SUSTAINABILITY IN CRISIS

AN EFFICIENT METHODOLOGICAL APPROACH FOR ENHANCING THE SHELTER DESIGN AND ADDRESSING THE NEEDS OF THE DISPLACED POPULATION

A dissertation presented

BY

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Abstract

Throughout history, architects have played an important role in delivering human needs, including the need to design shelters after disasters and crises which usually cause destroyed buildings and huge numbers of people without homes.

However, Existing literature shows that these housing solutions have critical sustainability issues. First, they caused high environmental impact due to the wrong selection of used materials, short lifespan, and high transportation emissions. Second, they are unsustainable regarding economic and socio-cultural aspects which are usually overlooked or partially considered in the shelter design and environment. Another critical issue in this type of housing is the design of sharing spaces. This caused a lack of privacy and a sense of unsafety that led to users' discomfort and dissatisfaction.

In addition to the fact that most of the existing shelter solutions are global standardized options, primary prefabricated units that concentrate on quick assembly with short-term needs, but often fail to address the long-term necessities which is the main key factor affecting the users' discomfort, and leading to the abandonment of these houses. The research used a mixed methods approach that combined qualitative and quantitative methods, including survey, life cycle assessment, and Evaluation and comparative analysis of current shelter designs. It aimed to determine the shortcomings and best practices in existing shelter solutions.

The significance of this research is to consider all the sustainability aspects equally and provide some scenarios and key insights of improvement gathered from the existing shelter analysis phases for developing a design framework that consists of strategies and guidelines for creating more sustainable shelter solutions that respond to the needs of displaced populations and are sustainable in terms of socio-cultural aspects, economic and environmental impact, then apply the findings to propose a shelter design to Accumoli, an Italian post-disaster settlement.

Keywords: Sustainable shelter, cultural appropriateness, environmentally friendly shelter, socially inclusive shelter, Low embodied shelters, low environmental impact shelter, and shelter users' satisfaction.

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"Architecture must not only provide shelter but also the possibility of dignity and hope, especially in temporary structures."

Shigeru Ban "Architect"

"Governments should stop thinking about refugee camps as temporary places, these are the cities of tomorrow. "

Kilian Kleinschmidt" UNHCR 'director of the Zaatari refugee camp"

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List of Abbreviations

IDPs: Internally displaced people.

UNHCR: United Nations High Commissioner for Refugees

WMO: World Meteorological Organization

GWP: Global Warming Potential

EE: Embodied Energy

RHU: Refugee Housing Unit

THUs: Temporary Housing Units

CLT: Cross-Laminated Timber

CO_2e: A CO_2 equivalent (CO_2e) is a unit of measurement that is used to standardize the climate effects of various greenhouse gases.

CGI: Corrugated Galvanized Iron

IOM: International Organization for Migration

T-Shelter: Transitional shelter

IFRC: International Federation of Red Cross and Red Crescent Societies

Chapter 1: Introduction

This chapter outlines the background of the research. It also presents the main aim and objectives of the study, in addition to its questions. It describes briefly the Methodology used and the scope of this research.

1.1 BACKGROUND OF THE RESEARCH

In recent decades the number and frequency of natural disasters and man-made disasters have increased. Due to climate change, Natural Disasters like earthquakes, floods, hurricanes, and storms have become more frequent [1]. Meanwhile, Wars and conflicts have existed throughout history and remain ongoing like the current conflicts in the Middle East, Africa, and even Europe [2].

Every Year due to the effects of disasters, millions of people face the danger of death or physical injury, they may also lose their homes and properties and become homeless. Disasters may also cause economic and environmental issues and serious damage to structures and infrastructures [3].

The role of architecture in the humanitarian sector has been summarized as delivering quick shelter for the displaced population [4]. However, the challenge is that these shelter solutions do not consider the long-term needs for habitability and sustainability in terms of economic, socio-cultural, and environmental levels.

Sustainable shelter design must follow the three pillars: environmental, social, and economic. [5] Environmentally, shelters shall have low impacts through the use of sustainable materials and efficient construction methods that also offer the potential for reuse or recycling. In the social aspect, shelters should respect the cultural practices, the existence of places to communicate and worship, and the daily routines of the inhabitants. In terms of economics, shelters should be affordable in their construction, transportation, and their maintenance.

Most existing shelter solutions are unsuitable options in terms of cultural suitability cost efficiency, and environmental impact, mainly due to choosing construction materials and methods for their availability and ease of transport rather than their long-term suitability or environmental impact.

This research focuses on improving and developing a design framework for future sustainable shelter solutions that address sustainability in all aspects including socio-cultural aspects and environmental impact. The framework is then applied to propose a design aimed at enhancing the living conditions of the inhabitants of the Accumoli post-disaster settlement.

1.2 RESEARCH QUESTIONS

The main research question for this dissertation is: what architectural strategies can be applied in shelter designs to meet the environmental, social, and cultural needs of displaced populations in post-disaster and refugee scenarios?

To answer this question, the below sub-questions will also be addressed:

Phase 1: Study of current Shelter solutions

1. What are the advantages and disadvantages of current shelter options?
2. Which key elements improve the effectiveness of shelters in disasters or refugee cases?
3. Which type of shelter is better, prefab modular shelters or local traditional shelter types when it comes to building time, cost, and impact on the environment?

Phase 2: Social, Cultural Aspects, and User's satisfaction

1. How do socio-cultural factors affect the acceptability and functionality of shelter designs?
2. What is the level of satisfaction of inhabitants of existing shelter solutions? What affects it?
3. Which architectural strategies create a shelter that meets the inhabitant's needs and ensures their comfort?

Phase 3: Environmental Impact

1. What is the environmental impact of current shelter types?
2. What kinds of materials are used in buildings that ensure low-embodied energy?
3. How can both the materials used and construction methods ensure a low embodied energy in the shelters?
4. How does the shelter's lifespan affect its environmental impact?

1.3 RESEARCH AIM AND OBJECTIVES

This study aimed to assess the current shelter solutions to identify opportunities for improvements and set strategies for enhancing this type of housing by developing a comprehensive design framework for emergency shelters that addresses the sustainability aspects: economic, Environmental, social, and cultural adaptability, in addition to the real needs of displaced populations.

To achieve the main aim of the study, there was a need to meet the following objectives:

1. To understand the role of temporary houses in post-disaster and refugee scenarios explore the existing shelter solutions, and compare case studies to learn from past experiences.
2. To identify gaps and challenges in existing shelter designs, including issues related to sustainability, durability, assembly, and user satisfaction.
3. To determine the similarities and differences of existing solutions by Comparing prefab modular Global shelters with local traditional shelter types in terms of both quantitative and qualitative factors: Assembly time, capacity, cost, Area, lifespan, Ease of assembly, weather protection, Facilities, comfort, sustainability, cultural and social suitability.
4. To Assess the level of satisfaction among inhabitants living in existing shelter solutions and identify what affects their well-being and comfort.
5. To evaluate existing emergency shelter designs in terms of their ability to meet user needs, including cultural appropriateness, and privacy, in addition to the thermal and Acoustic comfort.
6. To Explore architectural strategies in shelters that ensure the socio-cultural needs and comfort of its inhabitants.
7. To Identify materials and construction methods used in shelters that ensure low environmental impact.
8. To Develop a sustainable shelter design framework that considers sustainability principles, including affordability, socio-cultural suitability, environmental impact as well as modularity, structural resilience, and user satisfaction.

9. To apply the design framework principles in Acuumoli by proposing a sustainable shelter design that ensures better living conditions.

1.4 SIGNIFICANCE OF THE STUDY

shelters are used for various purposes: in post-disasters, in Refugee or Homeless situations, in construction sites, in healthcare emergency response like reusable quarantine shelters during pandemics, and vacation sector ….

The most common use of these houses is in response to natural disasters and humanitarian crises, which according to scientists, are predicted to continue occurring.

Moreover, these types of houses are usually provided to survivors of disasters during very sensitive periods of their lives, when they have often lost not only their homes and properties but also their loved ones. These shelters, therefore, serve as more than just temporary structures, they become critical spaces for stability, security, and psychological recovery during emergencies.

The research explores the economic, social, cultural, and environmental dimensions of these shelters, by examining their ability to meet the various necessary needs of users, including comfort, privacy, sense of safety, and cultural appropriateness. At the same time taking into account their environmental impact.

The significance of this study is to determine the main gaps and issues in existing shelter designs, which often fail to fully consider user needs and satisfaction or long-term sustainability. The research goal is to develop a design framework that Integrates functionality, and environmental sustainability with socio-cultural considerations for improving future shelter designs to meet the long-term needs of their inhabitants, and at the same time not harm the environment.

1.4 AN OVERVIEW OF THE RESEARCH METHODOLOGY

This section presents a summary of the research methodology, Further details about the methodology are illustrated in Chapter 3.

The study combines both qualitative and quantitative methods for data collection and analysis to ensure a better understanding of the humanitarian best and shortcomings strategies alike in existing shelter solutions for the development of more future sustainable shelters.

The methodology is divided into six key phases:

A. **Literature Review**: A critical review of the collected data will be conducted on the existing shelter solutions in humanitarian contexts. The literature review will be based on three themes: shelter typologies, as well as their affordability, sustainability in shelter design, and sociocultural and environmental impacts of the current shelter solutions, in addition to their user satisfaction. This phase is intended to provide a strong theoretical basis, identify gaps in previous studies, and further simplify the following phases of this study.

B. **Comparative Analysis**: This is followed by the comparative analysis of various shelter types. The comparison includes: Global shelters used by UNHCR, prefab modular shelters, and local traditional shelter types that present both post-disasters and refugee shelters used in different regions and contexts. The comparison is made based on quantitative and qualitative criteria. During this phase, an understanding of the various strengths and weaknesses of different shelter solutions will be developed, in addition to determining the main similarities and differences in each type of shelter. This study also helps in identifying which types perform better under different contexts.

C. **An assessment of sociocultural aspects and user satisfaction**: The third phase consists of a socio-cultural and user satisfaction assessment done with a survey and interviews for data collection regarding the acceptability and satisfaction among the shelters' inhabitants. There will be questionnaires developed regarding how far the shelters fulfill the cultural and social requirements of their users, in addition to numerous factors that ensure user satisfaction like: the sense of safety, thermal and acoustic comfort, facilities quality, area adequacy, and satisfaction with the time provision of the shelter.

D. **Environmental Impact Assessment**: This phase presents the evaluation of the environmental impact of four existing shelter types using the LCA method, The considered factors include embodied energy and the global warming potential. The result of this phase will highlight the construction methods and materials that have a low environmental impact.

E. **Design Framework Development**: Based on the findings from previous phases, a framework design for future sustainable shelters is developed.

F. **Design Framework Application to Accumoli**: in this part, a proposed shelter design was suggested based on the design framework principles.

1.5 STRUCTURE OF THE THESIS

The research is structured to address the research aim and objectives of the study. It includes Six chapters outlined as follows:

Chapter 1: introduces the research by giving some context on the necessity of sustainable shelter solutions in humanitarian crises. It presents the research questions, Main Aim, and objectives. It also highlights the significance of the study and briefly discusses the methodology and the main structure of the thesis.

Chapter 2: the chapter presents general information about the topic and reviews the background and existing studies of the main topic, which can be classified into three core themes:

1. **Shelter Typologies**: Definitions, history, phases of disaster relief, and categories of shelters.
2. **Sustainability Challenges**: Issues related to economic, socio-cultural, and environmental aspects in shelter design.
3. **User Comfort and Satisfaction**: Cultural and functional considerations in shelters.

This chapter identifies gaps in existing research to build a strong foundation for the study.

Chapter 3: This chapter describes clearly the methodology of the research, which combines both qualitative and quantitative methods to assess the sustainability of emergency shelters. The methodology consists of five phases: The first phase presents an Evaluation of 14 global shelter prototypes in terms of quantitative and qualitative factors. This comparison allows for a better understanding of the strengths and weaknesses of different shelter types. The second phase focuses on the Economic Affordability of the 14 previously mentioned shelters, where the cost per square meter per lifespan metric is used for calculation that allows a fair comparison of different shelter solutions. The third phase involves a Socio-Cultural Analysis, conducted through surveys, to assess user satisfaction and the cultural appropriateness of existing shelters. This includes factors like privacy, comfort, and overall functionality. The fourth phase uses the Life Cycle Assessment (LCA) method to measure the Global Warming Potential (GWP) from cradle to site and Embodied Energy (EE) from cradle to gate of four shelters among the 14 previously evaluated. This assessment aims to assess the shelter's environmental impact to identify opportunities for reducing environmental impacts. The final phase consists of addressing the main results of previous phases to develop a design framework.

Chapter 4: This chapter presents the findings from the comparative analysis, economic assessment, socio-cultural survey, and environmental impact assessment.

Chapter 5: discusses the implications of previous findings to develop a design framework.

Chapter 6: The conclusion summarizes the key findings, discusses the study's contributions, and offers recommendations for improving future shelter design.

Chapter 2: Literature Review

This chapter presents general information about the topic based on A Literature Review of the main sub-theme that form this thesis: Humanitarian Emergencies, shelter typologies, sustainability considerations in shelter design, sociocultural adaptability, and environmental impact.

2.1 HUMANITARIAN EMERGENCIES

Humanitarian crises are events causing a threat to the lives and health, well-being of large populations. Mainly results from natural or human-made disasters. The terms: Hazard, disaster, and emergency are major terms used to explain the complex challenges faced during humanitarian crises. [6]

A hazard is an event that may cause dangerous effects, such as a cyclone or drought. It describes a potential source of danger that could turn into a disaster event. While the word disaster has a Latin origin: It is formed of two words: ‘dis’ which means ‘without’, and ‘Astrum’ which means ‘star’, and is usually used to describe sudden and tragic events resulting in loss, damage, and distress. [7]

While, UNHCR defines a humanitarian emergency as "any situation in which the life, rights, or well-being of refugees and other persons of concern to UNHCR will be unsafe unless immediate and appropriate action is taken." [8]

In summary, the main difference between hazard, disaster, and emergency could be concluded that while a hazard is the ‘potential source of danger’, the disaster is the ‘event’ that causes high impacts and losses and an emergency is the ‘situation’ in the aftermath of that event.

2.1.1 Natural Disasters and Displaced Population

Natural disasters usually cause human loss as well as economic and environmental impacts. They have been highly destructive and costlier over the years and are predicted to continue to increase due to climate change. Based on the World Bank, there were over 7,000 major natural disasters between 1990 and 2020, with over 1.2 million deaths and more than 4 billion people affected worldwide. [9]

Over time, Natural disasters are becoming more frequent. For example, in 2020, 389 natural disasters were reported, which affected 98.4 million people across the world. Their economic cost is also high, with the World Meteorological Organization estimating losses of 210 billion US$ in 2020. Poor countries, mostly in Asia and Africa, carry a heavier load of disaster because of their reduced capacity for preparedness and response to this kind of event. [10]

- ✓ **Types of Natural Disasters and Their Consequences:**

Earthquakes: are one of the most dangerous natural disasters. For example, the 2010 Haiti earthquake caused more than 200,000 deaths and displaced about 1.5 million people. It also caused serious damage to infrastructure and structures, including homes, schools, and hospitals, which highlights the need and importance of providing shelter immediately after the event. **[11]**

Floods: are the most common type of natural disaster globally, with more people affected every year than by any other type. The 2017 South Asian floods affected more than 45 million people across Bangladesh, India, and Nepal, considered the widest-scale displacement and destruction of homes, according to the International Federation of Red Cross and Red Crescent Societies in 2020 [12]. Floods often lead to long-term displacement due to the difficulty in rehabilitating basic services, infrastructure, and safe shelter in these conditions.

Hurricanes: are strong storms that can result in massive destruction on the Seaside. For example, Hurricane Katrina in 2005 resulted in more than 1,800 deaths and over 650,000 displacements in the United States [13]. This type of event highlights the importance of disaster preparedness and response strategies, especially in Seaside areas.

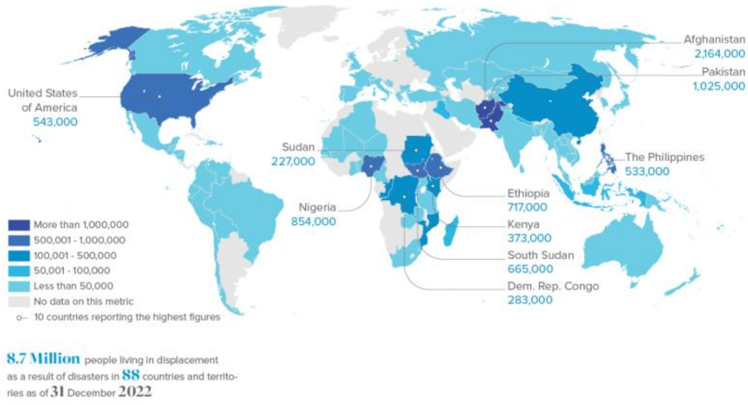


Figure 1: Total number of IDPs by Disasters in 2022. Source: [14]

2.1.2 Man-made Disasters and Displaced Population

Man-made disasters, or human-related disasters, result from human activities that are either planned or unplanned. They may include war, industrial accidents, and even terrorist attacks, which could cause damage to people, property, and the environment. [15]. According to the IOM 2021 report [16] , 82.4 million people were forcibly displaced worldwide because of conflicts and violence.

✓ **Types of Man-made Disasters and Their Consequences:**

Wars and Armed Conflicts: are the main cause of life loss and displacement over decades. For example, the Syrian Civil War began in 2011 and has killed over 350,000 lives and displaced more than 10 million people, causing one of the largest refugee crises in the last decades [17].

Industrial accidents are the reason behind damages that the environment never experienced before and compromise human health. For example, the 1986 nuclear disaster in Chernobyl forced the evacuation of over 100,000 people and resulted in numerous lands becoming uninhabitable, according to [18]. Such accidents direct toward the need for strict safety measures and preparedness during industrial emergencies.

Terrorism: Terrorist and violent activities, may cause death and building damage in addition to some psychological and social consequences. For example, nearly 3,000 people were killed in a chain of attacks in the United States on September 11, 2001, which forced a rethinking of security strategies across the world. Terrorism also causes severe long-term economic and social disruption, for which full recovery is difficult. [19]

2.1.3 Refugees' crises

The refugee crisis has been considered among the serious challenges during the past decades. Where Conflicts and wars have caused the forced displacement of millions of persons. According to UNHCR's 2023 report, more than 27 million displaced refugees came from Afghanistan, the Syrian Arab Republic, Venezuela, Ukraine, and South Sudan [20] become refugees in other countries. Based on the report five countries form about 40 percent of hosting refugees, often, these are the neighbours' countries of the countries of origin which are the Islamic Republic of Iran, followed by Pakistan, the United Republic of Tanzania, Germany, and Türkiye.

Shelter and camp conditions in these host countries vary significantly, often depending on the economic capacities and resources available. In low and middle-income countries hosting 75% of the world's refugees, shelter with basic services remains inadequate. While in developed countries that host about 21% of all refugees, the situation could be more horrible, since they have access to less than 5% of the resources globally allocated to support refugees that might face further challenges in these countries, given the fact that the hosted camps are overcrowding, have inadequate health facilities, and poor infrastructures [20] . See Table 1 below.

CATEGORY	DATA
Countries of Origin (73% of All Refugees)	Afghanistan (6.4 million), Syrian Arab Republic (6.4 million), Venezuela (6.1 million), Ukraine (6.0 million), South Sudan (2.3 million)
Top Host Countries (39% of All Refugees)	Islamic Republic of Iran (3.8 million), Türkiye (3.3 million), Colombia (2.9 million), Germany (2.6 million), Pakistan (2.0 million)
Children Below 18 Years of Age	47 million (40% of 117.3 million forcibly displaced people at the end of 2023)
Children Born as Refugees (2018-2023)	2 million (An average of 339,000 children born as refugees per year)
Refugees Returned or Resettled in 2023	1.2 million (1.1 million returned, 158,700 resettled)
Hosted in Low- and Middle-Income Countries	75% of refugees
Hosted in Neighbouring Countries	69% of refugees
Stateless People Reported (End-2023)	4.4 million (in 95 countries)
Asylum in Least Developed Countries	21% of the global total

Table 1: Key Statistics on Global Refugees, Host Countries, and Displacement Population (2023)

2.2 SHELTER AND TEMPORARY HOUSES

2.2.1 Definition and History

A temporary house is a shelter that is not permanently affixed. It is commonly used by people as a place to temporarily protect them from weather conditions or danger, and it can be removed when no longer needed.

The term Shelter has its origin in prehistory, dating back to the earliest human primitive times [21]. Human shelter has always meant protection from weather elements, and other dangers like wild animals. However, nowadays this term is often used to describe the houses provided after a disaster or homelessness cases.

2.2.2 Shelter categories and terminology

The words "emergency shelter," "temporary shelter," "transitional shelter," "progressive shelter," and "core shelters" are used by the International Federation of Red Cross and Red Crescent (IFRC) to describe different shelter categories [22]. The difference between them is based on different aspects which are: the duration of stay, the durability, permanence of the location, and its expected life span.

Emergency shelters are typically provided right after a disaster. While progressive shelters and core shelters are constructed to become a part of long-term solutions. However, temporary shelters, also known as transitional shelters or "T-shelters," are typically made to be moved and reused.

The stages of post-disaster response, emergency shelter, temporary shelter, and permanent housing are the basis for differentiation according to Felix et al. [23] who compared shelter terminologies and categories in different existing studies and based on that classified them. According to Johnson [24]"Temporary housing" is a unit that allows the resume of regular activities rather than just "sheltering" and serves as the foundation for the variation made between shelter and dwelling.

On the other hand, Refugee shelter designs are divided into four categories according to the UNHCR 2016 report [25]: global, emergency, transitional, and durable. For example, The UNHCR family tent and "Ikea Better Shelter's" flat-packed refugee accommodation are examples of global shelters. Emergency shelters include the ones that are made on-site using locally accessible materials and are usually composed of wood. Meanwhile, shelters constructed on-site but more durable are called transitional shelters, two examples of these types of shelters are the tiny bamboo shelters in Ethiopia and the Azraq camp shelters in Jordan. Sturdy shelters like the L-shaped shelter in Iraq and the one-room shelters in Pakistan were constructed using bricks and concrete blocks on concrete foundations [25].

According to D. Felix in his state of art paper [26], The difference between what is a 'temporary' and a 'permanent' shelter is rather complex. Usually, the structure of temporary shelters is lightweight, While, the infrastructure that is developed to carry out some of the basic daily activities-like cooking and bathing-tends to become permanent. Besides, some materials considered permanent in one area might be treated as temporary in other areas, depending on the regulations and laws of the region. For instance, materials such as mud or earth would fall into different categories in different contexts. This means that the categorization of what may be considered permanent or temporary cannot be universally defined but rather socially. The section that follows highlights some of the standard materials used in temporary shelters.

2.2.3 Shelter Typologies and Options

Sheltering solutions in post-disaster scenarios would vary depending on the population in the affected communities, as they involve both displaced and non-displaced individuals.

According to Shelter Center and IOM (2012), the non-displaced population has six possibilities for reconstruction: home tenant, apartment tenant, land renter, apartment owner-occupier, and tenancy with no legal status. However, there are different settlement options for displaced people which are: self-settled camps, planned camps, collective Centers settlements that use large existing buildings, informal urban self-settlement, rural self-settlement where they create a settlement on collectively owned rural land, and living with a host family [27]

Based on UNHCR [28], the most common types of shelter solutions are: Tents, plastic sheeting, shelter kits, prefabricated shelters, and rental subsidies.

Tents and plastic sheeting: are the most common form of temporary houses used in emergency relief, they are good for a rapid response due to their stockpiling, lightweight nature, and familiarity.

But tents are not appropriate for long-term residence because they provide a poor quality of life and less likelihood of basic facilities. Also, the people in tents are deprived of all privacy and constantly exposed to the weather elements (rain, cold, wind). [24]

The shelter kits usually are known for the use of local materials which offer social and cultural appropriateness but at the same time require time and training.

