed, leaving them without homes for extended periods.
- **Security Challenges:**
  - Overcrowding and unsanitary living conditions may lead to outbreaks of diseases.
  - Inadequate heating systems in temporary tents may increase the risk of fire.
  - Wild animals and wolves pose a significant threat to rural residents in tents.
  - The area is prone to frequent earthquakes, necessitating sturdy shelter solutions that can withstand seismic activity.
- **Execution Challenges:**
  - Executing relief efforts in this region is challenging due to logistical hurdles.
  - Transportation of construction materials, finding specialized labor, and material transportation are all difficult and expensive.

To address these issues, different types of emergency shelters were researched. Based on a survey of experts, eight criteria of environmental quality, conformity, efficiency, social and cultural performance, stability, security, and ability to execute were weighted using the Analytic Hierarchy Process (AHP) and the Paired Sample Test. The building systems were then evaluated based on these criteria, and the best system was selected. After analyzing the data, it was determined that gabion structures with waterproof fabric, super adobe, and combined structures of sheds and tents are the best solutions for emergency shelters. Considering the available facilities and constraints, it was determined that constructing the shelter using the Super Adobe method with simpler and more accessible materials would result in a lower cost in this region. This method is easier to construct than other structures and can be taught to local people, allowing them to participate in the construction process. Anyone with the necessary training can participate in the construction and work on different parts of the structure's implementation. The structure can serve a variety of purposes, including temporary shelter, livestock storage, storage, service, and utility rooms. It can be maintained and used even after permanent housing is built. It has the flexibility to be developed and constructed at any time and in any place. Part of it can be built as temporary shelter and then developed into permanent shelter. In addition, it has high resistance to natural factors such as earthquakes, fire, heat, cold, rain, and humidity. This method has been successfully implemented and tested in similar countries and regions and has met the necessary resistance standards set by various organizations. The structure of the form bears a resemblance to traditional and indigenous structures as well as rural houses found in different regions of Afghanistan. The factors and main criteria for choosing Super Adobe in this project are shown in Table 3.

Table 3. Factors for Choosing Super Adobe for Sanjab Temporary Shelter.

Factor	Reasons
Environmental	- Great use of local materials such as soil (a mine with about 17% clay and more than 75% silt was identified at a distance of 6 km) - Mine was presented to the villagers - Insulation against heat and cold - Good resistance to storms and strong winds in the region
Cultural	- Closeness of the form, materials, and structures of Super Adobe to the traditional structures of the region - Willingness of the people to use local, available and cheap materials - A sense of trust in designers and producers
Conformity	- Coordination of structures within the village context with each other and with previous structures - Its curvature and shape, follow the type of domed architecture common in the village
Efficiency	- Ability to use simpler materials such as sacks, barbed wire, soil, and additives such as lime and type 2 Portland cement - No need for skilled labor and no need for advanced technology that is not within the capabilities of the villagers themselves - Ability to build quickly and use the Super Adobe immediately upon completion.
Stability	- Possibility of employing villagers as laborers, which helps to strengthen the economy and stability of the village economy - Durability of the structure for a long time
Social	- Original plan of Super Adobe was accepted by the rural people and psychologically they were more at peace with this plan - Creating a good sense of empathy and cooperation during construction
Security	- Resistance to daily aftershocks - Effective against the bitter cold of winter and the scorching heat of summer
Ability to execute	-Possibility of creating conditions for the participation of the villagers in the reconstruction of the village.

Therefore, a feasibility plan and technical instructions for implementing Super Adobe emergency shelters in Herat were developed. Technical guidelines and a feasibility plan for implementing emergency shelters using the Super Adobe method led to the construction of the first Super Adobe shelter in Sanjab village, Herat, in November 2023. Following the successful implementation of the first shelter and positive feedback from the local community, 37 additional emergency shelters were constructed and completed within 32 days, and the shelters were used by the villagers during the harsh winter of January 2024.

Super Adobe construction is a sustainable building technique that uses earthbags filled with a mixture of soil and stabilizers to create durable and energy-efficient structures (Figure 3). The primary materials used in the construction of Super Adobe in Sanjab include (Table 4):

The bags must be filled and placed over the row below, working inward to meet the compass circle. It is necessary to use 2 compass chains or other non-stretch rope to form the dome shape. One in the center (center compass) extends the length at each row corresponding to a second one at the perimeter (height compass) (Figure 4).