Another common form of temporary houses is the Prefabricated shelter and containers. They are used as permanent and semi-permanent houses that can last for a long time with easy maintenance but unfortunately, they are expensive in terms of production and shipping, provide inflexibility, and cultural unsuitability, and need more time to be delivered to the affected communities compared to the tents and plastic sheeting [29]

Rental subsidies: provide a sense of independence and encourage integration in a community while at the same time leading to an increase in prices and inflation.

2.2.4 Classification of Shelter Types in post disasters and Refugee Scenarios

Shelters in post-disaster scenarios can be classified based on various criteria, including construction methods, the type of disaster, and their phase of usage after a disaster.

There are two main types of temporary houses depending on their construction approach: the first type is the ready-made houses which are housing solutions constructed in a factory that just need to be transported to the site where they will be placed. See Figure 3(A, B), while the second type is houses constructed in place. See Figures 2 and 3 below. [30].

A B

Figure 2: Ready-made units: (a) temporary housing units ready to be transported (source: www.katrinadestruction.com), and (b) local assembly of units (source: http://exc.ysmr.com).

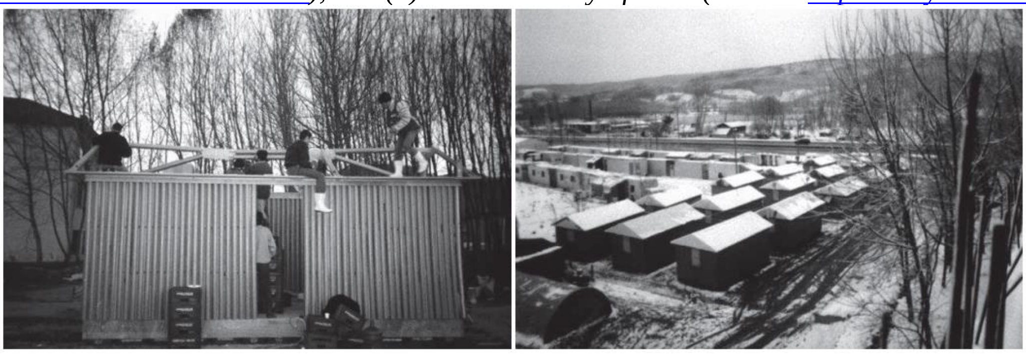


Figure 3: Kit solutions: assembly process by the local community and the cluster of the Paper Log Houses designed by Shigeru Ban source: https://archnet.org

2.2.5 Phases of Disaster Relief in Case of Natural Disasters

Temporary housing is extremely important to recover after disasters, allowing people to return to their normal activities such as work, cooking, housekeeping, school, socializing, etc. [29]

according to [31], in theory, After the disaster people should move from one shelter to another which varies according to the time response after the disaster, and before they get a permanent one since reconstruction phases take years.

In the emergency relief phase, the shelter provided is called emergency shelter which is the basic shelter kind used for short periods, usually provided a day or a few days after the disaster, and can last a maximum of 6 months like tents.

The next phase is called early recovery relief. The shelter provided is a Transitional Shelter, which is designed for intermediate-term periods such as six months to three years. It allows the affected population by a disaster to return to their normal daily activities. This form of shelter is typically built by the displaced people themselves like the paper log shelter by the Japanese architect Shigeru Ban and the sandbag shelter by Iranian architect Nader Khalili. Transitional shelters could be turned from temporary sites to permanent ones.

In the last phase called long-term recovery, people were provided with permanent housing [32]. See the figure below.

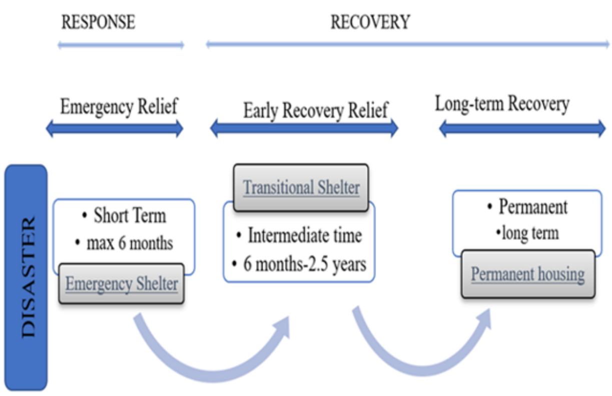


Figure 4: The Phases of disaster relief in theory.
Source: created by Author, published in [33]

But the reality is contrary to the theory, in most cases, these emergency houses turned into long-term like in the Haiti Earthquake in 2010, where people lived in an emergency shelter designed for a maximum of 6 months for more than 7 years [34].

In the case of the East Azerbaijan Earthquake in 2012, in Iran, where people lived in an emergency shelter for more than 4 years then they were provided with transitional shelter and they still live there now [35].

As well as the case of Accumoli after the 2016 earthquake, where the Italian government immediately provided emergency tent relief for those who had lost their homes which was not suitable especially since the town is located in a mountainous area and people had been exposed to the elements. Many chose to sleep in their cars due to the cold, while others preferred to book rooms in surrounding villages' hotels or apartments. Nowadays, only a few container homes are offered, even after years. [36]. See Figure 5 below

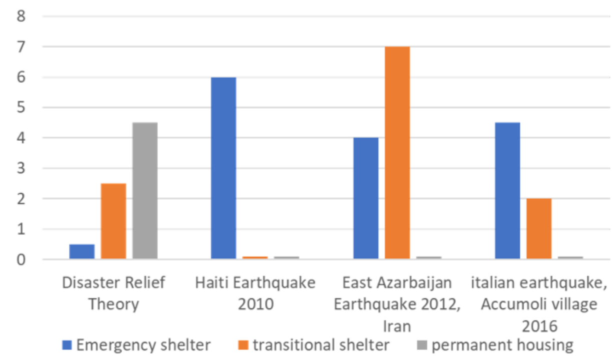


Figure 5: Theory vs Reality in disaster relief (3 case studies).
Source: created by Author, published in [33]

One of the most critical issues in housing families is the long process of achieving permanent accommodation which takes years for various reasons, including removing debris and finding available land.

2.3 SUSTAINABILITY IN SHELTER

Temporary housing units which are provided after disasters, are crucial in terms of sustainability pillars (economic, social, and environmental). [37]

In general, THUs, which are regular houses with minimum space and facilities, usually provided in a short time and under emergencies contain some negative aspects of the building industry [38].

Most of the provided units of shelters are unsustainable solutions in terms of costs and environmental impact. Usually, the units are universal prototypes constructed in a region and need to be transported to the affected area which makes them expensive and may cost more than a permanent house compared to their short life [39]. Frequently, after the end of the event, a polluted site is available in addition to a huge number of units that are still in good condition but without a plan to reuse them which could cause huge resource losses [40].

The main objectives of humanitarian action are to save lives, maintain human dignity by sheltering the displaced people, and provide food and necessities during and in the aftermath of man-made crises and natural disasters. However, there are many examples of humanitarian shelter solutions failing to consider the cultural and environmental issues as a result of unsuccessful strategies, misunderstandings about users' real needs and errors making when dealing with local conditions and resources [41].

According to Scanlon, J [42], reviewed the U.S. disaster sheltering and housing patterns, highlighting the transition from emergency shelters to permanent housing and the associated challenges. The study revealed that materials commonly used in temporary shelters tend to have high embodied carbon or problematic end-of-life strategies incompatible with sustainable development. To deal with that, this research underscores the importance of designing shelters that are not only rapid and resource-efficient but also socially and culturally appropriate. These considerations align with sustainability principles, emphasizing the need for low-impact materials, adaptability to local contexts, and reduced environmental footprints in post-disaster recovery efforts.

However, many existing shelter solutions are culturally isolated, environmentally harmful, and economically inefficient. They fail to meet the sustainability goals and user satisfaction due to the choice of construction materials and methods for their availability and ease of transport rather than their long-term suitability or environmental impact, in addition to the prolonged use. According to Pomponi. F [43], considering the sustainability of post-disaster shelters in Africa has become essential due to extended uses of temporary solutions beyond their lifespan for longer periods. The research highlights the need to address all the sustainability aspects, including environmental, economic, and social factors in the shelter design. It also underlines that natural material and locally based solution methods perform much better in the shelter's environmental, economic, and social dimensions of sustainability. This also aligns with the large need to consider sustainability as early as possible within the disaster response phase, since neglecting such considerations can enhance the impacts of the disaster and make long-term recovery more difficult to achieve, as noted by Yi & Yang [44] and Abrahams [45].

2.3.1 Socio-cultural issues in shelter solutions

Most existing shelter solutions focus on the technical aspects of the units rather than on the people who will occupy them, providing designs that are inappropriate for the local environment and culture that often result in unsatisfactory and poor outcomes. [46].

Souheil El-Masri [47] indicated that the use of universal prototypes constructed in another region by experts who are not familiar with the contexts where disasters occur is the main reason for users' unacceptance because of their cultural unsuitability. This leads in some cases the abundance or modification of the shelter by inhabitants of people which can compromise the safety of the building.

According to the Sphere Project, the participation of affected communities in design and construction is an important approach for ensuring cultural suitability. This could result in shelters that are not only more acceptable to the population but also more maintainable and adaptable over time [48].

Safety and security are also considered important elements of social sustainability, especially in post-disaster cases where the risks of dangers are high like aftershocks, flooding, or even violence.

Another important element of social sustainability is privacy, which is eliminated in most temporary shelters, especially tents and those with overcrowded camp populations causing problems like violence, tension, and stress. This is perhaps one of many factors undermining the overall resilience of any community [49]

According to the findings of Patricia Aelbrecht [50], the spatial organization of shelters within a settlement is the main factor in determining whether the social interactions among residents are upgraded or not. The research international comparative work underlines how spatial layout, access, and multifunctional designs have a direct impact on social dynamics and, correspondingly, the importance of intentional spatial planning for community resilience and integration.

The importance of designing social spaces that allow the inhabitants to be integrated into society and not feel isolated is also highlighted in the research of Paola Ardizzola [51] who sees that ensuring the dignity of refugees by considering their cultural traditions, religions, and social needs as well as their integration into the hosted community is essential for their well-being.

The survey findings of İsmail and Ciravoğlu [52], who conducted a questionnaire survey of Palestinians living in Jordan and Lebanon camps, reveal the need for social life in the camp environment concerning refugees' origins, as well as the importance of refugees' involvement in the decision-making processes. The study also underlines the need for addressing sustainability in camp planning from the early stages.

2.3.2 Environmental impact

Environmental sustainability in shelter solutions means a solution that has a minimal ecological footprint and does not harm the environment. Various literature identifies different environmental challenges in shelter solutions, mainly due to the use of unsustainable materials and construction techniques, and their short lifespan.

- ✓ **Use of Unsustainable Materials**

According to Matti's 2017 findings [53], Material selection for temporary shelters is the major contributor to the environmental impact of temporary shelters. His research about temporary homes in Japan after the 2011 Great Eastern Tohoku Earthquake showed that shelter materials greatly add to life cycle emissions due to their short period of use. Among the shelter types studied using the LCA method, including prefabricated, wooden logs, and sea container shelters, the use of wood material showed the best environmental performance.

One of the major challenges of shelter solutions is the use of unsustainable materials. Most existing shelters and tents are also made out of artificial material, such as polyester or PVC that do not easily break down, therefore posing a threat to the environment where they have been in use and thrown away. Based on Ungureanu-Comanita's study [54], which assessed the environmental impacts associated with the production of polyvinyl chloride (PVC), a commonly used plastic in manufacturing using the Life Cycle Assessment method, the use of recyclable materials, such as organic biodegradable waste as raw materials instead of crude oil can lead to significant reduction of environmental impacts.

On the other hand, earth, bamboo, and timber have very low embodied carbon emissions due to their simple processing and local availability. They also act as carbon stores due to their absorption of carbon dioxide during the growth phase, particularly in the case of Bamboo and Timber. [55]. Indeed, earth-based materials such as rammed earth and Compressed Earth Blocks (CEBs) involve very limited energy in making processes. These materials are often locally sourced, which significantly reduces their carbon footprint related to transportation [56]. As a summary, It is recommended to use local, renewable materials in the construction of the shelters.

2.3.3 Lessons from Case Studies in Emergency Shelter Implementation (Published papers)

- ✓ **Research Case study Accumoli (post-disaster settlement)**

Gueroui (2021) [57] presents some design scenarios to solve the homelessness problem in Accumoli after the 2016 earthquake in Central Italy. The study proposed innovative lightweight shelters using wood and membrane materials, highlighting sustainability, ease of assembly, and adaptability to local conditions. The research underlines the benefits of using locally sourced materials for reducing both costs and environmental impacts, while at the same time ensuring cultural and climatic needs. The proposed designs could be implemented quickly and dismantled efficiently, which makes them suitable for both short-term emergencies and possible long-term housing solutions. The suggested projects are presented in the figure below.

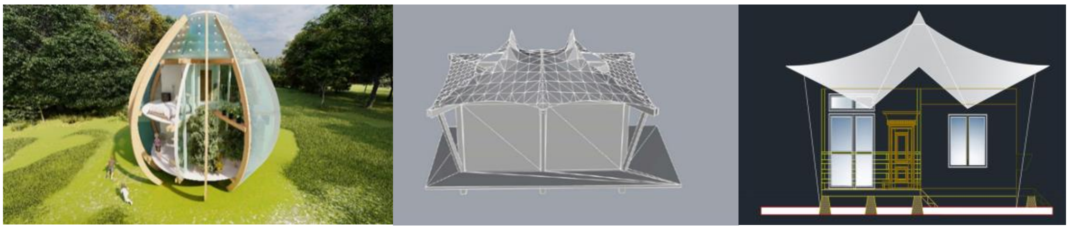


Figure 6: The proposed shelter projects for Accumoli.
Source: [57]

This paper provides critical insights for integrating sustainability principles in emergency housing design. It demonstrates the feasibility of lightweight, eco-friendly materials to balance rapid deployment and durability while considering the socio-cultural factors of displaced populations, the necessity of utilizing locally available resources, and involving affected communities in the design process for relevance and acceptance. The proposed designs are just basic Ideas, further improvements are suggested based on the dissertation's main findings in Chapter 5.

Another research paper written by A. Gueroui [58] conducted a survey and a comparative analysis of three shelter types, IKEA Better Shelter in Jordan, Mud-Brick shelters in Rwanda, and temporary housing units in Nepal. This research underlines the critical interplay between cultural appropriateness, environmental sustainability, and user satisfaction in the context of emergency housing. The study showed that shelters made of local materials, like Mud-Brick in Rwanda, achieved superior thermal performance, cultural integration, and social suitability compared to prefabricated units like the IKEA Better Shelter. These findings underscore the importance of integrating traditional building methods and the use of locally sourced materials to enhance shelter sustainability and user comfort. See Tables 2 and 3 below.

Case study /Sustainable strategies	The Azraq Refugee Camp in Jordan	The Muungano settlement in Rwanda	The Temporary Housing Units and Settlements in Nepal
Type of shelter used	IKEA Better Shelter (Modular Prefabricated Shelter)	Traditional Mud Brick Shelter (Community-Built Semi-Permanent Shelter)	Temporary Transitional Shelter (Locally Constructed Transitional Shelter)
Cultural Integration and Social Spaces Existence (settlement)	-Limited cultural elements and materials. -Organized but initially isolated.	- Uses traditional Rwandan architectural elements and local environmentally friendly materials (mud bricks, thatch). -Community-centric, resident participation.	- Incorporates traditional Nepali designs and locally sourced materials like bamboo, and timber … -Community-driven, resident involvement.
Natural ventilation and lighting	Basic +	++++++	++++++
Water management	Limited, Advanced systems but reliant on external supply	Basic system	Basic systems, some greywater reuse
Adaptability	Modular, easy to assemble	Customizable, community-driven construction	Adaptable, community-involved construction

Table 2. A comparative study between three different case studies according to different factors: Type of shelter used, Social and cultural integration, Natural Ventilation and lighting, Water management, and Adaptability.

Source: *[58]*

Aspect/ Case study	Azraq Refugee Camp (Jordan)	Muungano Refugee Settlement (Rwanda)	Nepal Temporary Settlements
Material Usage	Prefabricated, high embodied energy	Local materials, very low embodied energy	Local materials, low embodied energy
Energy Consumption (Construction)	Moderate due to modular design	Very low due to traditional methods	Low due to simple design
Energy Consumption (Operational)	Solar panels for lighting	Very low, natural ventilation and lighting	Low, natural ventilation and lighting
Water Usage and Management	Basic systems, reliance on external	Basic systems, potential for rainwater harvesting	Basic systems, some greywater reuse
Waste Generation	Minimal during construction	Minimal, high recyclability	Low, high recyclability

Table 3: A Summary of the comparative study of the environmental impact of the three case studies according to material Usage, Energy consumption, water usage, and management and waste generation.

Source: *[58]*

This study provides key lessons on how culturally and environmentally responsive design can lead to more sustainable and user-centered emergency shelters. By comparing diverse case studies, the research illustrates the shortcomings of universal shelter prototypes while advancing context-specific solutions. These insights are crucial for solving the long-term needs of displaced populations while minimizing environmental impacts and fostering a sense of community and cultural identity.

✓ **Based on the settlement scale**

A.Gueroui, Lujain ben khadra. (2024) [59] conducted a detailed analysis of the Sahrawi refugee camps in Tindouf, Algeria, focusing on their challenges with floods and infrastructures. The study suggested several sustainable and cost-efficient solutions to improve flood resilience and living conditions in the camps. Key recommendations included upgrading shelter materials, incorporating green infrastructure elements like rain gardens, and implementing flood mitigation strategies like swales and filter drains. These measures aimed to enhance the camps' resilience to environmental hazards while ensuring rapid implementation and resource-efficient ways.

This research provides critical insights into the intersection of environmental sustainability and urban planning in refugee settings. The proposed solutions emphasize the importance of integrating flood mitigation measures with sustainable shelter improvements. Therefore, the findings are especially relevant for addressing infrastructure vulnerabilities in protracted displacement situations. By combining local materials, community participation, and green infrastructure, the study has provided a valuable framework for creating more resilient and dignified living environments for displaced populations.

Chapter 3: Research Methodology

This research presents a holistic approach that assesses existing shelter solutions, combining qualitative and quantitative methods to address sustainability aspects in the shelter design: economic, socio-cultural, and environmental. While ensuring user satisfaction and comfort. The study integrates multiple methods to evaluate shelters as individual units and within settlement contexts. Each phase addresses specific research objectives, including comparative studies, economic assessments, socio-cultural evaluations, and environmental impact assessments. See the figure below.

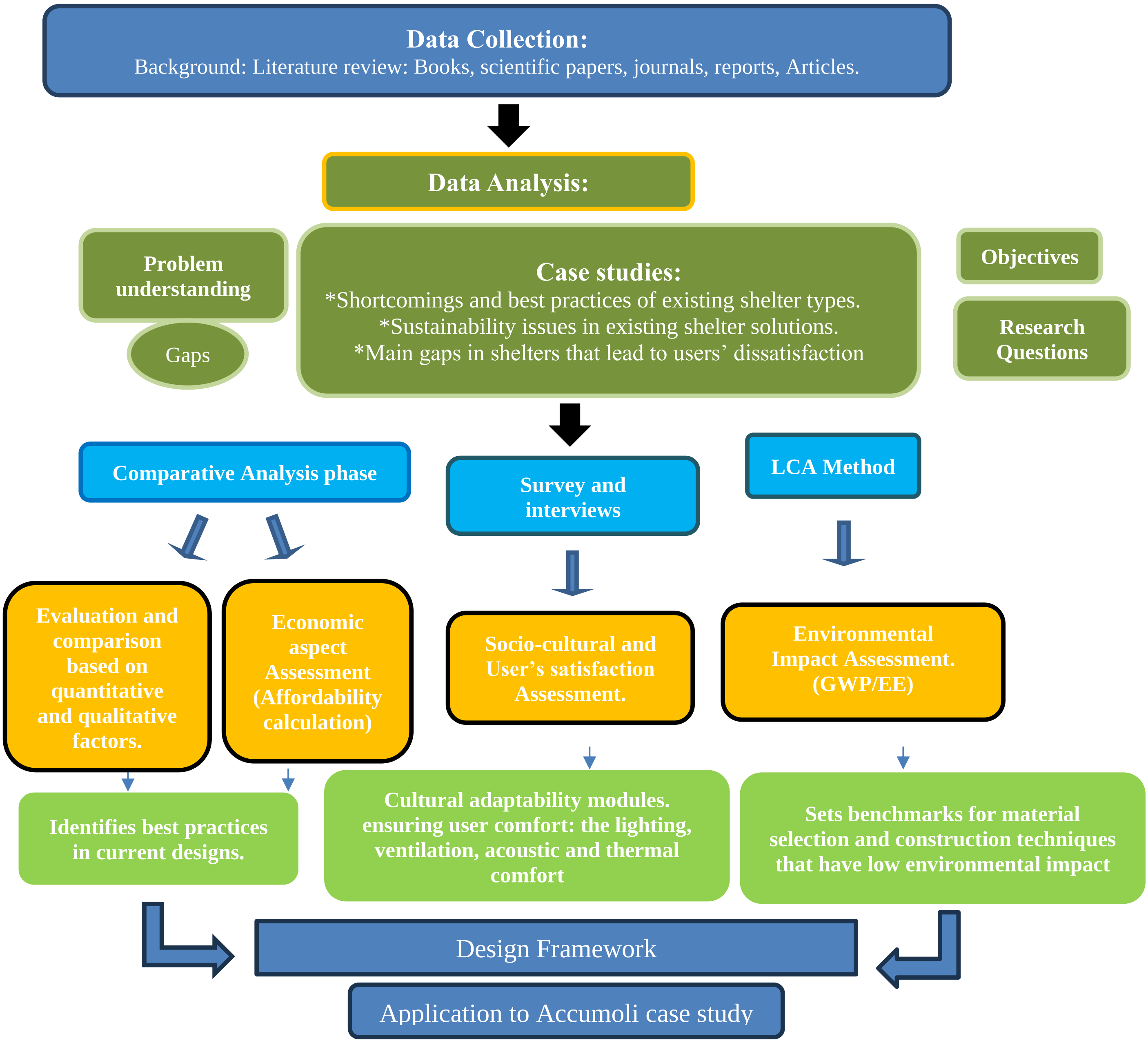


Figure 7: A conceptual framework of the research methodology.

3.1 GLOBAL PERFORMANCE EVALUATION OF 14 EMERGENCY SHELTER PROTOTYPES FOR POST-DISASTER HOUSING

3.1.1 Methodology

This research aims to assess and evaluate various designs of shelters based on key factors, The shelters involved in this study include tents, the Exo shelter, the Better Shelter by IKEA, the FEMA trailer, the sandbag shelter by Nader Khalili, and the paper log shelter by Shigeru Ban, in addition to the Tuareg tent, Azraq T shelter, one-room shelter, Mahama settlements durable shelter, compact bamboo shelter, Ituri settlements shelter, Tuareg shelter, wooden gable frame shelter. The goal of this study is to evaluate the appropriateness of such sheltering options in post-disaster situations and refugee settings.

As a First step, a classification of the evaluated shelters was made to determine the similarities and differences of these shelters.

The comparison is divided into two sections. First, a comparison is done concerning objective variables such as cost, area, Capacity (number of occupants), time of assembly, and lifecycle. Data is gathered from literature, case studies, and manufacturers' specifications, in addition to the UNHCR 2016 Catalog and UNHCR Shelter Sustainability Overview Report.

The second comparison section involved qualitative criteria like Ease of Construction, weather protection, sustainability, cultural and social suitability, facilities, comfort, facilities, and durability. The data is gained from peer-reviewed articles, field reports, case studies, and technical evaluations concerning various types of shelters.

3.1.2 Criteria of comparison

This section outlines the key factors used in evaluating those 14 emergency shelter types which are: cost, area, capacity, lifespan, time of assembly, ease of assembly, durability, sustainability, cultural and social suitability, weather protection, facilities, comfort, and sustainability.

***Cost**: Both construction cost and transportation cost are considered.

***Area/Capacity (number of occupants)**: The space provided and the number of people the shelter can accommodate is important to ensure the user's comfort, social inclusiveness, and health considerations in long-term situations.

***Assembly Time:** This suggests the time required for assembly or deployment of the shelter, it is an important criterion in disaster responses.

***Lifespan**: This varies from simple emergency solutions to long-term housing.

***Construction Materials**: Material selection is compared according to their availability, ease of construction, durability, and environmental impact.

***Transportation and Infrastructure**: This refers to the ease of transportation of the shelter and how the shelters have to rely on existing infrastructure in remote areas.

***The mobility of the shelter**: also considers those situations where the residents might have to shift frequently to different locations.

***Weather Protection**: The shelters are assessed based on how capable they are of protecting their inhabitants from harsh climatic conditions including extreme temperatures, rain, wind, or snow.

***Sustainability**: It checks their sustainability in terms of cost and terms of their environmental consequences.

***Cultural and Social suitability**: The shelter should be designed to conform to the culture or social convention of the population to fit into the culture of the community for social inclusion and psychological well-being.

***Facilities**: This relies on the availability of the necessary facilities required for living, such as sanitary facilities, electricity, and cooking facilities.

***Flexibility**: the ability of Modification or expansion of the shelter by occupants to meet their needs over time.

***Comfort**: A comparison depending on factors like ventilation, thermal comfort, privacy, and noise insulation.

***Durability and Strength**: shelters are assessed based on their resistance against disasters.

3.2 ECONOMIC ASPECTS ASSESSMENT (AFFORDABILITY CALCULATION)

The affordability of shelters is assessed by calculating the total cost of each type of shelter unit of the 14 shelter prototypes (mentioned in the previous section), considering all associated costs, including production, supply, transportation, and setup, along with the shelter's lifespan and covered living area. The data are gathered from the UNHCR catalog 2016 and the UNHCR sustainability overview report [60], the used metric ensures a comparable fair unit cost across different shelter types:

$$\text{Affordability} = \frac{\text{Total Cost}}{\text{Lifespan} * \text{Covered Living Area}}$$

The results of the Affordability calculation of shelters are then compared and analyzed.

3.3 SOCIO-CULTURAL ASPECTS AND USER SATISFACTION ASSESSMENT (SURVEY)

3.3.1 Methodology

This study uses a mixed-methods approach, utilizing a structured questionnaire in three different languages (Arabic, Turkish, and English) to collect both quantitative and qualitative data on inhabitant satisfaction and overall comfort in shelters and refugee camps. The survey concentrates on social and cultural issues of shelters provided in refugee scenarios by assessing the existence of spaces that allow for social connection and integration in the community, or cultural practices like spaces for religions and traditions practices, in addition to the essential aspects for comfort including safety, the availability of necessities (kitchen and sanitation facilities), the quality of shelters (space, privacy, acoustic and thermal comfort) and satisfaction with the shelter timing provision, aiming to assess the overall wellbeing within the shelter environment.

3.3.2 Aim and Objectives of the Survey

The main aim of this survey is to assess the comfort levels of refugees living in different shelters and camps worldwide, with an emphasis on identifying the key factors affecting their quality of life.

Objectives:

- To assess their sense of safety in the camp and within a shelter.

- To Evaluate the quality and availability of basic resources in the temporary shelters like kitchen and sanitary facilities.
- To examine the quality of shelters in terms of space, privacy, thermal and acoustics comfort, and how these factors impact refugees' overall satisfaction and well-being.
- To explore the opportunities and facilities available for socializing and cultural practices within the shelter environment.
- To assess the user satisfaction with the shelter time provision.

The survey results will allow us to better understand the refugees' personal experiences, needs, and suggestions.

- The Survey Content

The questionnaire was developed and administrated using Google Forms to include both closed-ended and open-ended questions, some important themes were:

- **Demographic Information**: Age, Gender, Nationality, Duration of stay in shelter, family size.
- **Social Issues**: Privacy, Common Areas Availability, and Relations between Inhabitants.
- **Cultural Aspects**: Area of cultural practices, availability of services suitable to refugee culture.
- **Overall Satisfaction**: Overall satisfaction with shelter facilities, time of provision, Area, thermal and acoustic comfort.

3.3.3 The Survey Distribution

The survey was distributed to refugees using social media tools and a field visit to a refugee camp in Darmstadt/ Germany.

- **Social media**: The survey was distributed through various social media platforms, including Facebook and WhatsApp, which are commonly used by refugees. A digital flyer was created to direct participants to the online survey form and then posted in refugee groups worldwide. See Appendices B
- **Field Visits**: In addition to online distribution, the survey was administered in person during field visits to refugee camps in Darmstadt/Germany. Printed

copies of the survey were distributed, and assistance was provided to complete the survey for those who required it.

- **Collaborating Organizations**: The distribution process was supported by the Red Cross and Social Services Office in Darmstadt/ Germany. These organizations played a crucial role in reaching out to refugees and getting permission for field visits which facilitated the survey process.

- **Data Analysis**

The Quantitative data from the closed-ended questions were automatically gathered and analyzed by Google Forms while the Qualitative data from the open-ended questions were carefully reviewed and analyzed to find common themes and vision. This helped us understand refugees' personal experiences and suggestions more deeply.

Technical terms

- *Thermal comfort in shelter*: is the state where occupants experience neither excessive heat nor cold, which plays an important role in occupant's well-being and health. [61]
- *Acoustics Comfort*: this presents another factor that plays a crucial role in occupants' well-being and health, especially in overcrowded shelters. It refers to reducing or minimizing noise to ensure a comfortable environment. [62]
- *Socio-Cultural integration*: in shelter design means the creation of a shelter that respects the occupants' traditions, customs, and social lifestyle, in adi` therefore, promoting dignity, and wellbeing. [63]

3.4 ENVIRONMENTAL IMPACT ASSESSMENT

3.4.1 Methodology

This study uses the Life Cycle assessment method to assess the environmental impact of four different types of emergency shelters (previously mentioned in the Global performance evaluation section): IKEA Better Shelter, Tuareg Tent, Super Adobe Eco-Dome, and Mahama Settlement Durable Shelter (Variation A). These designs represent a wide range of construction methods and materials in both post-disaster and refugee settlement situations, in addition to different geographical locations like Jordan, Iran, Algeria, and Rwanda….

The data on materials quantities about the IKEA Better Shelter and Tuareg Tent shelter designs are collected from the UNHCR 2016 Report [60], while the data about the Super Adobe "Eco-Dome" are collected from different sources like:

- Research papers: [64], [65], [66], [67], [68], [69], [70].
- Cal Earth's official website of the designer Nadir Khalili (the California Institute of Earth Art and Architecture): [71]
- Books written by the designer itself: [72], [73].

at the same time, the data on materials quantities of Mahama Settlement's durable Shelter (Variation A) are collected from the report [74]

The LCA methodology follows a set of steps in determining the environmental impacts of each shelter GWP (from cradle to site) and EE (from cradle to gate), considering the first two stages within the LCA: material extraction, and transportation.

Figure 8: LCA assessment stages. Source:https://degenkolb.com/se2050/what-you-should-know-about-life-cycle-assessments.

- **Goal and Scope Definition**

The LCA will quantify the GWP in kg CO_2 emissions of four shelter designs, from the 14 previously mentioned. It aims to assess their sustainability, considering the cradle-to-gate phase, and their transportation to the employment site. Moreover, the embodied energy in MJ/K of materials is calculated from cradle to gate.

Functional Unit: The functional unit of the GWP and Embodied Energy calculation is one unit of each shelter design as described in the UNHCR Shelter Design Catalogue. Each shelter has its set of characteristics: material composition, construction technique, and expected life span. In humanitarian contexts, the expected life span of shelters ranges from 6 months to 10 years. In this case: IKEA Better Shelter: has 1.5 years without maintenance and 3 years with maintenance, Tuareg Tent: has 2 years, Eco-Dome has an estimated long-term lifespan, and Mahama Shelter is estimated for extended temporary use.

The functional unit of comparison is Functional units are m2 of living area and estimated service life which facilitates the comparison of different types of shelters.

System Boundaries: According to EN 15978 the system boundaries can be classified as product stage (A1-A3), construction stage (A4-A5), use stage (B1-B7), and end-of-life stage (C1-C4) see the figure below.

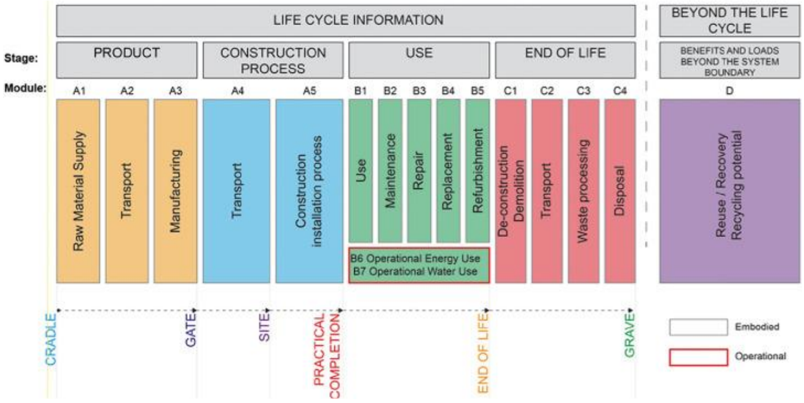


Figure 9: Stages of Life-Cycle Assessment (LCA). Source: [75]

In this study:

* A1-A3 the cradle-to-gate phase is included while the Material emissions and embodied energy Factors are collected from Ecoinvent and the ICE Database.

* A4 Transport to site phase is assumed based on the location of the site of deployment and its country of production, Emissions are calculated using standard emission factors for road and sea transport gathered from the Databases previously mentioned, while the distance is determined based on the port website [76] for sea transport and by using google maps for road transport.

* A5 Fabrication-Assembly/Construction: The construction phase was not included in this study due to lack of Data.

* B1-B7 Use phase:

The use phase considers operational energy and water usage, maintenance, repair, and replacement are excluded in this study due to the lack of Data.

* End-of-Life phase (C1-C4):

The end-of-life phase is also excluded due to the lack of Data.

2. Data Collection and Inventory Analysis

Data for the LCA have been derived from several sources:

Shelter Design Specifications: Material specifications and detailed bill of quantities, construction methods, and dimensions of 3 shelters were taken from the UNHCR Reports in addition to some research papers, websites, and books for gathering data about the fourth one (previously mentioned in the Methodology section).

Life Cycle Inventory Databases: Data on materials-mean embodied carbon, for example, steel, wood, and plastic-is taken from existing LCI databases like Ecoinvent, and ICE Database by circular ecology and some research papers.

Transportation distances: it was assumed based on the country of production to the site of deployment. Assumptions were made concerning transportation by sea freight class from manufacturing locations to the ports, and truck class from the ports to refugee camps.

- **3. Impact Assessment Methodology**

During the impact assessment step, the GWP was selected, it describes the total amount of GHG-only CO_2 emitted by each shelter throughout its production and transportation.

Material Production: The mass of material used for each shelter in kg of steel, plastic, and wood was calculated, along with others. The GWP per kg of material was then sourced from LCI databases for each of the former quantities. These two values were then multiplied together to give the overall total. Where data could not be found for certain materials, reasonable approximations were made based on similar materials in research papers, and factories' websites.

Transportation:

Sea Freight: For shelters whose materials were imported from abroad, the distance from the production site to the nearest port was assumed and estimated based on common routes of shipment. Emission factors for sea freight in kg CO_2 / ton-km were taken from LCI databases.

Truck Transport: Materials were assumed to be transported by truck from the port to the refugee camp, using Google Maps to determine approximate distance. The truck emissions factors in kg CO_2 per tonne-km were then applied to calculate the GWP for this stage.

- **4. Assumptions and Limitations**

Regional Specificity: Distances of transport and environmental conditions were assumed, for example, considered from the UNHCR center in the country of production to the location of the camp in the country of deployment.

Material Sourcing: The study assumed that materials sourced locally, such as soil, sand, and timber, were sustainably sourced. This might not always be true on the ground in emergencies.

Moreover, Due to the lack of data, conservative assumptions were made. Embodied carbon values for some materials are replaced with general or other similar materials with the same properties, for example, local tree species were replaced with general softwood values of the ICE database. Carbon storage was excluded from the study.

Some materials are exempted or estimated to be local in the calculation due to the lack of information, for example: Water typically has a negligible GWP.

Some used factors are gathered from secondary sources like papers and websites

- **5. LCA Calculations and Interpretation**

Calculations of LCA for each shelter were carried out using the following equation:

- GWP (cradle to site) = GWP (Material Production) + GWP (Transportation).
- EE (cradle to gate)= $\sum$ materials (Mass of material × Embodied energy coefficient)

For each shelter, the overall emissions through the considered stages were measured and given in kg CO_2e (GWP) and MJ (EE) per shelter. Then, these results were compared using a metric that considers both lifespan and area to ensure the sustainability of shelter designs in the shelter improvement suggestions.

Chapter 4: Results and Discussion

4.1 GLOBAL PERFORMANCE EVALUATION OF 14 SHELTERS

4.1.1 Shelters overview

This section presents a short description of the 14 shelters evaluated.

- UNHCR Family Tent

Figure 10: Family tent by UNHCR
Source: [25]

The Family Tent is kind of preparedness plan in emergencies, which used worldwide. It is a ridge double fly tent with elevated walls. It has 16m2 of main floor area plus two 3.5m2 vestibules for a total area of 23m2, double fold with a ground sheet.

To assure stability, the outer tent is supported by 3 upright poles, 1 ridge pole, 6 side poles, 4 door poles, 3 guy ropes on each side and 2 guy ropes at each end. [25]

- Exo Shelter

Figure 11: Exo stackable shelters (Photo credit: Michael McDaniel, 2016)
Source: [167]

The Exo shelter, designed by Reaction Housing, is a modular, stackable, and portable structure for disaster survivors. It provides a secure, climate-controlled living space for a family of four, with the option to combine units for additional space. Transported in two pieces—the base and upper shell. it is designed for quick assembly and offers greater durability and security than tents, while being more affordable than trailers or containers. [168]

- Ikea Better Shelter

Figure 12: The IKEA Better Shelter designed by Ikea
Source: [169]

The Better Shelter project is a flat-pack solution for a new, safer, and more durable shelter for refugee families. The Better Shelter designed by IKEA is a temporary lightweight, cost-effective, and durable shelter solution designed to meet the needs of the activities of basic living, for privacy, security, and familiarity – a safe base that offers a sense of peace, identity, and dignity. [25]

- The Fema trailer

Figure 13: The Fema trailer Shelter
Source: [170]

The term FEMA trailer is the name commonly given by the United States Government to forms of temporary manufactured housing assigned to the victims of natural disasters by the Federal Emergency Management Agency (FEMA). Such trailers are intended to provide intermediate term shelter, functioning longer than tents which are often used for short-term shelter immediately following a disaster. They include sanitary facilities, kitchen, and furniture. [171]

- The Eco-dome house is also called the "Sandbag Shelter Project"

Figure 14: Eco Dome shelter designed by Nadir Khalili in Iran
Source: [111]

the "Sandbag Shelter project" is established by the Iranian architect Nader Khalili. It combines traditional architecture with innovative design to offer a simple, economical, and durable alternative to conventional refugee and low-income housing. The Sandbag shelter is derived from a centuries old design, commonly used in certain parts of the world which considered the use of local materials like sand. [111]

- The Paper log houses

Figure 15: Paper Log Houses by Shigeru Ban.
Source: [172]

Shigeru Ban designed paper log houses after the 1995 Japan earthquake to address victims' needs while prioritizing environmental sustainability. Using recycled and donated materials like sand-filled beer crates for foundations, paper tubes for walls, and adhesive waterproof sponge tape for insulation, these modular units are simple to dismantle and their materials are recyclable, emphasizing efficiency in time, cost, and environmental impact. [172]

- Compact Bamboo shelter

Figure 16: Compact Bamboo shelter by UNHCR.
Source: [25]

This transitional shelter model consists of a eucalyptus post-and-beam structure, split bamboo wall cladding, and a durable corrugated iron sheet roof, utilizing materials commonly available in Ethiopia. Designed for hot climates, it provides excellent ventilation and effective protection against rain. The shelter includes an internal partition, two lockable windows, and a lockable door for improved security. [25]

- One room shelter

Figure 17: A one room shelter by UNHCR
Source: [25]

A one-room core shelter project was implemented after the devastating 2010 monsoon floods in Pakistan to support returning families. Designed for safety, durability, cost-effectiveness, and environmental sustainability, the project prioritized vulnerable households. Completed in March 2011, it provided permanent housing for 175 families displaced since August 2010, with significant community involvement in unskilled labor tasks like plastering. [25]

- Mahama Settlement durable shelter

 *Figure 18 : Mahama Durable Shelter* *Source :* [74]	This settlement, created in 2015, is UNHCR's largest, hosting about 60,000 Burundian refugees. It is transitioning from temporary shelters to durable brick homes, each shared by two families, to save space. The site includes water, toilets, showers, and cooking areas, aiming to support self-reliance and integration. [74]

- Ituri Settlement Emergency shelter

 *Figure 19:Ituri settlement emergency shelter by UNHCR* *Source:* [74]	In 2019, UNHCR provided emergency one-room shelters to 8,621 vulnerable households in Ituri province, Eastern Congo, following mass displacement due to violence. These simple shelters were designed to offer immediate protection and safety during the crisis. Community involvement was encouraged through cash-for-work activities to support shelter construction and maintenance. [74]

- Azraq T shelter

 *Figure 20: The Azraq T shelter by UNHCR* *Source:* [25]	The Transitional Shelter (T-Shelter) was designed for Azraq Camp in Jordan to house Syrian refugees, addressing climatic, financial, and cultural challenges. The camp includes 13,500 T-Shelters, providing accommodation for 67,000 refugees amid ongoing displacement. Made out of interlocking steel components, it is designed to maintain the privacy of individuals while sheltering them from storms and dust with high velocities of wind and extreme temperatures. [25]

- Tuareg Tent

Figure 21: the Tuareg Tent Shelter by UNHCR
Source: [25]

The Tuareg tent, inspired by traditional Bedouin designs, is a culturally appropriate shelter provided by UNHCR for Sahrawi refugees in Tindouf, Algeria. Measuring 49 m^2, it accommodates three people and lasts approximately two years. Made of bamboo or wood, canvas, blended cloth, cotton rope, and tarpaulin, it ensures familiarity and dignity for displaced communities. [25]

- Tuareg shelter

Figure 22: Characteristics of the Tuareg shelter.
Source : [25]

This shelter project in Burkina Faso supported nomadic Malian refugees by using traditional Tuareg designs to address protection and settlement challenges while preserving cultural traditions. It empowered Tuareg women in construction and provided mobile, relocatable shelters. Kits with materials for various shelter sizes were distributed based on family needs through tribal and social structures. [25]

- Wooden Gable frame shelter

Figure 23: the wooden gable frame shelter.
Source: [25]

The Wooden Gable Frame Shelter is an emergency shelter implemented in Ajuong Thok refugee camp, South Sudan. It was designed to provide adequate housing for refugees, utilizing locally available materials. The strategy was guided by two key factors: the rural background of the refugees, who possessed shelter construction skills, and the availability of abundant forest and thatch grass resources in the region. [25]

4.2 GLOBAL PERFORMANCE EVALUATION OF 14 EMERGENCY SHELTER PROTOTYPES FOR POST-DISASTER HOUSING

4.2.1 Comparative study Findings

The Results show that there is no ideal solution for all cases, all the existing solutions have cons and pros and they are not suitable for different climates, geographics, and environments [33].

- **Classification of the shelter according to their construction method, type of disaster, and usage period**

Shelter Type	Location	Year	Type of Disaster	Type of shelter according to the Usage Phase	Construction Method
Tent	Global	1900s - present	Refugee case, natural disaster	Emergency	Prefabricated (lightweight, modular)
Exo Shelter	Haiti	2010	Natural disaster (post-earthquake)	Emergency	Prefabricated (modular)
IKEA Better Shelter	Middle East, Africa (Jordan, Iraq, Ethiopia)	2015	Refugee case	Transitional/ Core	Prefabricated (flat-pack modular)
FEMA Trailer	Katrina (USA)	2005 - present	Natural disaster (post-hurricane)	Core	Prefabricated (movable unit)
Sandbag Shelter (Eco-Dome)	Bam, Iran	1995	Natural disaster (Bam earthquake recovery)	Core/ Transitional	On-site (manual, local materials)
Paper Log Shelter	Kobe, Japan	1995	Natural disaster (earthquake-recovery)	Transitional	Prefabricated (tubes, manual assembly)
Tuareg Tent	North Africa (Algeria)	2012	Refugee case, cultural tradition	Emergency/Traditional	On-site (traditional manual setup)
Ituri settlement emergency Shelter	Ituri province, Eastern Congo	2019	Man-made disaster (Violence)	Emergency	Prefabricated (modular)
Azraq T-Shelter	Middle East Azraq Refugee Camp, Jordan	2014	Refugee case	Transitional	Prefabricated (semi-permanent)
One-Room Shelter	Sindh Province, Pakistan	2010	Natural disasters (floods)	Core/ Transitional	On-site (local materials)
Mahama Durable Shelter	Mahama Refugee Camp, Rwanda	2015	Refugee case	Core/Transitional	On-site (concrete blocks, timber)

Shelter Type	Location	Year	Type of Disaster	Type of shelter according to the Usage Phase	Construction Method
Compact Bamboo Shelter	Ethiopia, Dollo Ado camp	2013	Refugee case	Transitional	On-site (bamboo frame, thatch)
Tuareg Shelter	Africa (Niger, Mali), Sahel region. Burkina-Faso.	2012	Refugee case, cultural tradition	Emergency/ Traditional	On-site (woven reed mats, wooden poles)
Wooden Gable Frame Shelter	Ajuong Thok, South Sudan	2013	Refugee camp	Transitional/ Core	On-site (timber frame)

Table 4: Shelters General Data: Location, Year, Disaster type, usage phase, construction method.

The table presents a wide range of shelter types used across various locations and disaster contexts.

- **Shelter types according to their usage phase**

Emergency shelters, such as tents, Exo Shelters, and Tuareg Tents, are primarily designed for immediate relief. These structures rely primarily on lightweight and modular prefabrication, which enables rapid deployment during crises. Transitional shelters, including the IKEA Better Shelter, Azraq T-Shelter, and Compact Bamboo Shelter, offer semi-permanent solutions with increased stability and a more extended period of use. Core shelters, such as FEMA Trailers and Sandbag Shelters (Eco-Domes), are built for long-term use and offer enhanced durability and comfort. Additionally, traditional shelters, like Tuareg Tents, blend cultural heritage with functionality, emphasizing the importance of local practices in disaster response.

- **Shelter types according to their construction Method**

The shelter construction methods also vary significantly. Prefabricated shelters dominate emergency and transitional shelters, with examples like tents, IKEA Better Shelters, and Azraq T-Shelters. Prefabrication is widely used in humanitarian contexts due to its reduced assembly time and portability. On the other hand, on-site construction methods using local materials, like sandbags, bamboo, and timber, highlight sustainability and integration with local traditions. Examples include the Sandbag Shelter, One-Room Shelter, and Mahama Durable Shelter.

- **Type of disaster**

The context of the disaster plays a key role in the type of shelter chosen. For natural disasters like earthquakes, floods, and hurricanes, transitional and core shelters are preferred, offering stability and support for recovery efforts. In refugee cases, shelters often combine emergency and transitional functions to address the prolonged displacement of populations. Cultural traditions also influence shelter design, as seen in Tuareg Tents, which integrate local traditions and practices into the shelter design to ensure local environmental and inhabitants' needs.

- **Geographic location**

Geographically, Africa and the Middle East are prominent regions for these shelters, reflecting ongoing conflicts, displacement crises, and resource limitations. In contrast, high-income countries like the United States prefer advanced prefabricated solutions, such as FEMA Trailers, which align with their technological and economic capacities.

✓ **First Section" Quantitative factors comparison":** the study is based on: cost(dollar), area(m^2), Capacity (people), Assembly time (hours), and lifespan(years).