Figure 3. Execution of foundation and wall of Super Adobe shelter in Sanjab, Herat.

Table 4. Technical specifications of the materials used in the Sanjab Super Adobe shelter.

Material	Technical features
Soil	Soil with 15—17% clay, 70—80% silt, and optimum humidity, with a grain size of 0.05 to 0.3 mm
Lime	Add lime, 8 to 10% by weight of soil.
Cement	Type 2 Portland cement in the amount of 8 to 10% of the weight of the soil
Sack	Polypropylene bag for Super Adobe
Barbed wire	2 mm galvanized barbed wire and four pointed barbs, three rows of barbed wire between each row of bags, two parallel rows, and one spiral row.

Figure 4. Exterior and interior of the Super Adobe shelter in Sanjab, Herat.

The Super Adobe shelter is finished with locally appropriate materials to resist moisture and erosion, especially a water-resistant smooth cement/lime plaster such as Reptile (cement or lime mud balls), layered from bottom to top (Figure 5).

Certainly, construction projects, including Super Adobe construction, can face various challenges that require effective solutions. Here are some of the challenges and possible solutions that arose when trying to build a temporary shelter in Sanjab (Table 5).

Figure 5. Construction processes of Super Adobe shelter in Sanjab, Herat.

Table 5. Challenges and solutions in using the Super Adobe shelter in Sanjab.

Factor	Challenges	Solution
Environmental	- Arrival of early cold weather at the project site - Strong winds and storms during project implementation - Infiltration of water into the house in rain and snow and flooding - Predominant and strong north winds	- Bring in more workers and speed up project execution - Create a shelter and stop work during wind and storms - Shelters were built at the highest level - Up to a height of one meter, the outer wall was built with a 45-degree angle with soil protection - Installation of gates and windows on the east and south sides and skylights on the roof.
Cultural	- Public opposition to the construction of the Super Adobe structure - Negative influence of prejudices of people who had experience in construction work. - Unwillingness of workers to work in the new type of construction - People's use of traditional structures and thatched houses - Rural culture and suspicion of foreigners	- Targeted advertising and use of trusted and familiar people to justify the project - Hiring workers with less work experience and retraining experienced workers - Using workers who had experience working with soil and rural houses -Use of straw, a traditional material used in the region - Building a pilot model and allowing local people to visit it
Conformity	- Rushed use of structures and lack of opportunities for beautification. - Dispersal and lack of order and coordination of structures in a given area - Impossibility of using traditional straw joinery due to slow drying speed - Impossibility of drying the external coating due to the cold	- Beautification and facade construction were postponed to the future - Building structures on a site close to each other - Use a combination of gypsum and soil due to the high drying speed - Postpone exterior coating until the summer season
Efficiency	- Lack of skilled labor to implement the project. - Early cold weather harmed worker productivity	- Immediate training of workers and retraining of skilled workers - Increase heating facilities and wages for workers
Stability	- Lack of soil strength in all places - Possibility of destruction by storms and strong winds during construction - Frequent aftershocks during project implementation	- Soil testing and identification of better sites for the structure, as well as leveling and strengthening the structure's foundation - Suspension of work during severe storms - Consider a shelter with a diameter of 3.6 meters and a height between 3.5 and 4 meters due to the existing aftershocks

Table 5 continued

Factor	Challenges	Solution
Social	- Banning the transportation of lime in the region due to the government's failure to use it - Creation of negative publicity in the news and virtual space - Lack of coordination and empathy between residents and workers who came from outside the area to work - Preventing the continuation of construction and operation - Low level of literacy and rural culture in the project area and the problem of education	- Transporting lime in small shipments and from multiple routes to the site - Help from media activists to deal with negative publicity in cyberspace - Establishing a friendly relationship between the elders and trusted people of the village and the workers - Advertisements for not showing the positive aspects of using shelters - Training local people in a simple language to produce Super Adobe by a family in 7 to 15 days.
Security	- Possibility of destruction of part of the structures due to haste in construction - Possibility of destruction during construction due to strong wind and storm, earthquake shaking - Possibility of destruction of the structure due to human pressure and physical impact - Possibility of the structure disintegrating over time due to the decrease in resistance	- Accuracy in construction and continuous inspection of structures - Stopping work in case of possible destruction by wind and storm and resuming work after removing the danger - Consider the thickness of the walls from the foundation with a thickness of 70 cm and ends at 30 cm in the last layer of the bag on which the roof window is installed - Consider the thickness of the walls from the foundation with a thickness of 70 cm to end at 30 cm in the last layer of the bag on which the skylight is installed - Transfer the center of gravity to the lower part to stabilize it as much as possible. Make the rows resistant to sliding due to shocks - Make the house resistant to heat and cold, snow and rain, and also ensure the uniformity of the wall width as much as possible for the weight has been transferred to the ground
Ability to execute	- Lack of bags used in Sanjab, Herat - Storm and wind scattered materials into the air, causing respiratory and visual problems - Lack of suitable barbed wire for the project in local markets - Lack of workers at the project site - Lack of space to continue living in the long term - Moving to permanent housing - Changes in the structure of shelters	- Buying sacks from the neighboring country and transporting them to the site - Creating parapets to deal with wind and storms - Creating different groups to find materials in several places - Creating a working group to find and train workers continuously - Possibility of adding additional rooms to the shelter and building a new shelter by the residents - Easy and transferable destruction and use of construction materials - Possibility to reduce and increase the space of the shelter with a few changes in the shelter as a standard