  As mentioned in the research paper by [33] which analyzed six types of shelters: Tents, Exo Shelter, IKEA Better Shelter, FEMA Trailer, Sandbag Shelter, and Paper Log Shelter, key factors like cost and deployment efficiency, capacity to accommodate people, and lifespan are crucial in determining the most suitable shelter.

Shelter type		Cost	Area	Capacity (people)	Assembly time(hours)	Life span
Emergency shelter	Tents	100to 500$	10 to 30 m^2	10 to 15 persons	4 - 6	typically lasting 6-12 months
	The Exo shelter	5000$	7.5m^2	4 persons	2 - 4	About 10 years
	Tuareg Tent	1190$	49m^2	4 or 5 persons	24	2 years
	Tuareg Shelter	288$	21m^2	4 persons	24	2 years
	Ituri Emergency Shelter	124 $	10.5m^2	4 or 5 persons	48	1 year
Transitional shelter	The Ikea Better Shelter	1150$	17.5m^2	4 persons	5-6	1.5 to 3 years
	Azraq T-Shelter	3442 $	24m^2	4 or 5 persons	12-16	2 to 4 years
	The paper log shelter	2000$	16m^2	4 or 5 persons		About five years
	Mahama Durable shelter	1 060 $	34.6m^2	4 or 5 persons	10 days	10 years
	Compact Bamboo shelter	708 $	21m^2	4 or 5 persons	24	2 to 4 years
	Wooden Gable Frame Shelter	223$	12m^2	4 persons	6	1 year
Core shelter	The FEMA trailer	14000$	23m^2	4 persons	24–48	About 10 to 12 years
	The Sandbag shelter	150to 300$	37m^2	4 or 5 persons	72–120	It can last for more than 30 years.
	One-Room Shelter	1949 $	25m^2	4 or 5 persons	5 to 7 days	10 years

Table 5: A table presenting a comparison between the shelters according to the cost, Area, number of people, Assembly Time, and Life span.

Source: [33]

These projects were compared,

***According to the cost**: Among the shelters assessed, Tents (100–500$, Ituri Emergency Shelter (124$), Wooden Gable Frame Shelter (223$), and Sandbag Shelter ($150–300) represent the most affordable options.

The tent's low cost is primarily due to its lightness which ensures low transportation costs. The low cost of the Wooden Gable Frame Shelter, and Sandbag shelter is due to the use of locally available materials.

At the same time, the Exo Shelter (5,000$) and FEMA Trailer (14,000$) are the most expensive options due to their transportation and construction high cost, but offering advanced features like weather resistance, mobility, and longer lifespans (10–12 years). However, their high cost limits their flexibility in large-scale displacement scenarios.

The Azraq T-Shelter ($3,442) and IKEA Better Shelter ($1,150) balance affordability with better privacy, durability, and thermal comfort, making them ideal for transitional use in camps.

***According to the area and Capacity:**

Most of the shelters in this comparison are designed to accommodate approximately four to five people but with variations in the living space area:

First, Tuareg Tents (49 m^2) and Sandbag Shelter (37 m^2) provide the largest living areas, accommodating up to 10–15 people (Tents) or 4–5 people (Sandbag Shelter).

While the Exo Shelter (7.5 m^2) offers minimal space for 4 people, limiting user's privacy and comfort.

At the same time, the Wooden Gable Frame Shelter (12 m^2) and Ituri Emergency Shelter (10.5 m^2) prioritize emergency needs with compact designs.

According to the Sphere Project (2011), it is recommended to provide an area of 3.5 m^2/person as a minimum personal space in sheltering response, which means about 14 m^2 for 4 persons. Unfortunately, four of the shelters have shelter sizes below this 'recommended' average. In addition, the shelters' facilities, users' needs and culture, and the number of household members differ between cases. One of the most common challenges faced by beneficiaries is the one-size shelter as it fails to meet the needs of individuals.

***Assembly Time**

Shelters like the Exo Shelter (2–4 hours) and Tents (4–6 hours) prioritize rapid deployment in emergencies. These designs are critical for providing immediate relief in disasters but often lack the durability for long-term use.

Sandbag Shelter (72–120 hours) and One-Room Shelter (5–7 days) require significant time and effort for construction but offer exceptional durability, lasting up to 30 years like the Sandbag Shelter. These are better suited for recovery or core shelter phases where long-term stability is prioritized.

***Lifespan**

- Short-Term Shelters:

Tents (6–12 months) and Ituri Emergency Shelter (1 year) are designed for immediate, short-term solutions, necessitating immediate deployment. Their low durability limits their use to initial disaster phases.

- Long-Term Shelters:

The Sandbag Shelter (more than 30 years), FEMA Trailer (10–12 years), and Mahama Durable Shelter (10 years) are ideal for stable, long-term living conditions. Their longer lifespans justify higher costs.

- Mid-Term Shelters:

Shelters like the Azraq T-Shelter (2–4 years) and Compact Bamboo Shelter (2–4 years) bridge the gap between emergency and permanent housing, offering flexibility during recovery.

4.2.2 The Shelter Affordability calculation' findings (Economic aspects of sustainability)

The affordability of shelters is calculated by considering all associated costs, including production, supply, transportation, and setup, along with the shelter's lifespan and covered living area. This metric ensures a comparable fair unit cost across different shelter types:

$$\text{Affordability} = \frac{\text{Total Cost}}{\text{Lifespan} * \text{Covered Living Area}}$$

Shelter Type	Cost ($)	Lifespan (Years)	Area (m²)	Affordability ($/Year/m²)
Tents	100	1	10	10
The Exo Shelter	5000	10	7.5	67
Tuareg Tent	1190	2	49	12.14
Tuareg Shelter	288	2	21	6.86
Ituri Emergency Shelter	124	1	10.5	11.80
The IKEA Better Shelter	1150	1.5	17.5	43.8
Azraq T-Shelter	3442	2	24	71.7
The Paper Log Shelter	2000	5	16	25
Mahama Durable Shelter	1060	10	34.6	3.07
Compact Bamboo Shelter	708	2	21	16.86
Wooden Gable Frame Shelter	223	1	12	18.58
The FEMA Trailer	14000	10	23	60.87
The Sandbag Shelter	150	30	37	0.13
One-Room Shelter	1949	10	25	7.8

Table 6: Cost Affordability of the 14 shelters.

Source: created by the Author.

✓ **Most Affordable Shelters:**

The Sandbag Shelter offers exceptional affordability at $0.13 per year per m², due to its low cost, large area, and longer lifespan of 100 years.

Mahama Durable Shelter is the next most affordable option at $3.07 per year per m², combining moderate cost with a lifespan of 10 years and a large area.

- **Lowest Affordable Shelters:**

Azraq T-Shelter is the most expensive shelter at $71.70 per year per m², driven by its high cost and relatively short lifespan of 2 years.

The Exo Shelter and The FEMA Trailer also rank as less affordable at $67.00 and $60.87 per year per m², their higher costs are primarily due to the advanced prefabrication methods used in their construction and their longer durability.

➢ **Summary:**

Emergency shelters like Tents and Ituri Emergency Shelter have low initial costs but higher affordability values due to shorter lifespans.

Core shelters like Sandbag Shelter, Mahama Durable shelter and One-Room Shelter are more cost-effective over time due to their durability and larger areas.

Transitional shelters like The IKEA Better Shelter and Compact Bamboo Shelter balance affordability and medium-term usability but can vary widely in cost-effectiveness depending on context. See the figure below.

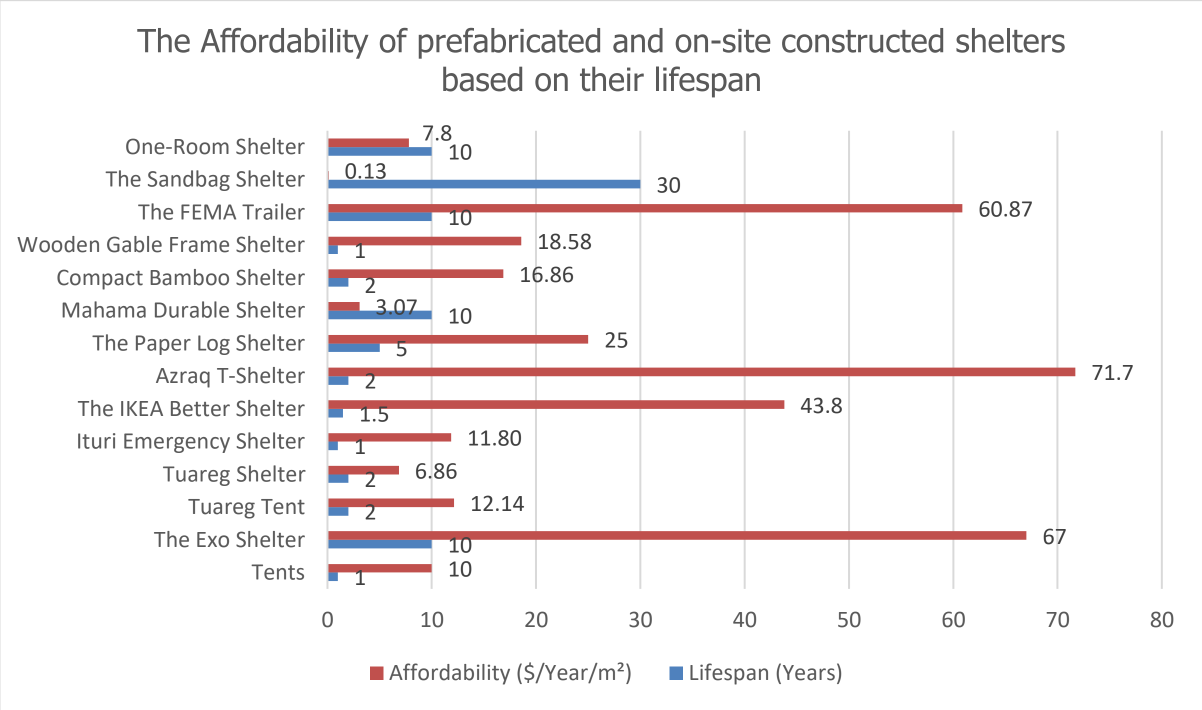


Figure 24: The Affordability Analysis results.

✓ **Second Section "Qualitative factors comparison":** A comparative study based on qualitative factors: the materials used (local or imported), foundation type, ease of assembly, weather protection, sustainability, cultural and social suitability, mobility, comfort, flexibility, and durability.

Shelter type/ factors	**Materials used**	**Foundation type and materials**
Tents	Canvas, synthetic fabric, aluminum poles (Imported)	No foundation pegged directly into the ground
The Exo shelter	Steel frame, composite plastic walls (Imported)	Flat slab or ground anchors (steel stakes)
Tuareg Tent	Canvas and blended cloth, bamboo poles (Local), iron pegs, cotton rope, rivet pins.	Sand base, no fixed foundation
Tuareg Shelter	Straw mats, fabric covers or plastic sheetings, timber poles (Local), fixing rope	Sand base, no fixed foundation
Ituri Emergency Shelter	Plastic tarpaulin, timber frame, (Imported)	ground anchors
The Ikea Better Shelter	steel frame, panels, pv system (Imported)	Flat ground, or concrete slab (optional)
Azraq T-Shelter	Galvanized steel frame, metal cladding, plywood (Imported)	Concrete slab foundation
The paper log shelter	Paper tubes, wooden joints (Local/Imported)	bottle crates
Mahama Durable shelter	Plastic, steel, sand and quarry stones (Local/Imported)	Concrete slab foundation
Compact Bamboo shelter	Bamboo frame, Eucalyptus, , corrugated metal roofing (Local)	Earthen or bamboo platform
Wooden Gable Frame Shelter	Timber frame, corrugated iron sheets (Local)	Stone or concrete footings
The FEMA trailer	Aluminum panels, wooden frame, fiberglass insulation (Imported)	Concrete slab or wheeled base
The Sandbag shelter	Earth-filled sandbags, barbed wire (Local)	Rubble trench foundation
One-Room Shelter	Brick walls (Local), ceramic tiles, steel beams, cement plaster	stone foundation

Table 7: A summary of the materials used in every shelter created by the Author.

The analysis of shelter types shows variations in materials and foundation types. Shelters using locally available materials, including the Tuareg Tent, the Tuareg Shelter, Compact Bamboo Shelter, and Sandbag Shelter, demonstrate reduced environmental impacts and lower costs due to minimal transportation requirements. In contrast, shelters like the Exo Shelter, Ikea Better Shelter, and FEMA Trailer, which use imported materials, may have higher embodied energy and global warming potential (GWP) due to manufacturing and transportation processes. designs, such as the Paper Log Shelter and Mahama Durable Shelter, balance sustainability and durability by integrating both local and imported materials.

While the foundation type plays a critical role in stability and suitability for different contexts. Shelters with no fixed foundations, such as tents and Tuareg Shelters, are ideal for short-term emergency scenarios due to their portability and ease of assembly but lack long-term stability. Contrary, shelters with concrete slab or rubble trench foundations, such as the Azraq T-Shelter, Mahama Durable Shelter, and Sandbag Shelter, offer enhanced structural integrity and durability, making them more appropriate for transitional or permanent use.

Cultural relevance and adaptability are also crucial factors. Traditional shelters like the Tuareg Tent and Tuareg Shelter, constructed using goat/camel hair fabric, woven reed mats, and wooden poles, align closely with local practices and resources, ensuring cultural acceptance. In contrast, imported designs such as the Exo Shelter and Ikea Better Shelter may face challenges due to the limited availability of spare parts and unfamiliar materials in remote areas.

Note: The details provided for each type of shelter, including materials and foundation specifications, are general guidelines and may vary depending on specific contextual adaptations, updates or modifications in the field.

- **Comparative study based on qualitative factors**

The comparison of the shelters reveals notable differences in key factors such as ease of assembly, weather protection, sustainability, cultural and social suitability, mobility, comfort, flexibility, and durability.

***Ease of Assembly**

Tents and Tuareg Shelters are the easiest to assemble, requiring minimal tools or expertise, making them ideal for rapid deployment in emergencies.

Prefabricated options like the Exo Shelter and Ikea Better Shelter are moderately easy to assemble due to their modular components, while structures like the Mahama Durable Shelter, Wooden Gable Frame Shelter, Azraq T-Shelter, and Sandbag Shelter require more time, effort, and expertise due to the use of heavier materials and the need for foundation preparation.

Sandbag Shelters require significant effort and time due to the filling and stacking of sandbags, despite their simplicity in design.

***Weather Protection**

shelters like the Azraq T-Shelter, Exo Shelter, and Ikea Better Shelter provide robust weather protection due to their durable materials, including steel frames and insulated panels, offering reliable protection in various climates. Traditional options like the Tuareg Tent and Tuareg Shelter provide limited protection, particularly against harsh weather such as heavy rain or snow, as they are designed primarily for arid climates. The Sandbag Shelter, with its thick earth-filled walls, provides excellent thermal insulation and weather resistance, especially in extreme conditions. Other options like Compact Bamboo Shelters and Wooden Gable Frame Shelter perform well in moderate climates but may require additional measures for extreme weather.

***Sustainability**

Sustainability varies significantly across shelter types. Those utilizing local materials, such as the Tuareg Tent, Compact Bamboo Shelter, and Sandbag Shelter, have lower environmental impacts and are highly sustainable. In contrast, prefabricated shelters like the Exo Shelter, Ikea Better Shelter, and FEMA Trailer which constructed from imported materials, leading to a higher carbon footprint due to manufacturing and transportation. Shelters constructed on-site, like the Paper Log Shelter, incorporate both local and imported materials, offering a balance between sustainability and durability.

***Cultural and social suitability**

Traditional shelters like the Tuareg Tent and Tuareg Shelter align with the cultural practices of nomadic populations, ensuring social acceptance.

Prefabricated designs, including the Exo Shelter and Ikea Better Shelter, may face challenges in cultural adaptability as they often lack integration with local building traditions. Shelters like the Compact Bamboo Shelter and Mahama Durable Shelter, which combine modern designs with local materials, provide cultural flexibility and social acceptance.

***Mobility**

Lightweight options like Tents and Tuareg Shelters are highly mobile due to their lightweight and modular components, making them ideal for transient populations.

Prefabricated shelters, including the Exo Shelter and Ikea Better Shelter, offer moderate mobility as they can be disassembled and relocated with some effort.

Meanwhile, Permanent shelters like the Mahama Durable Shelter and Sandbag Shelter are not designed for mobility and are better suited for long-term use.

*** Comfort**

Comfort is highest in shelters like the Ikea Better Shelter, with its insulated panels, and the FEMA Trailer, with fiberglass insulation, provides higher levels of comfort in varying climates. Similarly, the Sandbag Shelter offers thermal comfort through its thick walls. Traditional shelters like the Tuareg Tent and Compact Bamboo Shelter provide natural ventilation and are well-suited to hot climates but may lack comfort in colder conditions.

***Flexibility**

Tents and Tuareg Shelters are highly flexible in terms of layout and assembly, adapting easily to different site conditions. Modular shelters, such as the Exo Shelter and Ikea Better Shelter, provide moderate flexibility, as they come in modular components that can be slightly modified. While Permanent shelters like the Sandbag Shelter and Mahama Durable Shelter have limited flexibility once constructed.

***Durability**

durability is strongest in shelters like the Azraq T-Shelter, Exo Shelter, and Mahama Durable Shelter, which are built with robust materials designed to withstand long-term use. The Sandbag Shelter also offers excellent durability with its earth-based construction, while tents and Tuareg Shelters are the least durable, typically lasting only a few years due to their lightweight and perishable materials.

Summary

This analysis underscores the importance of selecting shelters based on their intended purpose, environmental conditions, and cultural context, balancing immediate needs with long-term sustainability and usability.

4.3 SOCIO-CULTURAL ASPECTS AND USER'S SATISFACTION ASSESSMENT (SURVEY)

4.3.1 General Data about the respondents

- ✓ **Demographic Information**

  404 persons from different countries, most of them are refugees or asylum seekers have responded to the questionnaire,

- ➢ **<u>Age and Gender of respondents:</u>**

*Among the 404 respondents, only 400 persons answered the question related to the age.

The age group of the survey respondents shows a diverse demographic: 59 persons are aged between 20-30 years, 103 persons are aged between 30-40 years, 156 are aged between 40-50 years, 57 are aged between 50-60 years, and 24 are aged between 60-70 year, while 1 person is aged 85 years. Based on the literature review, the needs and demands of shelter occupants are changing with age: young people may need education and Leisure areas, people of middle age may pay more attention to safety and family services, and older people may need accessible conditions of living and healthcare services.

These differences highlight the necessity for shelter design that considers such specific characteristics and enables the ability to construct more effective, inclusive shelter models to ensure the satisfaction of all refugees and their well-being. See the figure below.

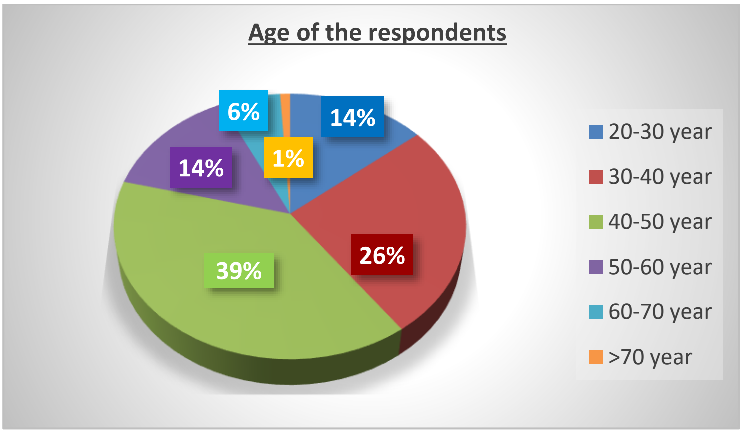


Figure 25: A chart presenting the Age of the 400 respondents.
Source: Created by the Author

*The result of the survey shows participants from both genders. Males were 228 males, forming approximately 57% of the respondents, while females' numbers were a little lower about 172 females, forming approximately 43% of the survey's respondents. See the Figure below.

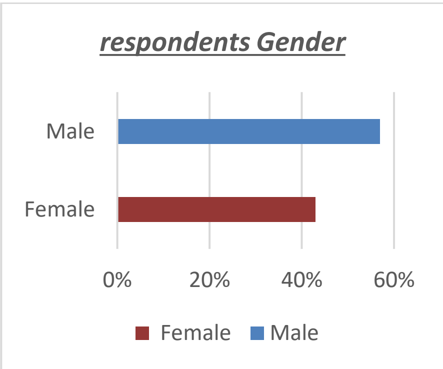


Figure 26: A chart presenting the Gender of the simple participants.
Source: Created by the Author

- **<u>Nationality</u>**

The survey's respondents come from different countries, representing a wide range of nationalities from different contexts and regions. Among the 404 participants, only 399 persons responded to the question related to Nationality:

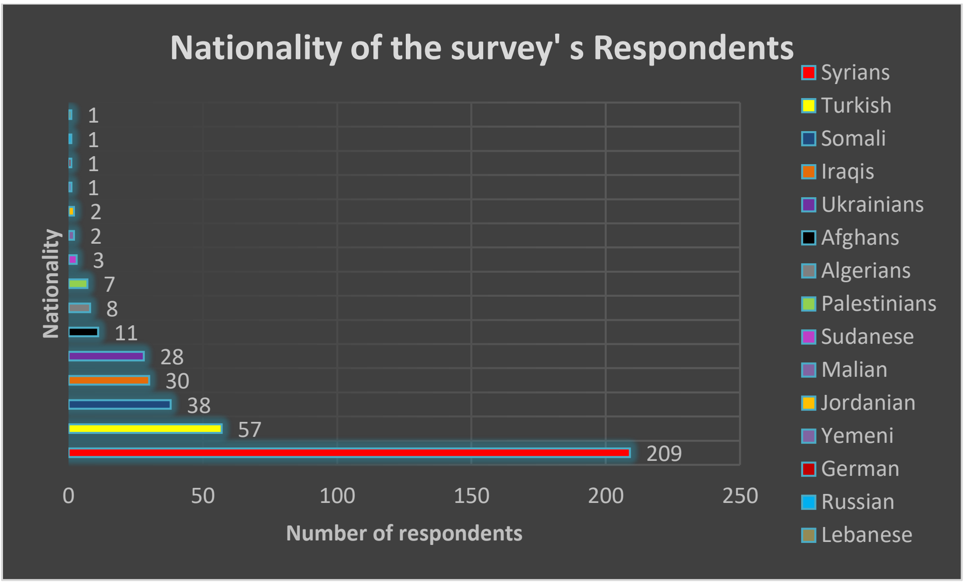


Figure 27: A chart presenting the Nationality of the Survey's Respondents

Source: Created by the Author

***Syrians (209 Respondents):** present the major group of respondents, with 209 persons in total. These respondents present those displaced because of war. Based on the UNHCR Report, more than 12 million Syrians have become internally or externally displaced. [77]

***Turkish (57 Respondents)**: This number presents probably the Kurdish population while The majority of the Turkish refugees who have fled to Europe, particularly Germany are of Kurdish origin. [78]

* **Somali (38 Respondents):** this number presents a small group of the displaced population because of the war, which caused huge numbers of refugees across the world. [79]

* **Iraqis (30 Respondents)** The 30 Iraqi participants present those displaced by wars. The statistics show that about 1.2 million Iraqis have been internally displaced or been refugees. [80]

* **Ukrainians (28 Respondents)**

According to the UNHCR 2023 report [81]. By the end of 2023, the war in Ukraine had displaced an estimated 3.7 million people within the country and forced 6.3 million refugees and asylum-seekers to seek protection abroad, nearly 6 million of them in Europe and practically in Germany, the 28 respondents form a small group of those population.

* **Afghans (11 Respondents)**

These 11 Afghans represent those displaced by war who experience living in temporary camps or shelters as Asylum seekers in Germany. [82]

***Other respondents are from other Nationalities:**

Algerians, with 8 respondents probably affected by natural disasters like the 2003 Boumerdas earthquake Or Asylum seekers due to political or economic issues.

Palestinians, with 7 respondents, come from a country that has been affected by conflict for decades as well as recent forced displacement of Palestinians, many of whom remain in refugee camps all over the Middle East. [83]

Sudanese, 3 in number, come from a country affected by civil war and political issues across its large area, resulting in the country's division. As a consequence, many Sudanese become refugees or Asylum Seekers. [84]

Malian, 2 respondents, who have faced internal conflict that has caused displacement internally within the Sahel region.

Jordanian, 2 respondents, may be displaced because of natural disasters or other internal problems faced by the people.

Yemeni, 1 respondent, comes from a country that is passing through one of the worst humanitarian crises in the world, resulting in war, food crises, and collapse of the economy [85].

German, 1 respondent, may represent an internally displaced citizen due to natural disasters or migration or even been a witness.

Russian, 1 respondent, probably affected by political tension or migration or been a witness.

Lebanese-1 respondent, from a country that has gone through economic collapse, political instability, and the Beirut port explosion in 2020, which again is causing internal displacement.

4.3.2 Data about the Type and condition of living in the shelter

The survey shows that respondents have lived in various types of shelters, including tents, prefabricated structures, and semi-permanent housing.

Out of the 402 survey respondents, 11 indicated that they had never lived in a temporary shelter before. Among those who have experienced temporary shelters, 82 have lived in tents, which are considered a traditional short-term shelter type.

Additionally, 155 respondents reported that they have lived in prefabricated shelters or caravans, which offer a more structured and resilient solution than tents.
Also, the shelters made from local materials are reported to represent vernacular and often culturally relevant solutions and have housed 71 respondents. Furthermore, 231 respondents have lived in semi-permanent or permanent housing, which are typically more organized, long-term shelter solutions. Finally, one respondent has experienced working on these types of housing, providing a unique perspective on their functionality and effectiveness. See the Figure below.

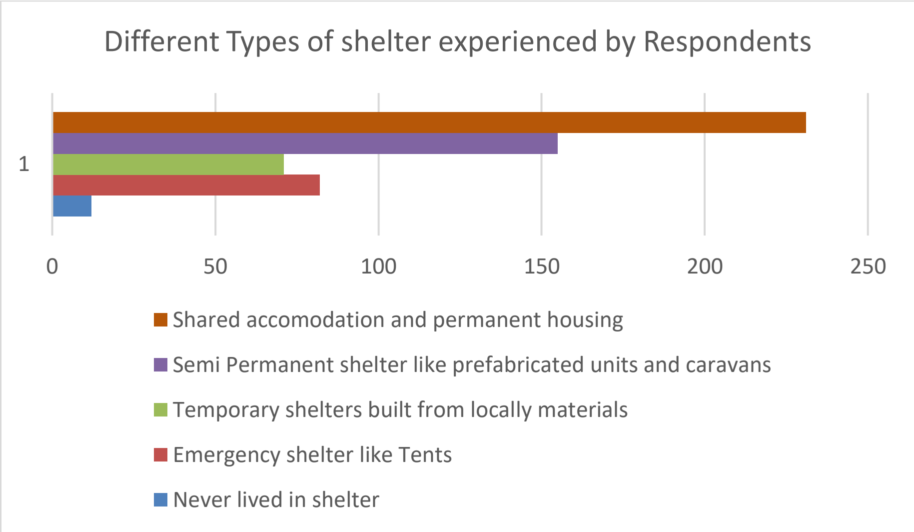


Figure 28: the graph presents the different types that the respondents have lived in.
Source: Created by the Author

It's crucial to note that some respondents mentioned more than one shelter type, indicating that over time, they have lived in different shelter types. This highlights that people after natural disasters or during the period of applying for asylum live in a state of instability as they move between different forms of shelter. In most cases, they were provided with emergency tents followed by temporary shelters and later moved to semi-permanent or permanent housing solutions, depending on the availability of resources and government or NGO interventions in each location. These results highlight the gap between short-term needs and long-term needs in this type of housing solution previously discussed in the literature review.

✓ **Duration of living in a shelter**

Among the 402 survey respondents, 16 individuals reported living in a shelter for less than three months. Another 64 individuals have lived in such conditions for three to six months, while 271 respondents experienced shelter life for six months to one year.

Additionally, 34 respondents have lived in shelters for one to two years, and 15 have lived in such conditions for over two years. Three respondents indicated they have not lived in any type of temporary shelter. See the figure below.

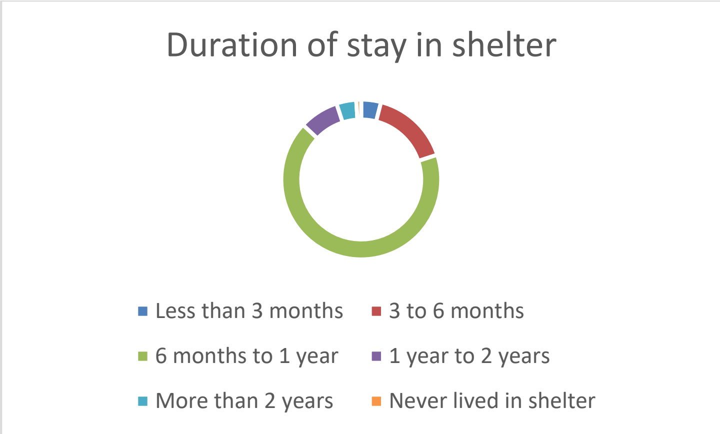


Figure 29: A chart showing the respondents 'duration of stay in shelters

Source: Created by the Author

- **Reason for their stay in the shelter**

  Among the 404 Respondents, only 338 persons provided answers about the reasons for their stay in shelters. They reported that they have lived in shelters for different reasons, while 7 respondents indicated that the reason was because of natural disasters, 37 individuals reported that the reason was war and conflicts that led them to displacement. At the same time, 294 persons lived in such conditions during the Asylum seeker period.

✓ **Location of the shelters**

A total of 394 respondents provided answers regarding the shelter location. The highest number of responses came from Germany, with 349 respondents, presenting significant data on the shelter experiences within this country. Followed by Jordan, Algeria, and Lebanon, with each of these countries represented by 3 respondents. In addition, 4 respondents indicated that their shelter was located in Palestine, while Iraq, Spain, and Ireland were each mentioned by 2 respondents. A few respondents reported staying in Turkey (6 people) and Syria (7 people). The following countries were each mentioned by 1 respondent: Egypt, Ethiopia, Sudan, Greece, Russia, Afghanistan, Iran, and Yemen. One respondent remained neutral about the location.

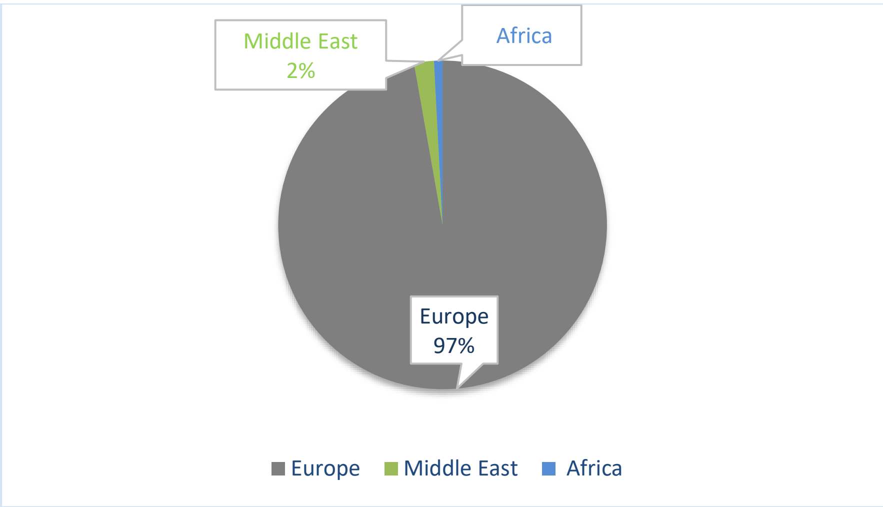


Figure 30: A chart presenting the location of the shelter reported by respondents.

Source: Created by the Author

✓ **The arrangement of people within the shelter**

The living arrangements of the people in emergency shelters are an interesting form of the social dynamic of a post-disaster or refugee context. Approximately 334 of the respondents reported that they have lived with other families or strangers, while the other 60 persons indicated that they have lived alone or with their own family. Besides, 2 answers were evaluated as "not applicable.

The results show that 84% of respondents, or the majority, share their living space with strangers or other families, this indicates that shared or communal sheltering arrangements are very common in emergencies.

However, shared dwelling can be an efficient way to minimize the use of resources, but it can also lead to issues with privacy, security, and stress when people from different cultural or familial backgrounds are forced to live together under one roof as mentioned in the literature review [86]. On the other hand, the considerably smaller group of responders (60 persons, or 15%) who live alone or with their families are probably in a better situation in terms of ensuring personal comfort and familial structures.

4.3.3 User’s comfort results: A sense of Safety, Area Adequacy, facility conditions

✓ **A sense of Safety and necessities within the shelter environment**

The feeling of safety in a shelter environment plays a crucial role in their inhabitant's mental health and well-being. From the total respondents, only 400 persons answered the question related to the sense of safety within a shelter environment: 301 indicated that they felt safe, 79 persons expressed feelings of unsafety, and 20 responded that they feel safe only sometimes. Results show that the majority of residents consider the shelter environment to be safe, however, the other respondents do not agree with them, and this raises very serious questions concerning issues of shelter design and management that would need to be dealt with.

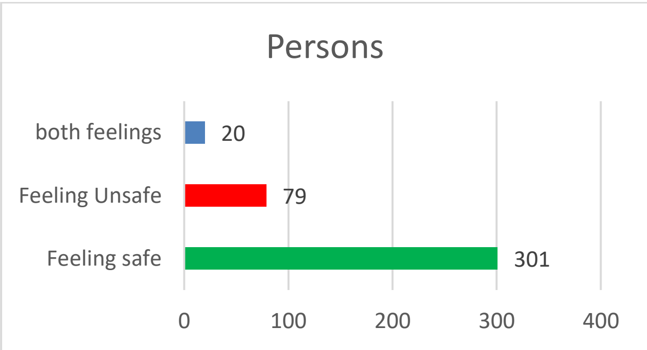


Figure 31: A chart presenting the sense of security between the respondents within the shelter environments.

Source: Created by the Author

✓ **Area Adequacy (391 Respondents in total)**

The result regarding the question of satisfaction about the area adequacy of shelter rated on a scale from 1 (very agree) to 5 (very disagree) presents critical data on the degree of satisfaction among shelter inhabitants. Results are as follows: First, only 14 respondents, about 3.5%, reported being very satisfied with the Area adequacy of the shelter, and 44 persons, around 11% just agree, this combined group of 58 individuals (14.5%) indicates that a small group of shelter inhabitants are satisfied with the current living conditions of existing shelter solutions. 121 respondents, about 30.5% are neutral, this might mean that they found the shelters are neither particularly adequate nor particularly inadequate regarding the living area, they only meet the basic survival needs. Most notably, the highest number of respondents is 160 individuals, with about 40% expressing clear dissatisfaction with the adequacy of the shelter, and 52 persons about 13% are strongly dissatisfied with the adequacy of the shelter. The majority of respondents 212, or 53% are not satisfied with the area adequacy of the shelter.

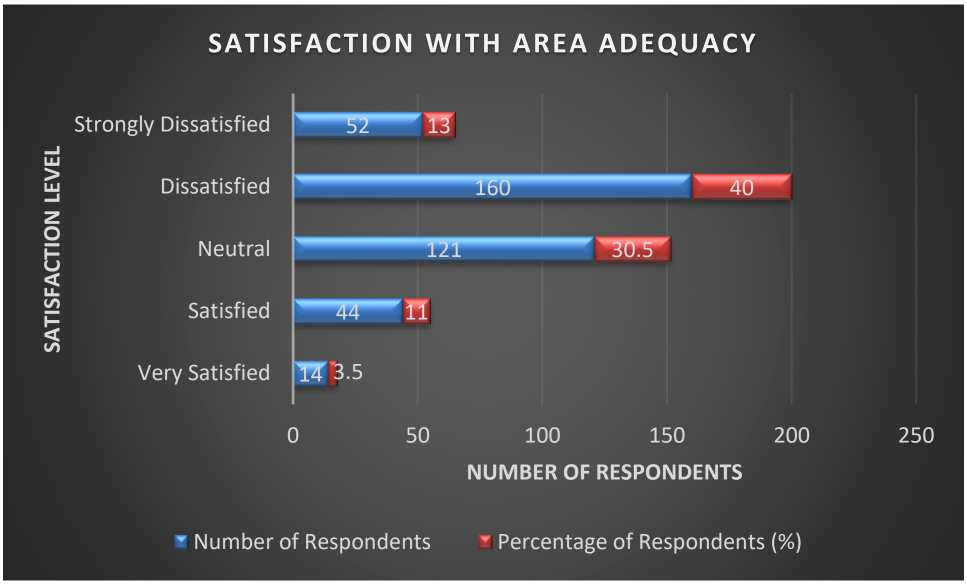


Figure 32: A chart presenting the Respondents' satisfaction with the Area adequacy.

✓ **Shelter user's satisfaction regarding the availability of facilities in the shelter that are sufficient for daily needs (cooking, bathing, laundry)**

These findings demonstrate that even while a large number of people had access to facilities within the shelter, there was an important gap in the availability of those services and their level of comfort and efficiency.

On one hand, A large number overall 343 respondents, approximately 82%, reported that while facilities were accessible, they were not comfortable nor adequate for daily activities like cooking, bathing, and laundry. This may be due to communal facilities, and inadequate privacy within the shelter.

Among the respondents, only 22 persons (about 5% of the total number) indicated that their shelters (mostly tents) lacked any facilities of this kind inside the shelter.

In Another hand,13 respondents about 3%, reported that the facilities were not sufficient to fulfill their needs. This offers another indication that existing shelter solutions may have problems in their design or maintenance, which leads to dissatisfaction and unfulfilled basic needs.

Only 19 persons, about 5% reported that the facilities were enough and comfortable. This is because the 19 respondents have the chance to live in more permanent or semi-permanent shelter types that offer better facilities or management.

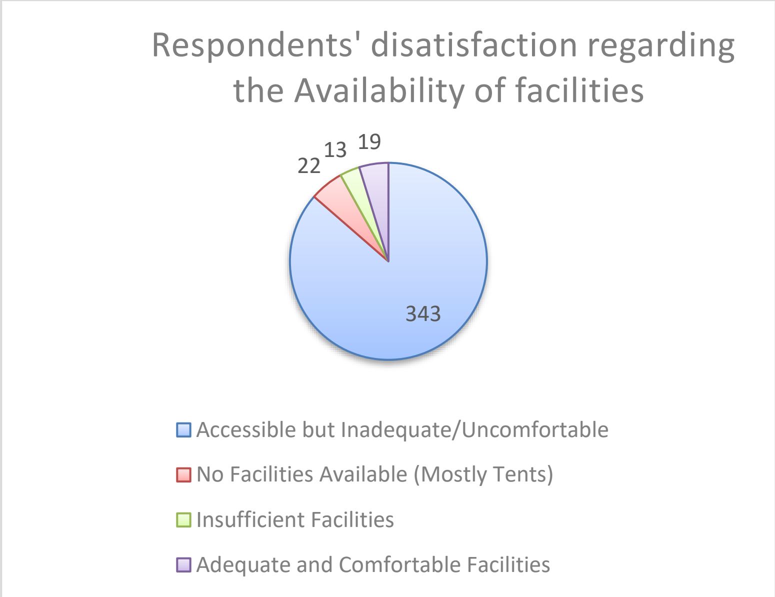


Figure 33: A chart presenting the Respondents' dissatisfaction regarding the Availability and adequacy of provided facilities.
Source: Created by the Author

✓ **Thermal and Acoustic Comfort**

➢ **The noise levels assessment in shelters (392 Responses).**

The survey evaluates noise levels at different times of the day. The data are gathered from 392 respondents. The Results are summarized as follows:

-In the morning, 77 respondents, about 19.6% find the noise level very high, 188, approximately 48% of respondents find it high, 101 persons, forming 25.8% of respondents find it low, 22 persons about 5.6% find it very low, and 4 respondents approximately 1% find it almost non-existent. It can be summarized that during the morning, the majority about 67.6% reported high noise levels while the rest reported low noise levels or non-existent. This indicates that the morning hours are particularly disturbing for most shelter inhabitants. This may be due to the small separation between shelter units, the non-existence of sound insulation, and overcrowding within this type of settlement. Which results in user dissatisfaction and discomfort.

In the afternoon, 219 individuals, which is about 55.9% of the total respondents, report experiencing very high noise levels. Meanwhile, 126 respondents, approximately 32.1%, find the noise levels to be high, 41 individuals, or about 10.5%, consider them low, and 3 persons, roughly 0.8%, perceive them as very low. Additionally, another 3 individuals, also about 0.8%, find the noise levels to be almost non-existent. Overall, afternoon noise levels are significantly higher, with 88% of respondents indicating that they experience high or very high levels of noise during this time. While Afternoon activities in shelters typically include social gatherings, child play, and communal cooking, and more spaces become in active use; thus, they would result in higher noise levels than during the morning hours. Most of the existing Shelters are designed without effective acoustic zoning, which separates noisy areas from quieter areas.

-In the evening, 251 about 64% of the respondents experience very high noise levels, 105 approximately 26.8% of the respondents find it high, 25 about 6.4% of the total respondents find it low, and 11 about 2.8% find it very low.

Normally, evening is the noisiest time of the day, with 90.8% of the respondents facing very high noise levels. This may also be because all these daily activities of communal dining, cleaning, and socializing take place in an overall overcrowded populated environment with little absorption of sound. Which affects the activities of the inhabitants, including relaxing or reading…

-At night, 31 about 7.9% of respondents report very high noise levels, 53 persons approximately 13.5% find it high, 238 respondents about 60.7% find it low, 63 persons about 16.1% find it very low, and 7 respondents about 1.8% find it almost non-existent.

The noise levels are also much lower at night compared to morning, afternoon, and evening. A total of 77% of the respondents reported either a low or very low noise level during night times, while 21.4% found it high or very high. This decrease in noise is understandable because people for the most part are sleeping or resting. While the 21.4% who still report high noise might represent problems concerning poor sound insulation and the noise being transmitted through the walls, floors, or ceilings. Noise even at nighttime and at much lower levels interrupts sleeping patterns, leading to sleep distress and as a result, poor health, both mentally and physically.

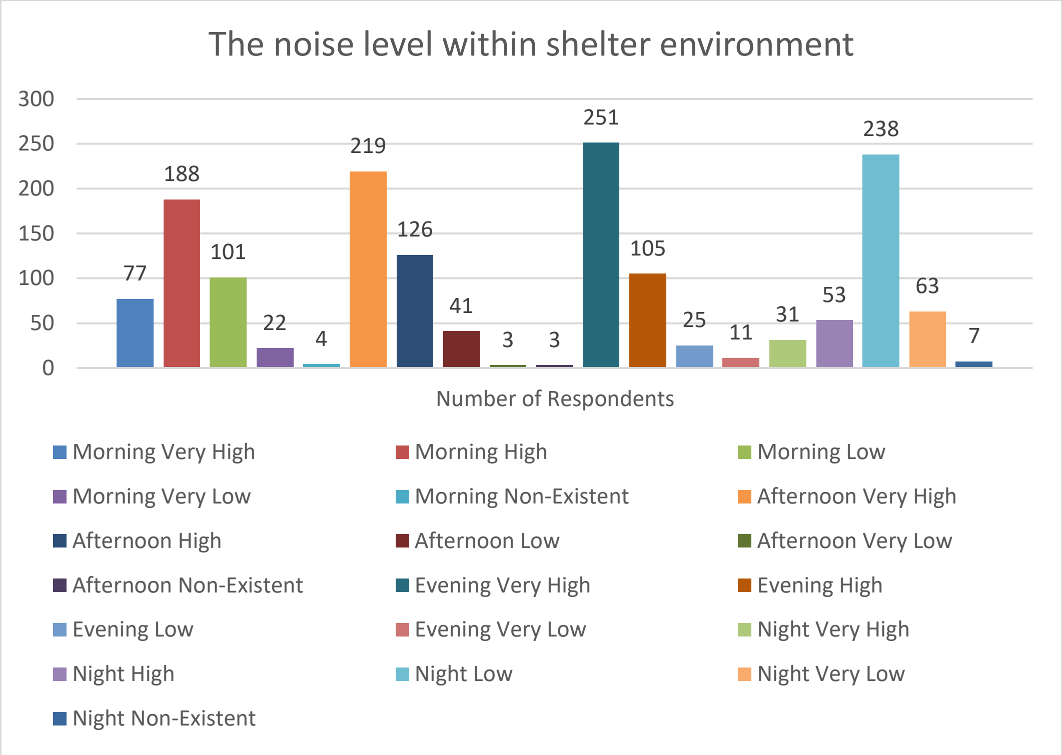


Figure 34: A chart presenting the noise levels a different time of the day within the shelter environment.

Source: Created by the Author

➢ **Analysis of Main Sources of Noise Disturbance in Shelter Environments**

Data obtained from 392 respondents on the main sources of noise disturbance within the shelter environment gives an insight into the type of noise disturbances affecting acoustic comfort. The sources of noise reported are as follows:

- Human sources of noise, particularly children's noises, were reported by 348 respondents.
- Housekeeping activities such as cooking and cleaning were reported by 287 respondents.
- Traffic noise was mainly reported by 73 respondents.
- Industrial and construction noises disturbed 113 respondents, notably from the urban shelters situated close to the industrial zone.

- Environmental and mechanical noises, such as rain and wind, or even the water-pumping system, were mentioned by 88 respondents who have experienced living in short-term shelters like tents.

- One person mentioned gunshots, however, this is a very traumatic noise source in conflict zones, adding to the psychological distress experienced by displaced people.

➢ **Analysis of the Thermal Comfort within a Shelter:**

The study of thermal comfort in shelter environments shows great discomfort among the respondents.

- Thermal Discomfort in Summer: 55%

During summer, the respondents reported that their shelters become very hot. This is basically because of materials used such as containers, which easily transfer heat, as well as the absence of thermal insulation and proper ventilation in the shelter.

- Cold Discomfort in Winter (37.5%):

A very high number, 37.5% of the respondents reported that they face cold conditions in winter, which indicates that the insulation and heating provision in shelters is inadequate.

- Acceptable Conditions (7.5%):

Only 7.5% indicated that the conditions were acceptable during both summer and winter, probably because of either better shelter construction with more moderate climate conditions, or adaptive measures such as using additional heating or cooling equipment.

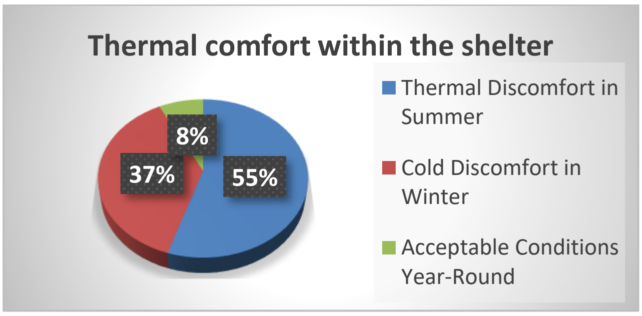


Figure 35: A chart presenting the thermal comfort within a shelter
Source: Created by the Author

✓ **User's satisfaction with time of receiving shelter after displacement or arrival at the site**

- High Dissatisfaction: The level of dissatisfaction was high, where 76.5% reported being very dissatisfied or dissatisfied with the time for shelter provision.
- Neutrality: About 17.3% of the respondents felt neutral about the issue of shelter provision time.
- Satisfied: 6.3% reported being satisfied or very satisfied with the time for shelter provision.