Overall, the construction of Super Adobe shelters in Sanjab presented a myriad of challenges in terms of environmental, cultural, compliance, efficiency, stability, social, safety, and execution. However, the successful implementation of this project exemplifies the power of adaptability in overcoming obstacles. The solutions adopted ranged from practical construction techniques to social and cultural engagement strategies, reflecting a holistic approach to problem-solving. The project's success underscores the importance of collaboration, community engagement, and continuous adaptation in the face of unforeseen challenges. It serves as a valuable case study for future construction efforts in diverse and challenging environments, emphasizing the need for a multi-faceted and flexible approach to address the unique complexities that can arise during such initiatives.

Although there were some challenges in the construction process of the Super Adobe Shelter in Sanjab, the ability to implement in a short time, use of local materials, compatibility with the rural context, resistance to cold, heat, and climatic conditions of the region, earthquake resistance, low cost, and compatibility with sustainable rural development are the main reasons for the compatibility of this plan with the existing post-earthquake conditions.

7. Conclusions

The Cal-Earth Institute, located in California, USA, serves as a research center and demonstration site for Super Adobe construction techniques. These structures have been used in disaster-prone areas for emergency relief purposes in Canada, Mexico, Brazil, Chile, Iran, India, Siberia, Thailand, Nepal, as well as in South Africa.

The study of the construction of post-earthquake shelters using the Super Adobe method in Herat, Afghanistan, has provided valuable insights into a sustainable and resilient approach to addressing the urgent need for shelter in earthquake-prone regions. The Super Adobe method, with its reliance on locally available materials and its adaptability to different environmental conditions, is emerging as a promising solution for communities coping with the aftermath of seismic events. This approach highlighted the importance of community involvement and local empowerment in the construction process, which fosters a sense of ownership and resilience among the affected population. In addition, the cost-effectiveness and simplicity of the Super Adobe technique make it a practical choice for regions with limited resources and infrastructure.

It is critical to further refine and adapt the Super Adobe method to the specific needs and challenges of Herat, taking into account factors such as climate, soil composition, and cultural preferences. Collaboration among local communities, NGOs, and government agencies can be crucial in implementing and expanding this innovative approach to constructing shelters in the future. Given the successful implementation of Super Adobe technology in addressing shelter needs in the Herat region of Afghanistan, it is worth exploring further research and practical applications to expand its impact and sustainability. Documenting experiences, lessons learned, and best practices from Super Adobe projects in Herat, and other post-earthquake regions in Afghanistan, and around the world is crucial. This knowledge exchange can inform future initiatives, guide policy development, and inspire similar endeavors in different global contexts. in addition, Super Adobe technology aligns with various Sustainable Development Goals (SDGs), including Goal 11 (Sustainable Cities and Communities), Goal 13 (Climate Action), and Goal 15 (Life on Land). Future research and applications can emphasize the role of Super Adobe in achieving these goals and contribute to broader efforts towards sustainable development and resilience-building.

Ultimately, the exploration of the Super Adobe method in Sanjab, Herat serves as a testament to the potential of sustainable, community-driven solutions in the face of natural disasters. By prioritizing resilience, adaptability, and inclusivity, we can contribute to the development of safer and more sustainable living environments for vulnerable communities affected by seismic events.

Conflict of Interest

There is no conflict of interest.

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