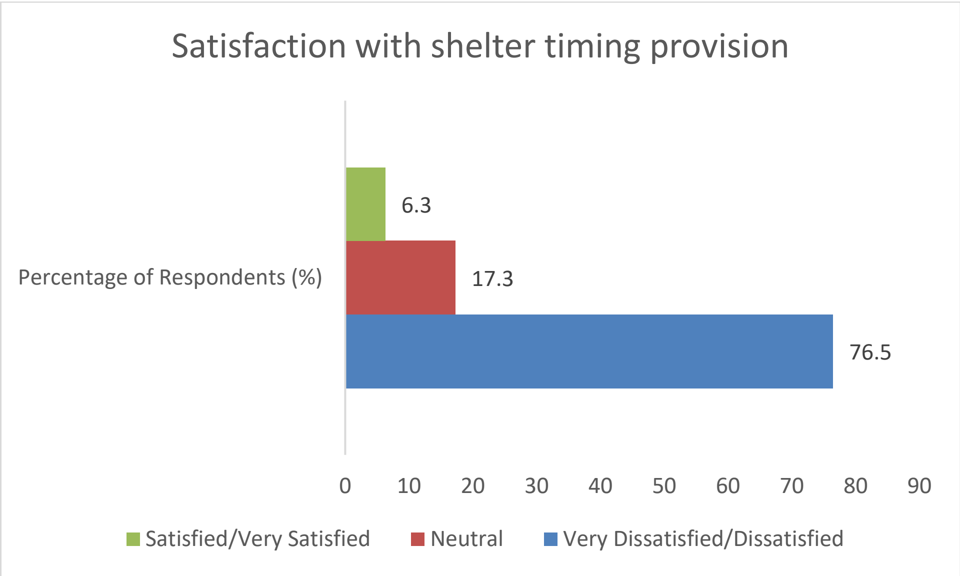


Figure 36: A chart presenting the satisfaction levels regarding the shelter timing provision

Source: Created by the Author

4.3.4 Cultural and Social Aspects Assessment

These aspects are assessed based on factors like feeling socially connected or isolated, as well as the existence of places that allow for social or cultural practices.

Among the 399 responses in total regarding the question of whether people feel socially connected or isolated within the shelter environment, only 103 persons, about 26% of the respondents reported feeling socially connected within the shelter environment. However, the largest group, 171 respondents (43%), reported feeling socially isolated. This is a highly serious problem within the shelter environment concerning social interaction and building community. Which can lead to serious problems for the user's mental health and well-being. This feeling of isolation among respondents may be because of the shelter design that does not allow interaction, in addition to the overcrowding and lack of privacy and the difference in cultural background and the languages spoken. One-third of them (32%) felt neither connected nor isolated this group may represent those people who either interact little with others but without deep social connections that build a sense of community.

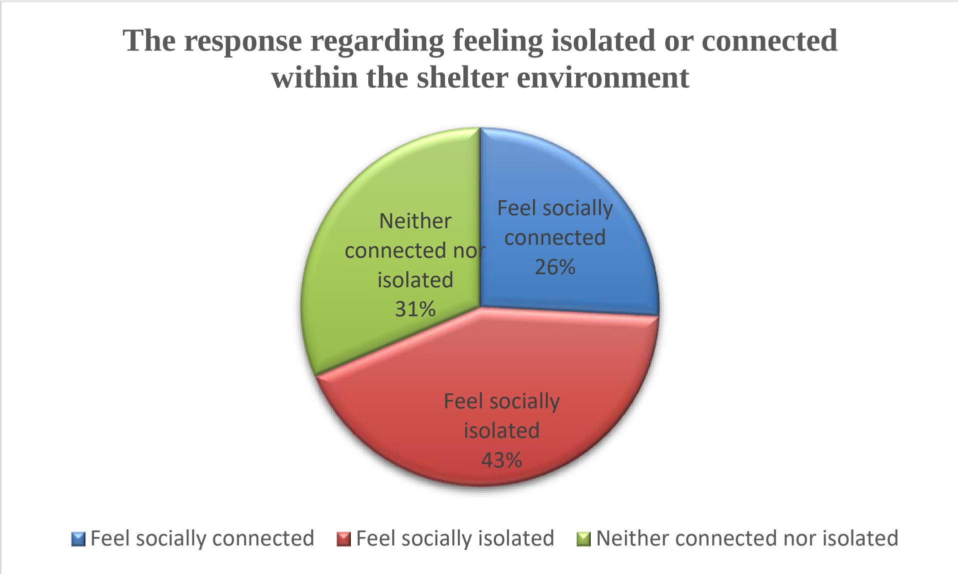


Figure 37: A chart presenting the response regarding feeling isolated or connected within the shelter environment.
Source: Created by the Author

- **The existence of social and cultural places within the shelter environment**

Only 399 respondents provided answers regarding the existence of social places that allow social activities and cultural practices, like: play areas for children, and places for prayer and religious practices. The results are as follows:

Only 93 persons, 23% of respondents indicated that their shelter environment includes social and cultural spaces. This type of space plays a crucial role in providing a better sense of community, improved social interaction, and overall satisfaction. A significant majority of respondents 306, about (77%) reported the absence of such social and cultural spaces.

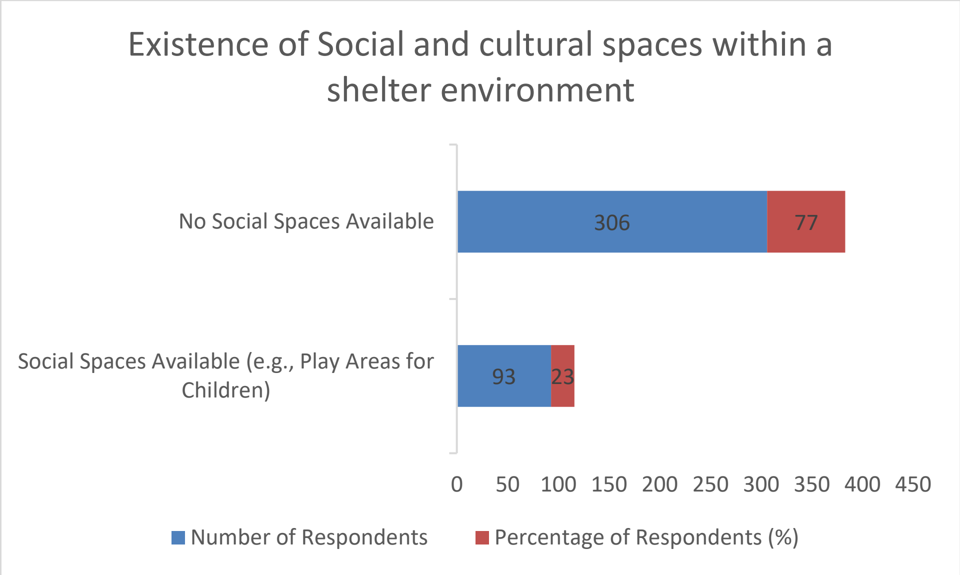


Figure 38: A chart presenting the Respondents' answers regarding the Availability of social spaces.

Source: Created by the Author

4.3.5 Discussion and Recommendation

The survey findings highlight numerous challenges and discomforts experienced by respondents living in temporary shelters, particularly concerning thermal comfort, noise levels, availability of social and recreational spaces, and shelter provision process satisfaction.

Thermal Comfort and Acoustic Issues: Most of the respondents, the majority of them, showed high thermal discomfort, with 55% feeling high heat in summer and 37.5% experiencing heating during winter, therefore presenting clear inadequacy related to insulation and ventilation within shelters. Moreover, noise disturbance is also highly reported throughout the day, with over 90% reporting high or very high levels during afternoon and evening periods. This would seem to show that the shelter design failed to provide adequate protection from thermal and acoustic comfort.

Shelter Facilities and Conditions: Regarding the facilities available like kitchen facilities, bathrooms, and laundry, 82% who lived in shelter and prefabricated shelters had reported their inadequacy which negatively affects daily life and basic comfort. In addition, privacy, sanitation, and shared spaces were also major concerns, with respondents expressing dissatisfaction. Only a small number found the facilities comfortable, mainly because they were in more permanent shelters.

Social Spaces and Connectivity: The survey also showed the lack of adequate social spaces within the shelter environment; 77% reported that there were no social places, such as playgrounds, for their children. Also, 43% of the respondents indicated that they felt socially isolated in their shelters, which underlines a significant gap in the design of shared living spaces that encourage communication and develop a sense of community.

Satisfaction with Shelter Provision Timing: 76.5% of the respondents were dissatisfied with the time it took to be provided with shelter after being displaced. This is an indication of inefficiency in the process of shelter allocation, which, if improved, may reduce stress and uncertainty significantly among the displaced. Only a small group of 6.3% expressed satisfaction with the shelter provision process.

Demographic and Shelter Type Diversity:

The survey included respondents from various age groups and nationalities, illustrating the diversity of needs among shelter occupants. Younger people, families, and the elderly have different needs such as education, healthcare, and accessible facilities. The types of shelters ranged from emergency tents to more stable prefabricated and semi-permanent housing, with a notable transfer from temporary to more permanent solutions as resources allowed.

The overall results of this survey, therefore, show a high degree of discomfort and dissatisfaction among shelter occupants in several important dimensions: thermal and acoustic comfort, social space, privacy, and timing of shelter provision. This points to the need for a more inclusive approach to shelter design that takes into consideration the thermal, social, cultural, and practical issues of diverse occupants. Improvement in insulation, sufficiency of social and recreational spaces, optimization of shelter allocation time, and ability of the shelter solution to serve various demographic needs are very important to improve the quality of life for the displaced people.

These insights are the basis for improving shelter solutions, which are functional not only in emergency contexts but also ensure the social and cultural well-being of occupants during extended situations. Such addressing of these key areas plays a significant role in the alleviation of the stress and discomfort that refugees face and contributes to their overall resilience and quality of life.

4.4 ENVIRONMENTAL IMPACT ASSESSMENT (LCA)

4.4.1 Results and Discussion

See Appendix C for hand calculation details

The results of the LCA Assessment of the shelters are as follows:

*Mahama Durable Shelter:

- GWP: 2887.06 kg CO_2e
- EE: 18021.25 MJ
- Lifespan: 10 years
- Area: 34.6 m^2
- GWP per year per square meter: 8.34 kg $CO_2e/Year/m^2$
- EE per year per square meter: 52.08 MJ

*Eco-Dome:

- GWP: 2008.42 kg CO_2e
- EE: 29282.15MJ
- Lifespan: 30 years
- Area: 37.16 m^2
- GWP per year per square meter: 1.80 kg $CO_2e/Year/m^2$
- EE per year per square meter:26.26 MJ

*Tuareg Tent:

- GWP: 1331.71 kg CO_2e
- EE: 6191.38MJ
- Lifespan: 2 years
- Area: 49 m^2
- GWP per year per square meter: 13.58 kg $CO_2e/Year/m^2$
- EE per year per square meter: 63.17MJ

*IKEA Better Shelter:

- GWP: 586.44 kg CO_2e
- EE: 9102.5 MJ
- Lifespan: 1.5 years
- Area: 17.5 m^2
- GWP per year per square meter: 22.34 kg CO_2e/Year/m^2
- EE per year per square meter:346.76MJ

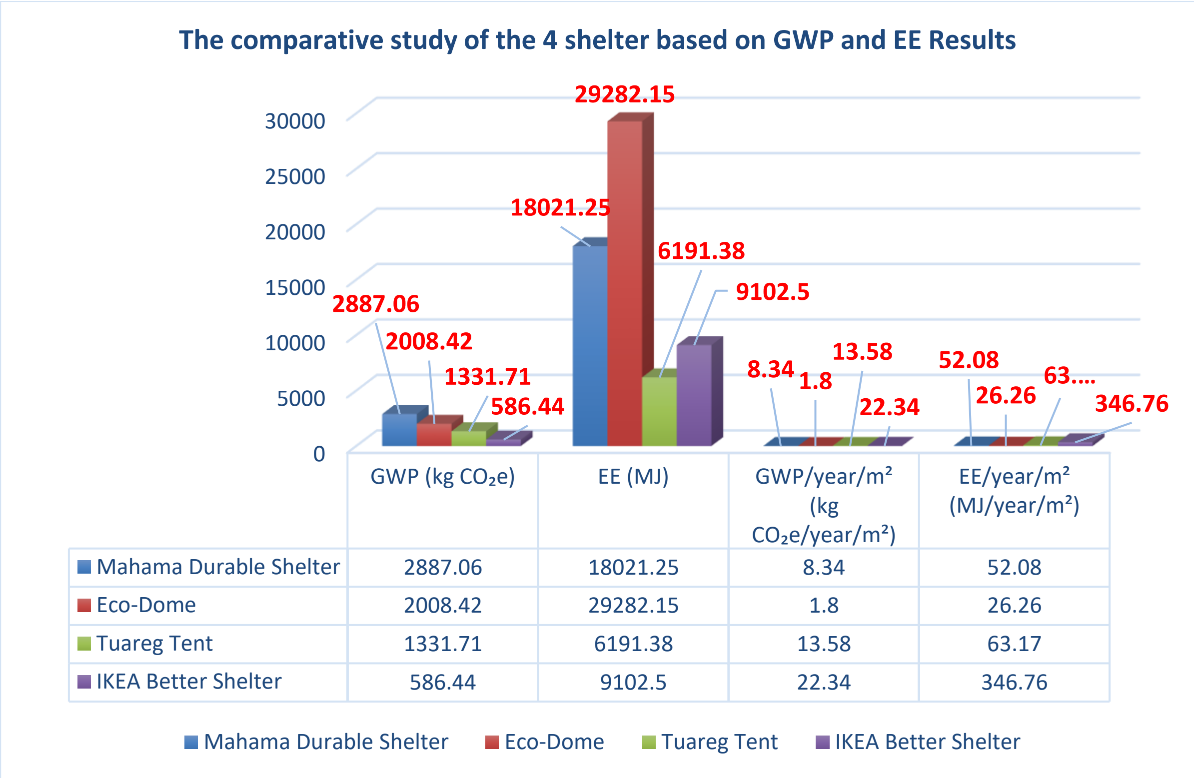


Figure 39: A summary of the environmental impact (GWP and EE) results, created by the Author.

Discussion

The environmental impact of the 4 shelters, including IKEA Better Shelter, Tuareg Tent, Eco-Dome, and Mahama Durable Shelter is assessed based on the Life Cycle Assessment (LCA) method. This study is divided into two parts, first, the results are gathered by calculating the Global warming potential (from cradle to site, which means cradle to gate+ transportation to the site) and the embodied energy (from cradle to gate) of the different materials used in the shelters. The second part presents a comparative study of the GWP or the EE per lifespan per area, this measurement metric according to UNHCR enables a fair comparison and sustainable assessment between different types of shelters including emergency and transitional shelters. [74]. Each shelter has different characteristics, including materials and construction techniques, lifespan, usage locations, and conditions.

1. **The IKEA Better Shelter** is made of a lightweight steel frame and polypropylene plastic panels, improved by a photovoltaic (PV) system for minimal energy requirements. Its modular construction technique (kit of parts) with a small area and short lifespan ensures the shelter's rapid deployment and assembly.

A. Materials impact:

The materials' total embodied energy (EE) is 9,102.5 MJ, with plastic panels contributing the most at 6,205 MJ, followed by steel frames at 1,350 MJ. These materials: steel and plastic also formed the major emissions in terms of the total Global Warming Potential (586.44 kgCO_2e per shelter), with about 381.65 kg of plastic panels CO_2e, and about 89.55 kg of CO_2e of steel frame. Other materials like aluminum and glass contribute less to both EE and GWP compared to plastic and steel but still add to the overall effect. See the figures below.

- The total GWP of the shelter from manufacture to site of employment is CO2e.

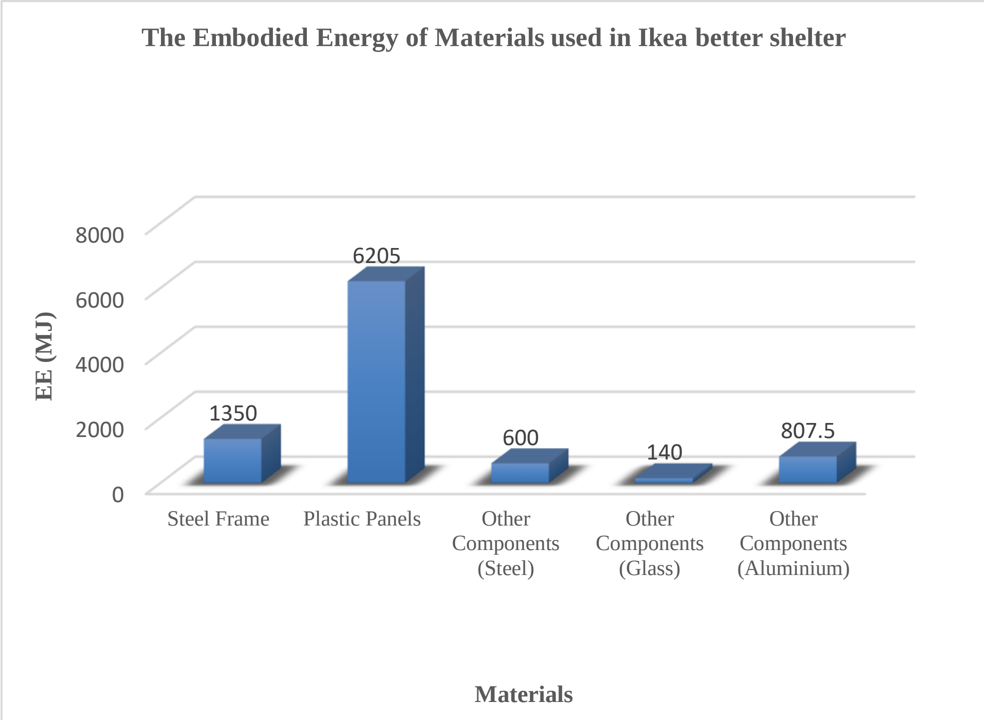


Figure 40: Ikea better shelter materials 'Embodied Energy calculation results (from cradle to Gate). Source: created by the Author.

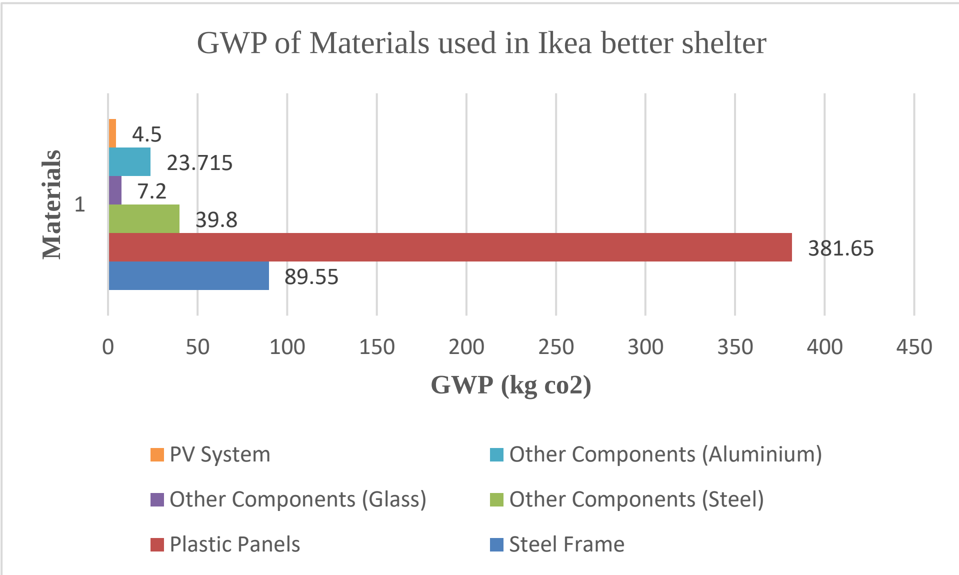


Figure 41: Ikea better shelter materials 'GWP calculation results (from cradle to Gate). Source: Created by the Author.

Findings: Plastic and steel materials which are usually used in shelter constructions have a high embodied energy (EE) and global warming potential (GWP).

Key-Insight:

Replace them with more sustainable materials that have lower EE and GWP, such as recycled plastics, natural fibers, or renewable materials (bamboo or timber).

B. Transportation Impact

The transport phase adds 40.04 kg of CO_2 to the GWP of the shelter. This is mainly due to sea emissions of about 28.29 kg of CO_2, which form about 70% of the total transportation emissions, as the distance between the two countries is assumed equal to 8,843.3 km. In comparison, the trucking phase contributes about 11.75 kg of CO_2 for the same package weight, forming about 30% of the total transportation emissions. While transportation emissions are smaller than those from the materials production phase, they still add to the overall impact due to the shelter's international transportation emissions. The table below presents a summary of the transport emissions phase:

Transport Mode	Route	Distance (km)	EF (kg CO_2/ton-km)	Weight (tons)	Emissions (kg)
Sea Transport	Sweden to Jordan	8843.3 km	0.02	0.16	28.29
Truck Transport	within Sweden and Jordan	496 km + 422 km	0.08	0.16	11.75
Total	-	-	-	0.16	40.04

Table 8: summary of the transport emission phase (from Gate to site) created by the Author.

Findings: international transportation affects the shelter's overall GWP, especially for long-distance routes.

Key insight: Localizing production or manufacturing closer to the deployment site, in addition to using locally available materials, could minimize transportation emissions.

C. The overall impact compared to the other shelter

Based on the comparative study of the GWP and EE of the 4 shelters using the metric that considers the life span and area, it's found that the Ikea Better Shelter has the highest environmental impact among the 4 shelters assessed. In terms of both Global Warming Potential (22.34 kg CO_2/year/m²) and EE (346.76 MJ/year/m²) when considering its short lifespan of 1.5 years and smaller area (17.5 m²).

Unfortunately, the Shelter features increased its environmental impact, especially its short-term use, small area, and material selection.

2. **The eco-dome shelter** is made of earth-filled polypropylene sandbags stabilized

with barbed wire and plaster. This construction creates a robust and sustainable structure that can last over 30 years, in addition to its resistance to high seismic and integrated passive climate control features.

A. Materials impact:

The materials used in the shelter produce a total global warming potential (GWP) of 1,965.06 kg CO_2 and an embodied energy (EE) of 29,282.15 MJ. Polypropylene sandbags form the highest embodied energy (18,104 MJ) and critical GWP (1,113.52 kg CO_2), reflecting the impact of the manufacturing process of the synthesized polymers and plastics. Followed by Barbed wire (galvanized steel) which Contributes 549.34 kg CO_2 (GWP) and 8,470 MJ (EE) mainly due to the high energy needed for steel production. On the other hand, Sand has a low environmental impact of about: 156.60 kg of CO_2(GWP), and 1,812.15MJ (EE) due to its availability and minimal processing requirements. Cement-based plaster has about 145.6 kg CO_2(GWP) and 896 MJ(EE), mainly because of its small quantity (15% cement mixed with 85% sand or earth).

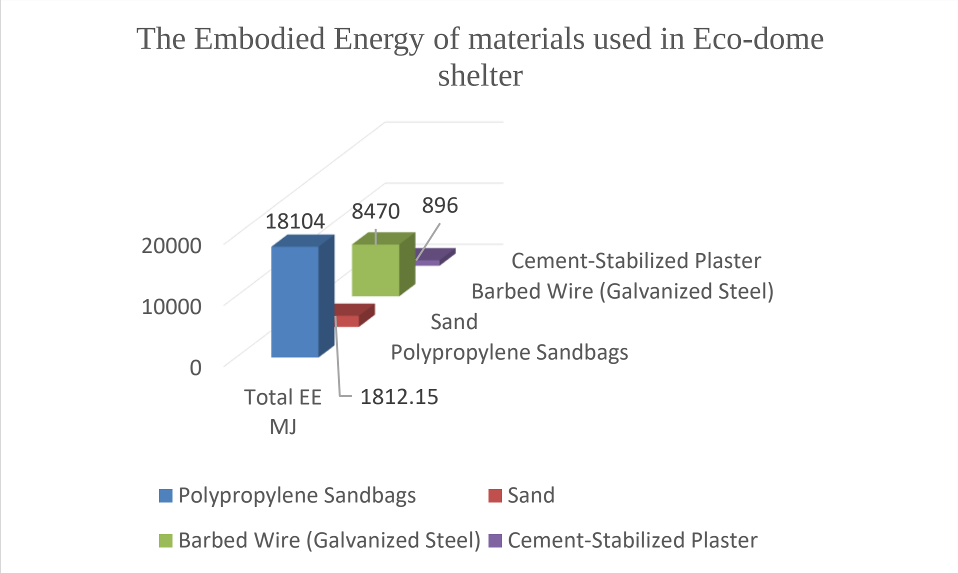


Figure 42: Eco-dome shelter materials 'EE calculation results created by the Author.

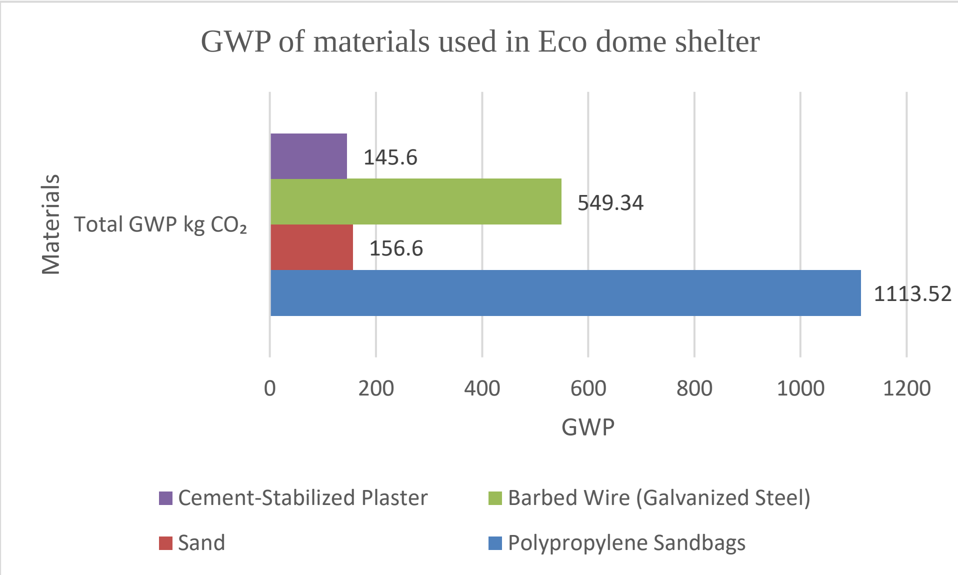


Figure 43: Eco-dome shelter materials 'GWP calculation result created by the Author.

Key- Insight:

-The use of sand as a locally available material ensures a low environmental impact

-The mixed approach of 15% cement with 85% earth (or sand) helps to reduce the cement's environmental impact

- The use of high-impact materials like: polypropylene and steel together with local, biodegradable, or renewable materials, reducing their effect on the environment.

B. Transportation Impact

The Total transport emissions are found equal to 43.36 kg of CO_2. Polypropylene sandbags are assumed transported about 1,219 km, forming about 24.18 kg of CO_2 e of the total transportation emissions. Followed by Barbed wire (steel) which transported about 859 km, adding 16.49 kg of CO_2 e. On the other hand, Cement which transported 210 km, contributed 2.69 kg of CO_2 e. The Sand caused no emissions since it is locally sourced.

Material	GWP transportation
Polypropylene Sandbags	24.18
Sand	0
Barbed Wire (Galvanized Steel)	16.49
Cement-Stabilized Plaster	2.69
Total	43.36kg CO_2

Table 9: presents a summary of the life cycle assessment results created by the author.

Key-Insight:

Using local resources and materials like: sand collected from the site or materials manufactured near it reduces carbon emissions from transportation.

C. The overall impact compared to the other shelter

Based on the comparative study of the GWP and EE of the 4 shelters using the metric that considers the life span and area, it's found that the Eco-dome Shelter has the lowest environmental impact among the 4 shelters assessed. In terms of both Global Warming Potential (1.80 kg CO_2/year/m²) and EE (26.26 MJ/year/m²) when considering its long lifespan of 30 years and bigger area (37.16m²). This is mainly due to the use of locally sourced materials that make it the most sustainable option for long-term use in post-disaster or refugee situations.

3. The Tuareg Tent is constructed with cotton canvas, blended cloth, and bamboo poles. The structure is lightweight, simple to assemble, and well-suited for short-term needs in arid climates.

A. Materials Impact:

The materials used in the Tuareg tent present a total embodied energy (EE) equal to 6,191.38 MJ and a total global warming potential (GWP) of 1,206.23 kg CO_2, with Cotton canvas and blended fabric, forming the highest impact in terms of GWP and

EE alike, with Cotton canvas presenting 1,197 MJ (EE) and 676.82 kg CO_2e(GWP), while blended cloth: 4,189.5MJ(EE) and 430.29 kg CO_2e (GWP).

The other small emissions come from materials like: bamboo poles, which have the lowest EE (51.28 MJ) and GWP (10.26 kg CO_2e) for both dimensions (1.8 and 4 m), and other small parts including rivet pins and iron pegs together form 44.82 kg of CO_2e of the GWP and 675.6 MJ of the total material (embodied energy).

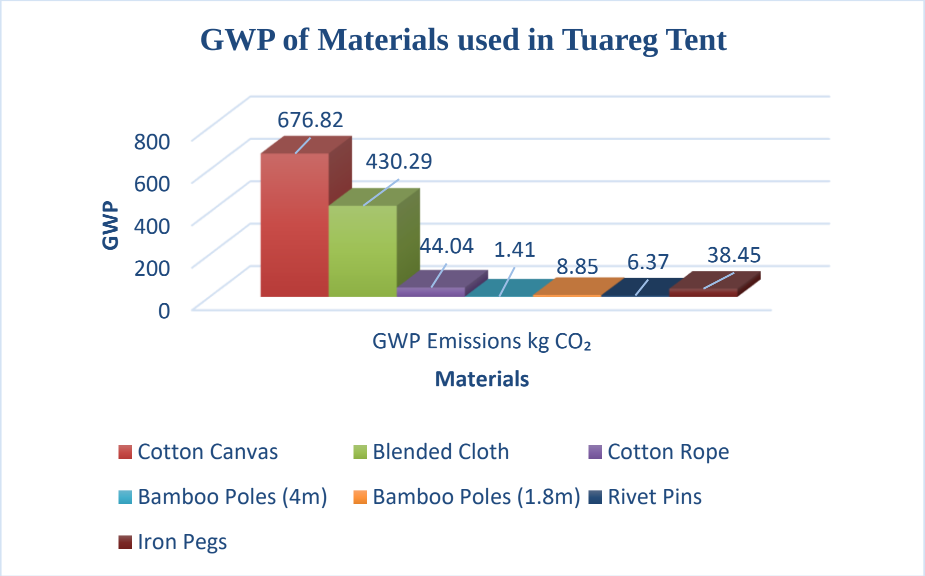


Figure 44: Tuareg Tent materials 'GWP calculation results created by the Author.

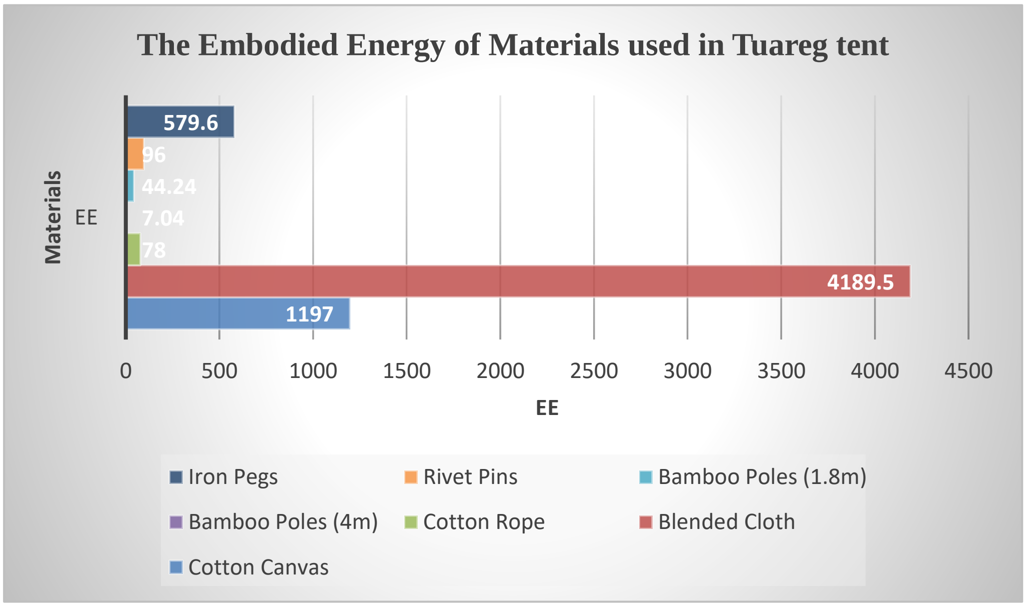


Figure 45: Tuareg Tent materials 'EE calculation results created by the Author.

Key Insights: The high GWP and EE come from produced fabrics like cotton canvas and blends (a polyester-cotton mix) and transport requirements, therefore, it is recommended to replace these energy-efficient fabrics with other locally sourced or recycled materials, such as hemp fabrics, which can significantly reduce the GWP and EE of shelters.

B. Transportation Impact

The transport phase adds 125.49 kg of CO2 to the total GWP of the shelter. This is mainly due to sea-high emissions due to the long distance of 16208 Km, which was found equal to 68.06 kg of CO_2, while the trucking transportation phase presents about 57.43 kg of CO_2 for a distance equal to 3418 Km. It can be observed that the total transportation emissions are smaller than those from the materials production phase. However, they still add to the overall impact due to the shelter's international transportation emissions. The table below presents a summary of the transportation emissions:

Transport Mode	Route	Distance (km)	Ec Factor (kg CO_2/ton-km)	Weight (tons)	Emissions (kgCO_2)
Sea Transport	Shanghai Port to Algiers Port	16,208	0.02	0.21003	68.06
Truck Transport	Beijing to Shanghai (within China) + Algiers to Tindouf (within Algeria)	1,427 + 1,991	0.08	0.21003	23.96 + 33.47
Total	-	-	-	0.21003	125.49

Table 10: A summary of the transportation emissions created by the author.

Key-Insight

This highlights the need for localizing manufacturing and using locally available material within the country and stops thinking about the global standard design that is manufactured in a country and then transported to another for employment, as it is not only climatic and culturally unsuitable as seen in the comparative study of 14 shelter sections but also has a bad environmental impact due to the transportation's high emissions as mentioned in the literature review.

C. The overall impact compared to the other shelter

Based on the comparative study of the GWP and EE of the 4 shelters using the metric that considers the life span and area, it's found that the Tuareg tent Shelter has the second highest environmental impact among the 4 shelters assessed. In terms of both Global Warming Potential (13.58 kg CO_2/year/m²) and EE (63.17 MJ/year/m²) when considering its short lifespan of 1.5 years and smaller area (17.5 m²).

Unfortunately, despite using natural materials, The Tuareg Tent's environmental impact is high, because of its short lifespan, small area, and materials transportation long distances.

3. **The Mahama Durable Shelter** is constructed of sun-dried mud bricks with cement plaster and corrugated iron sheets, in addition to the integration of local materials like soil, timber, and straw, which reduces the need for complex supply chains. Designed to withstand longer-term use.

A. Materials Impact:

The total embodied energy (EE) of the materials used in the Mahama durable shelter was 18021.25 MJ, with major contributions from components, including nails, corrugated galvanized iron (CGI), and bars, forming the highest EE among non-local materials (6090 MJ) for just a low weight about 174 kg. Followed by wood (gum trees) at about 4,875.35 MJ for 538 Kg of weight, mainly due to the chosen EE factor. Then quarry stones at about: 2358.4 MJ, this could be because of their high weight (14740Kg) and extraction method, followed by Cement at 2268MJ for just 405 Kg, then plastic at 1372.4MJ for a low weight of 18.8 Kg, coming at the end of the rank, the sand at 777.6MJ for 9600 Kg, followed by soil at 279.5MJ for 27950 Kg of weight.

The total Global Heating Potential (GWP) of the materials is 2,807.56 kg CO_2e, with quarry contributing the most due to its high volume (1,164.46 kg CO_2) and wood gum (141.49 kg CO_2e) and steel due to its content (346.26 kg of CO_2e). Also, make important contributions. Local materials, like clay and sand, have very little influence.

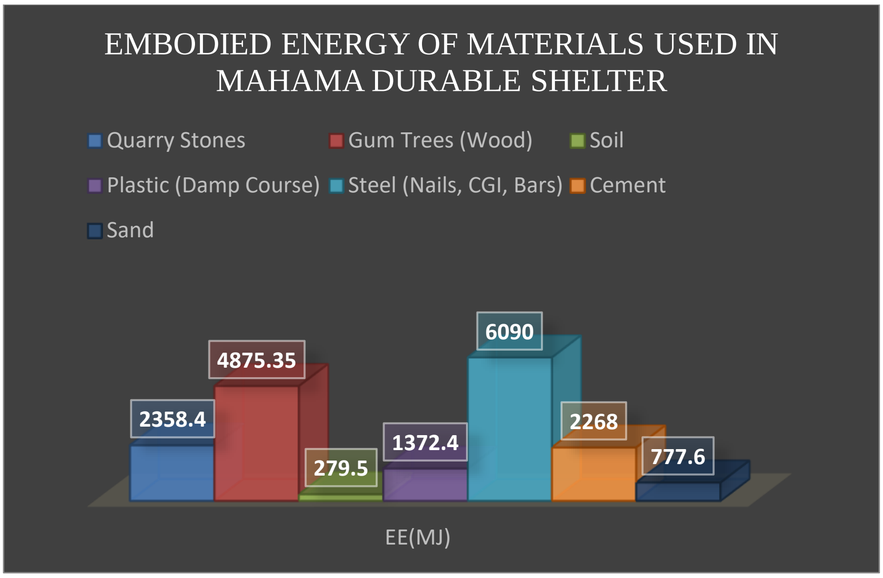


Figure 46: the calculation results of the Embodied energy of materials used in the Mahama shelter created by the author.

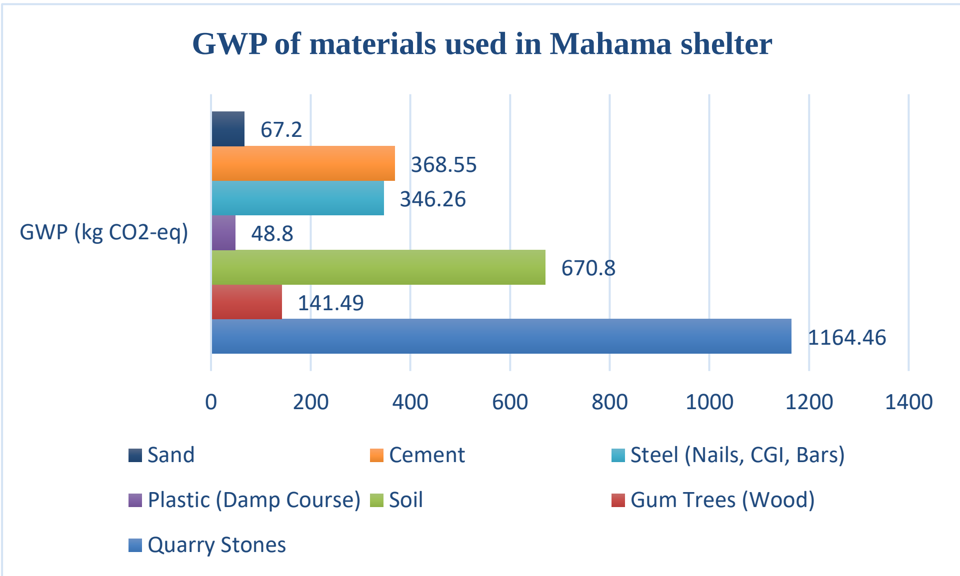


Figure 47: the results of GWP calculation of materials used in Mahama shelter.

Source: created by the author.

Findings: Steel presents the highest embodied energy despite its small quantity due to its energy-intensive production process, meanwhile sand, despite its large quantity, has a much lower embodied energy because it requires minimal processing.

Key-Insight: Encouraging local renewable resources, for example, timber from managed forests, can increase sustainable shelter

B. Transportation Impact

The transport phase adds 79.5 kg of CO2 e to the GWP of the shelter. Imported materials via international roads and sea, including plastic damp course and steel formed about 50.66 kg of CO_2e, While Local materials transported from factories within 350 km of the settlement caused about 36.68 kg CO2e from the total transportation emissions. This highlights the key insight gathered from the transportation phase analysis of the other 3 studied shelters, regarding the use of locally available materials on the site or from nearby manufacturers.

Material Type	Route	Distance (km)	Transport Mode	Weight (tons)	GWP (kg CO_2-eq)
Imported	Beijing to Shanghai Port	1,427	0.08 Road	0.1058	12.07
	Shanghai Port to Dar es Salaam Port	12,967.40	0.02Sea	0.1058	27.43
	Dar es Salaam Port to Mahama Settlement	1,319	0.08 Road	0.1058	11.16
Total Imported					50.66
Local	Local Factories to Mahama Settlement	350	0.08 Road	1.03	36.68
Total					79.5 kg CO_2-eq

Table 11: Summary of Transportation Gwp results created by the Author.

C. The overall impact compared to the other shelter

Based on the comparative study of the GWP and EE of the 4 shelters using the metric that considers the life span and area, it's found that the Mahama Shelter ranks as the second most sustainable option lowest after the Eco-dome shelter among the shelters assessed. In terms of both Global Warming Potential (8.34 kg CO_2/year/m²) and EE

(52 MJ/year/m²) when considering its moderate lifespan of 10 years and bigger area (34.06m²). This is mainly due to the use of locally sourced materials that make it the most sustainable option for long-term use in post-disaster or refugee situations.

Findings: Mahama durable shelters exhibit lower environmental impacts compared to short-term shelters, such as IKEA better shelters and Tuareg tents.

Key Insight: it is recommended to design shelters with longer lifespans to ensure low environmental impact.

4.4 CHAPTER MAIN FINDINGS AND KEY INSIGHTS

- **Strengths and shortcomings in existing Shelter Design**

Findings:

The evaluation of 14 global shelter prototypes highlighted significant exchange between environmental, socio-cultural, and economic dimensions. Prefabricated shelters, such as the IKEA Better Shelter, were found to excel in rapid deployment and structural resilience, making them suitable for emergencies. However, they showed limitations in terms of Affordability, cultural adaptability and environmental sustainability. In contrast, locally constructed shelters, like the Mahama Durable Shelter and Eco-Dome, demonstrated better socio-cultural suitability and lower environmental impact but required more time and resources for construction.

Discussion:

While prefabricated shelters are effective as emergency response due to their rapid deployment, they are often criticized for lacking cultural relevance and environmental sustainability. Their design focuses on short-term solutions, which may not be suitable for long-term stays, especially in regions with distinct cultural practices. In contrast, locally constructed shelters may take longer to assemble but offer improved cultural integration and a reduced environmental footprint. This highlights the importance of balancing rapid deployment with the socio-cultural and environmental needs of displaced populations.

Key Insight:

The design of sustainable shelters must balance efficiency, affordability, and cultural suitability with rapid deployment and environmental considerations.

- **Affordability of Shelter Prototypes**

Findings:

The affordability analysis showed that the Azraq T Shelter had a higher cost per lifespan per square meter, at 71.7$/year/m², mainly due to production and transportation expenses. In contrast, the Eco-dome Shelter emerged as the most cost-effective option, with a cost of 0.13$/year/m² and a 30-year lifespan.

Discussion:

While prefabricated shelters offer quick assembly and structural resilience, their economic feasibility is often limited by expensive production processes and long transportation routes. On the other hand, shelters constructed using local materials, such as the sandbag shelter, provide a more affordable solution. These shelters not only reduce transportation costs but also lower dependency on imported materials, making them more viable for large-scale use in regions with access to local resources.

Key Insight:

Building with local materials can significantly reduce costs while also minimizing transportation-related emissions. This makes locally constructed shelters a more affordable and sustainable solution for long-term use in disaster and refugee situations.

- **Socio-Cultural and User Satisfaction Insights**

Findings:

404 Survey responses revealed that many displaced populations find emergency shelters inadequate for habitation due to insufficient comfort, area inadequacy, lack of privacy, and the lack of social spaces within the shelter environment, in addition to the unsuitability of their basic and shared facilities.

Discussion:

The survey findings underscore the importance of socio-cultural considerations in shelter design, in addition to factors like: privacy, cultural relevance, and thermal comfort which are essential for the well-being and satisfaction of displaced individuals.

Key Insight:

Involving communities in the design process is crucial to ensure that shelters meet cultural and privacy needs. Such involvement not only improves user satisfaction but also enhances the functionality and long-term success of the shelter.

- **Environmental Performance of Shelter Prototypes**

Findings:

The LCA analysis underscores the importance of selecting materials and construction techniques that align with the intended use and lifespan of each shelter type. Short-term emergency shelters like the IKEA Better Shelter and Tuareg Tent prioritize rapid deployment but have a higher environmental impact when assessed over time, due to their energy-intensive manufacturing and transportation processes. In contrast, shelters with longer lifespans, including the Eco-Dome and Mahama Durable Shelter, which employ earth-based or locally sourced materials, exhibit lower annual environmental impacts.

Discussion:

The results of the LCA indicate that while prefabricated shelters provide advantages like structural resilience and quick deployment, they also have a high environmental impact. mainly due to their embodied energy and carbon emissions linked to their production and transportation which makes them less sustainable over time. In contrast, shelters constructed from local materials, such as the Eco-dome and Mahama Durable Shelter, are more eco-friendly because they minimize transportation emissions and utilize local, renewable resources.

Key Insight:

To reduce the environmental footprint of shelters, it is essential to use renewable and locally sourced materials.

Application of the findings for creating a sustainable design framework

The findings highlight the need for a balanced approach to shelter design. While quick deployment is critical in emergencies, it can lead to issues with user satisfaction and environmental impact. Shelters that mix prefabricated elements with local materials can improve both speed and cultural/environmental fit. A combination of these features can offer a more sustainable and appropriate solution for displaced populations.

Key Insight:

A hybrid approach to shelter design that merges modular prefabricated components with locally sourced materials and adaptations presents the greatest opportunity for achieving a balance between efficiency, affordability, cultural significance, and environmental sustainability.

Chapter 5: Design Framework Development

This chapter shows how the findings from the research phases have informed the development of a design framework for guiding the creation of more sustainable shelters in future emergencies. It highlights the integration of key insights gathered from literature review analysis, existing shelter evaluation, survey responses analysis, affordability calculation, and environmental impact assessments into a practical, flexible, and sustainable framework that adapts to diverse disaster contexts and ensures user satisfaction.

5.1 INTRODUCTION

The findings from the literature review analysis and the research phases' results show that the existing shelter design often lacks adaptability, sustainability, and cultural suitability, leading to inefficiencies and user dissatisfaction. Addressing these gaps requires a comprehensive framework, that integrates insights from the results and findings included in Chapter 4, aiming not only to serve immediate needs but also to allow transitions effectively into long-term housing solutions over time.

This chapter explains the connection between the research findings and the proposed design framework, demonstrating how a systematic approach to assessing existing shelter solutions informed the creation of a more effective sustainable model. By considering modularity, sustainability, and user-centric principles, the proposed framework aims to improve shelter issues previously discussed in other chapters by addressing the sustainability aspects combined with long-term needs in the shelter design.

5.1.1 the relation between the findings and the framework development

- <u>Prolonged Use of Emergency Shelters Beyond Their Intended Lifespan highlights the need for developing emergency shelter design that serves immediate needs and allows the transitions to long-term needs.</u>

The literature review reveals that in most cases, short-term shelters are used for extended periods beyond their intended lifespan, a fact also reported by survey respondents. These results highlight the need for shelter solutions that can bridge the time gap between short-term needs (Emergency shelter) and long-term requirements (Transitional and core shelter).

- The inadequacy of Standardized Shelters for Local Needs highlights the need for adaptable shelters across different regions and contexts.

  Based on the literature review and the comparative study findings, which discussed the inadequacy of standardized global shelters for addressing the local cultural and climate needs, as well as their high cost of transportation, which usually results in more costs and user dissatisfaction and discomfort, all of these issues highlight the necessity of considering climatic and culturally specific needs in shelter designs.

- The users' dissatisfaction regarding privacy and the sense of safety in the shelter environment highlights the importance of creating more private spaces and zoning systems within the shelter environment.

  The Survey indicates unsatisfactory results regarding privacy and the sense of safety within the shelter which underline the need for the creation of a policy requiring movable partitions or creating different zones within shelter units and settlements alike.

- Importance of Socio-cultural Integration in Shelter Design that ensures user satisfaction

Based on the literature review, the integration of socio-cultural factors in shelter design plays a crucial role in ensuring the acceptability and functionality of temporary shelters. Survey findings highlighted the necessity of communal spaces and culturally appropriate facilities that allow for religious practices, in addition to spaces that allow for integration into the current community, especially in the refugees' cases. This can be achieved by creating places where people can learn about the culture (food, language, and traditions) of the host country.

- Thermal and Acoustic Comfort as Essential Design Aspects

Thermal and acoustic comfort are essential factors in shelter design, that affect daily well-being. However, Many existing shelter solutions do not adequately address these needs, mainly due to inadequate insulation, poor ventilation, and limited soundproofing. This highlights the importance of improving insulation, ventilation, and soundproofing in shelters to ensure user comfort and livability.

- The use of local, recycled, or renewable materials in Shelter Designs reduces their costs and environmental impact.

The environmental impact of the 4 shelters was assessed using the Life Cycle Assessment (LCA) method. This analysis encourages the selection of regionally sourced, low-impact materials. At the same time, it highlights the importance of selecting materials and construction techniques that align with the intended use and lifespan of each shelter type. At the same time, the literature review discusses the issues with recycling of this type of units and settlements, which underlines the need to set Strategies for minimizing environmental impact (e.g., using recycled materials, the possibility of recycling the units, and adopting circular economy principles).

- Considering Gender-specific needs is essential in shelter design

The results of the survey highlight the importance of considering gender-specific needs and preferences in shelter design which plays a crucial role in addressing cultural appropriateness and ensuring user satisfaction. For example: creating spaces for women-only or family-specific use, such as private or gender-separate sanitary facilities, and child care zones.

- Offer a shelter unit to one family without sharing with other families is essential to ensure users' comfort and satisfaction.

The survey's results indicate that most of the respondents reported feeling unsafe and dissatisfied with privacy, sanitary conditions, and the area's adequacy, mainly due to sharing living spaces with strangers, especially in the case of families living together, which leads to discomfort and lack of privacy, particularly with women expressing concerns about their safety and the challenges of managing household tasks in a shared and crowded space. The Lack of separate spaces in the shelters where they could relax and practice freely their daily activities caused social stress and mental health issues.

5.1.2 General Framework Design Principles

Based on the above theories and findings, the following principles are suggested to guide the design of more sustainable emergency shelters:

a) **Durability, flexibility, and Adaptability**:

Shelters must be designed to accommodate prolonged use, ensuring structural integrity and adaptability to changing user needs over time. The research findings show that emergency shelters like tents are effective for rapid deployment but lack durability and adaptability for long-term use while transitional and core shelters are more durable and adaptable solutions, however, they need more effort and time for assembly, and at the same time, they offer limited flexibility once constructed.

Principle: Combine rapid deployment principles with durability and adaptability for long-term use.

For example: design rapid deployment units to serve immediate residential functions, which can later be extended with semi-permanent components for kitchens, sanitation, or storage. These additional structures can be attached or placed nearby, enabling the shelter to evolve across different phases by integrating modular components. See the figure below.

✓ Framework Contribution:

- Incorporate modular designs to allow shelters to evolve from emergency to transitional phase (shelter design that can be easily adapted and expanded to meet changing needs and circumstances).
- Consider modular construction that allows for easy disassembly, relocation, and reconfiguration in the initial phase. While incorporating features that can be upgraded or modified over time to improve durability and comfort for example:

  Prefabricated components are proposed for initial deployment, with upgrades like the possibility of adding materials that ensure insulated walls, local materials, and other units that can serve as (additional rooms, toilets, kitchens, and storage...) over time to meet long-term needs.
- Allow flexibility to meet the changing needs of residents by ensuring adequate spacing between shelter units within the settlement to allow for future expansions or additions, and to allow flexibility to meet the changing needs of residents

✓ Implementation:

- Start with prefabricated units for emergency use (as pre-design), considering the use of lightweight prefabricated components to allow untrained individuals to assemble or dismantle the structure without heavy machinery based on the Assembly Instructions guide.

- Upgrade with modular panels and local materials for transitional phases.
- Ensure scalability to accommodate varying population sizes.
- Enable users to improve their shelter incrementally with locally sourced materials to enhance durability, thermal comfort, and functionality.

b) **Cultural and Social Relevance**:

Designs should integrate local cultural, social, and lifestyle requirements to ensure user acceptance and satisfaction. Cultural acceptance increases when shelters align with local practices and provide adequate privacy and communal spaces in the shelter environment, as well as community integration in the construction process.

Principle: Ensure cultural relevance and community integration.

- ✓ Framework Contribution:
    - Modular layouts offer privacy and communal spaces tailored to cultural preferences.
    - Incorporate traditional materials and construction techniques to enhance acceptance.
    - The creation of Gender-specific spaces
    - Provide spaces for social interaction, cultural expression, and community building within the settlement.
    - Ensure respect for local customs and values.
    - Involve local communities in all phases of the design, construction, and maintenance of shelters that ensure their satisfaction.
- ✓ Implementation:
    - Modular layouts include private and communal spaces based on cultural needs.
    - Incorporate traditional materials and techniques to improve acceptance.

c) **Climatic Suitability:**

Shelters must incorporate adequate thermal insulation, ventilation, and resistance to environmental hazards to provide comfort and safety in diverse climates. Shelters designed for specific climatic conditions (e.g., thick walls for cold climates, and open layouts for hot climates) provide better user comfort.

Principle: adapt designs to specific geographic and climatic conditions.

- ✓ Framework Contribution:
  - Integrate climate-specific adaptations such as reflective roofs for hot regions and insulated panels for cold climates.
  - Modular roof components allow for flexibility based on geographic needs.
- ✓ Implementation:
  - Provide natural ventilation and shading for hot regions.
  - Use insulated panels or thick walls for cold climates.
  - Adapt roofs to include reflective surfaces or insulation layers as needed.

d) **Communal Spaces and Accessible Facilities:**

Incorporating communal spaces and culturally appropriate facilities in the shelter settlement enhances social cohesion and improves the mental well-being and comfort of displaced populations.

- ✓ Framework Contribution:
  - Modular rooms that can be rearranged to support individual living quarters in shelters, and religious rituals, or group activities must be included in the settlement.
  - Ensure adequate living space, privacy, and access to essential amenities (cooking, bathing, laundry).
  - Create inclusive and accessible designs for people with disabilities.

e) **Enhanced Thermal and Acoustic Comfort:**

Effective insulation, ventilation, and soundproofing measures are essential for daily well-being and user satisfaction within the shelter environment as shown in the survey results.

- ✓ Framework Contribution:
    - Utilize locally available materials with high thermal performance, such as compressed earth blocks, sand-filled walls, or lightweight insulating panels for comfort in extreme climates.
    - Incorporate passive cooling techniques, such as cross-ventilation, operable windows, wind scoops, or stack ventilation, to regulate airflow and reduce reliance on mechanical systems.
    - Design shelters with thermal zones that optimize living spaces based on daily and seasonal temperature variations, such as positioning sleeping areas in cooler zones.
    - Use construction methods that reduce noise transmission, like the use of double-layered walls, sound-absorbing panels, or acoustic insulation between partitions.
    - Position communal and noisy spaces away from sleeping and private zones to minimize disturbances.

f) **Low Environmental impact:**

Employing locally sourced, renewable, or recycled materials reduces the environmental impact and costs. Locally sourced materials, like sandbags and bamboo, reduce transportation costs and embodied energy, whereas prefabricated shelters often have higher environmental impacts due to their transportation and high-emission materials like: steel.

Principle: Balance prefabrication for speed with local materials for sustainability.

- ✓ Framework Contribution:
    - Encourage hybrid approaches combining prefabricated components for speed and local materials for sustainability.

- Materials such as bamboo, timber for framing, and sandbags for insulation are prioritized to align with environmental and economic goals.

✓ Implementation:

- Use prefabricated wooden panels, or timber frames with locally sourced walls (e.g., sandbags or bamboo).
- Integrate renewable or recyclable materials to reduce environmental impact, like the use of Soda crates for foundations or to ensure elevated floors, especially in flood areas.

Efficient Use of Resources and Affordability: Design solutions should optimize the use of materials and energy, ensuring sustainability and minimizing cost.

Principle: Maximize cost-effectiveness without compromising quality.

✓ Implementation:

- Emergency shelters prioritize affordability for rapid deployment.
- Transitional and core shelters use cost-efficient upgrades and durable materials.

This framework can act as a basis for creating shelters that meet urgent needs while promoting long-term sustainability, enhancing the living conditions for displaced communities, and reducing environmental and socio-economic effects.

5.2 SPECIFIC CONSIDERATIONS OF THE DESIGN FRAMEWORK

1. Demographic and gender Specific Shelters

Based on the shelter unit scale

✓ **Family Units shelter (Family of three to four people):** Show a transition from a small, single-room emergency shelter to a semi-permanent shelter with defined spaces like sleeping, cooking, and a shared living area.

- Layouts are designed for shared living, prioritizing family bonding, privacy, and a central sleeping/living area.
- Include basic partitions for bedrooms, upgradeable to permanent walls.

Details:

Phase 1: Emergency Shelter

- Materials: Lightweight, temporary materials like tensile fabric or tarpaulin supported by timber or bamboo for roofing, and prefabricated panels (Timber, bamboo matting, or treated plywood) for walls.
- Layout: One enclosed space (12-16 m^2) with a shared sleeping/living area. Basic ventilation is achieved using openable panels or vents and openings like windows and doors.
- Construction Method: Easy-to-assemble modular units using kit-based assembly with residents' participation.

Anchoring with screws or stakes for stability.

While keeping walls modular for future extensions.

Phase 2: Transitional and Core Shelter

- Materials: Retain initial walls and add locally sourced wood or treated bamboo partitions for sleeping zones. Upgrade tensile fabric roof with corrugated sheets and thermal liners for insulation. Add more spaces like:

Kitchen Area: Bamboo or metal frame with a small chimney for ventilation.

Toilet: Prefabricated eco-friendly unit or locally built elevated latrine.

- Layout:

Separate sleeping areas for parents and children using partitions (e.g., 2-3 m^2/person).

A corner dedicated to cooking, ventilated via a mesh window or exhaust pipe.

Central communal space for family bonding and dining.

- Construction Method:

Extend the base structure using modular units.

Introduce plaster or fabric liners on walls for thermal insulation.

Add verandas or overhangs for passive cooling and shaded outdoor space.

- ✓ **Shelters for Girls Living Together:** Highlight privacy and security, with women-shared spaces for cooking and socializing while ensuring safe, individual sleeping areas.

High-security features such as reinforced doors and lockable compartments.

Additional privacy within sleeping and sanitary areas.

Details

<u>Phase 1: Emergency Shelter</u>

Materials: Lightweight and temporary, like prefabricated panels with lockable fabric curtains for privacy, combined with a sturdy frame for security.

Layout: Open plan (10-12 m²) with sleeping pods or shared mats. A communal outdoor cooking area.

Construction Method: Quick-assembly kits with bolted joints for structural stability.

<u>Phase 2: Transitional and Core Shelter</u>

- Materials:

  Walls: Reinforced bamboo partitions for semi-private sleeping zones.

Roofing: Corrugated sheets with an inner layer of reflective foil insulation.

Kitchen: A dedicated indoor kitchen area with fire-resistant materials and ventilation.

- Layout: Partitioned sleeping areas (2-3 m²/person) for privacy. In addition to a communal kitchen with lockable storage and a dining/socializing space.

Construction Method: Extend the shelter with bamboo or wood-based modular units. Add secure fencing or gates to the perimeter for privacy and safety.

- ✓ **Men Living Together Shelters:** Focus on shared functionality, such as communal sleeping and cooking areas, while considering space efficiency and adaptability.

Open-plan layouts with shared facilities to foster communal living.

Details

<u>Phase 1: Emergency Shelter</u>

- Materials:

Walls: Bamboo or prefabricated panels with tarpaulin coverings.

Roofing: Tensile fabric or plastic sheeting.

- Layout: Open-plan layout (10-15 m²) with shared sleeping mats and an outdoor cooking area.
- Construction Method: Rapid deployment with simple anchoring methods like stakes. With the use of modular kits to allow future extensions.

Phase 2: Transitional and Core Shelter Shelter

- Materials: Walls: Corrugated metal or bamboo panels for partitioned sleeping areas.

Roofing: Corrugated sheets with thermal insulation liners.

Kitchen: Covered indoor space with a small exhaust fan or mesh-covered vent

- Layout: Semi-private sleeping areas (2-3 m² per person) with a shared central space for dining and socializing (6-8 m²). Outdoor latrine shared between units.
- Construction Method: Modular systems that can be reassembled or extended as needed. Raised structures prevent flooding Enhance the structure with raised flooring and insulated walls.

  Introduce passive cooling features like shaded overhangs or ventilated roofs.

2. Region-Specific Design

Climate-Responsive Shelters:

Hot Climates:

Use tensile structures or woven walls for ventilation.

Incorporate reflective roof materials to reduce heat absorption.

Cold Climates:

Thicker walls with sandbags or natural insulation materials.

Small windows to minimize heat loss.

Local Material Utilization:

Use sandbags, adobe, or bamboo in areas with resource availability.

Integrate tensile structures, such as rolled-up fabric roofs or canopies, to provide quick, weather-resistant coverage.

4. Implementation Phases

The framework outlines a phased approach to ensure shelters meet evolving needs:

Phase 1: Emergency Deployment

Focus: Rapid assembly and immediate relief.

Key Features:

Prefabricated lightweight shelters (e.g. tents, Exo Shelters, Ikea Better Shelter).

Lightweight and portable designs for quick transport and setup.

Assembly time: 2–6 hours.

Phase 2: Transitional and core shelter Adaptation

Focus: Enhancing stability and functionality.

Key Features:

Modular components like insulated walls and roofing.

Integration of local materials to improve durability and reduce costs. Expansion with communal and private spaces to meet long-term needs.

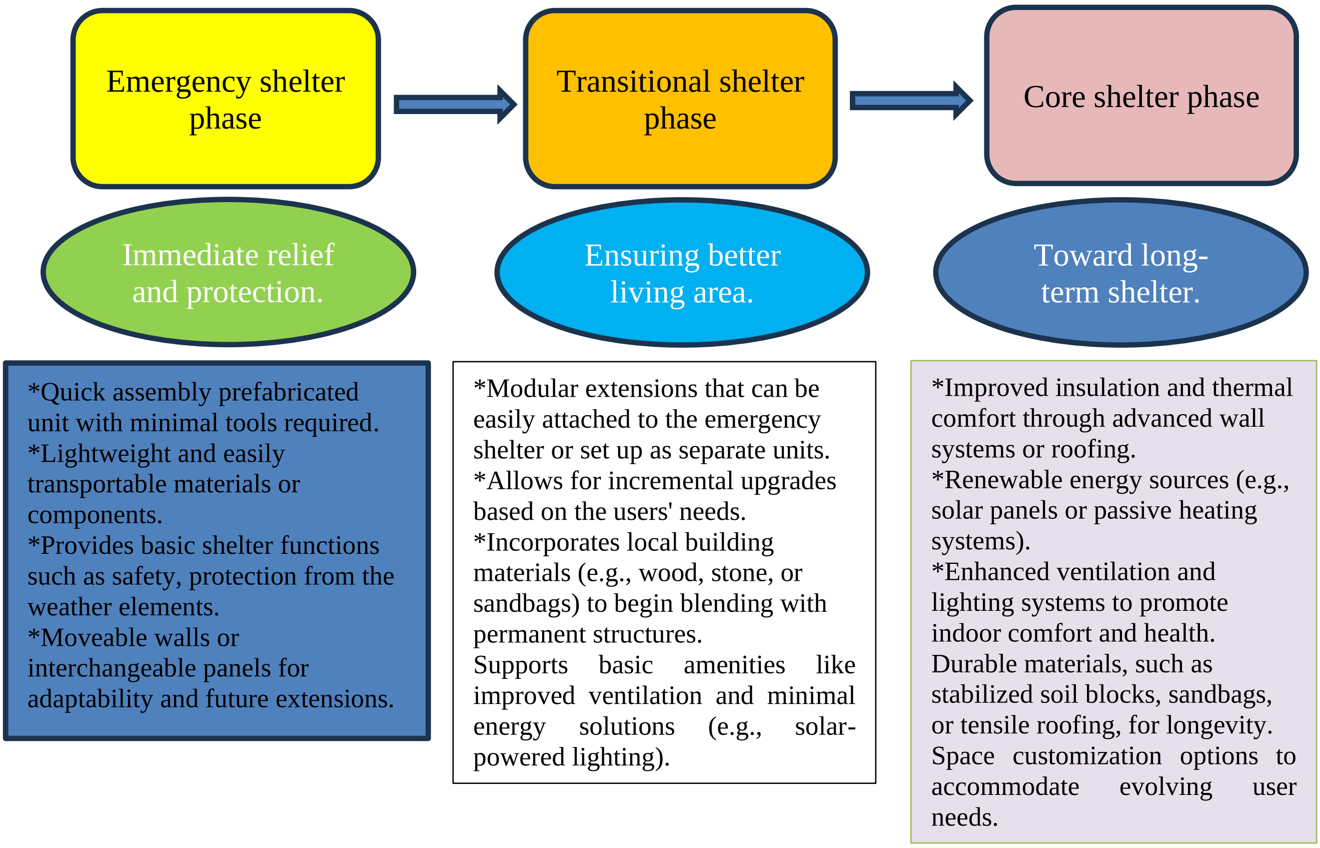


Figure 48A flowchart illustrates the progression from emergency to transitional to core phases.

Thermal Comfort: Use passive strategies such as:

Thick walls for thermal mass (stabilized soil, sandbags).

Ventilation systems like wind scoops or roof vents.

Shaded outdoor spaces for cooling during the day.

Lighting:

Install translucent roofing sections or small clerestory windows for natural light.

Solar panels with battery storage for nighttime lighting.

Water and Sanitation:

Incorporate water collection systems (e.g., rainwater harvesting) and shared access to latrines for transitional and core shelters.

Greywater recycling for small garden areas if space allows.

Adaptability:

Modular designs ensure flexibility to add, remove, or repurpose spaces as family sizes or needs change.

Use lightweight partitions that can be rearranged easily.

Cultural Relevance:

Design spaces respecting privacy, gender dynamics, and community living norms.

Include culturally familiar materials and forms where possible.

✓ **Material selection table**

The following table identifies various region-specific, locally available, sustainable, and/or recycled materials that can be used for shelter construction across different regions. These materials have been selected based on their availability, low cost, environmental sustainability, and ability to meet local needs and cultural norms. The aim is to highlight materials that are not only effective in providing shelter but also contribute to reducing environmental impact and promoting the use of local resources. The selection emphasizes materials that are familiar to local communities and have a lower carbon footprint compared to imported or industrially processed alternatives. The data is collected from different websites and papers regarding the locally available material in each region.

region	Locally Available Materials	Sustainable/Recycled Materials	Cultural Norms & Low-Cost Options
Sub-Saharan Africa	Mud bricks, thatch, straw, stone, clay	Recycled metal sheets, wood	Use of clay for plastering and straw roofing
North Africa	Adobe, limestone, palm fronds, mud	Recycled wood, natural fibers	Thick adobe walls for cooling in hot climates
Middle East	Earthbags, sand, clay bricks, palm leaves	Recycled plastic, reused wooden pallets	Use of earth-based materials for insulation
South Asia	Bamboo, thatch, mud bricks, coconut leaves	Recycled corrugated sheets, coir	Bamboo frames and coconut for local roofing
Southeast Asia	Coconut timber, bamboo, nipa palm, mud	Recycled wood and plastic sheets	Lightweight bamboo frames with palm roofing
East Asia	Timber, straw, clay tiles	Reclaimed timber, recycled papercrete	Wooden frames and clay tiles for cultural fit
Latin America	Timber, palm leaves, adobe, volcanic rock	Recycled plastic bottles, corrugated metal	Adobe bricks and palm for roofs
Pacific Islands	Coconut timber, pandanus leaves, coral rocks	Recycled fishing nets, wood scraps	Thatch and pandanus leaves for roofing
Arctic/Cold Regions	Ice, snow, stone, driftwood	Recycled wool, natural fibers	Igloos or stone shelters
Europe	Timber, stone, clay	Recycled bricks, straw bales	Stone walls and timber roofs in rural areas

Table 12 A table summarizes the sustainable and local materials available based on specific regions. Source: [122], [123], [124], [125], [126], [127], [128], [129], [130].

Suggested Combination of Traditional and Modern Materials:

A new generation of emergency shelter design may consider a mix of traditional and modern materials for better cultural fit and sustainability. Locally sourced materials combined with innovative, modern materials could offer greater adaptability, lower cost, and better durability. Examples of such combinations are as follows:

• Bamboo + Recycled Plastics or Geotextiles:

Because of its rapid growth, lightweight, and cultural relevance to so many areas, bamboo becomes quite feasible for framing, roofing, and wall components. Blending these bamboos with other, more modern recycled materials such as geotextiles or recycled plastics, the shelter will be able to become much more durable and waterproof while offering a greatly reduced waste factor and environmental impact.

- Mudbrick or Earth + Solar Panels:

For the walls and insulation, traditional materials such as mudbrick or rammed earth can be used cheaply with very good thermal performance. Adding solar panels to their roofs for renewable energy will make the shelters more energy-efficient, thus providing lighting and possibly ventilation with the use of modern technology.

- Timber + Insulated Panels:

In most regions of Sub-Saharan Africa, timber is available for framing and structural elements. Traditional timber frames can be combined with insulated panels or earth-based plasters to enhance insulation and meet modern requirements. These panels can be sourced from recycled materials or natural fibers, ensuring the shelter remains energy-efficient while keeping construction costs low.

- Thatch + Tin Roofing:

Thatch is conventionally used as roofing material in some rural or peri-urban areas. In combination with either tin or corrugated iron sheets, thatched roofs can become more weather-resistant and also maintain the cultural perspective of the structure. The natural insulation provided by thatch is therefore supplemented by that of the overlaying tin or iron, ensuring enhanced weathering resistance and further longevity. Examples of such other natural materials and techniques include

- Two layers of fabric sandbags between The Sandwich Layer Concept: Two Layers of Fabric:

This can be achieved by using sandbags as the primary structural element in the walls with two layers of fabric between the sandbags odd kind of "sandwich" that combines old and new materials. For hot climates, this will combine the strength and insulation provided by the sandbags with the lightness, durability, and elasticity provided by the fabric. It is a practical way to improve shelter functionality. These fabric layers further allow for thermal regulation of the inside by a reduction in heat transfer, keeping the shelter cool in hot climes and warm in cooler climes. Besides, such a design resists moisture-water-resistant/waterproof fabrics that allow water not to penetrate the sandbags, erosion, and degrading them which are quite relevant for regions with high rainfall or damp conditions. Besides, durable fabrics such as geotextiles, recycled materials, or polypropylene reinforce the sandbag structure for improved stability and lifetime, preventing shifting or spilling. Further, cost-effectiveness and simplicity translate to the fact that the fabric sandwich is easy to implement; besides, fabrics can often be sourced locally or from recycled materials further reducing costs. Besides, it allows for easy assembly and disassembly because the layers of fabrics can be rolled out and easily placed between the sandbags, thus making it flexible and quite user-friendly. Some materials go excellently with this method and withstand harsh weather conditions, like geotextile fabrics, recycled textiles, and durable synthetic fabrics such as polypropylene and nylon. In brief, the fabric sandwich will be an environmental, cost-efficient, and adaptable strategy in the building of shelter to enhance thermal comfort, resistance to moisture, and structural stability through the usage of locally available or recycled materials to achieve sustainability and attend to various community needs during post-disasters or refugees within the hot arid region, say, Tindouf.

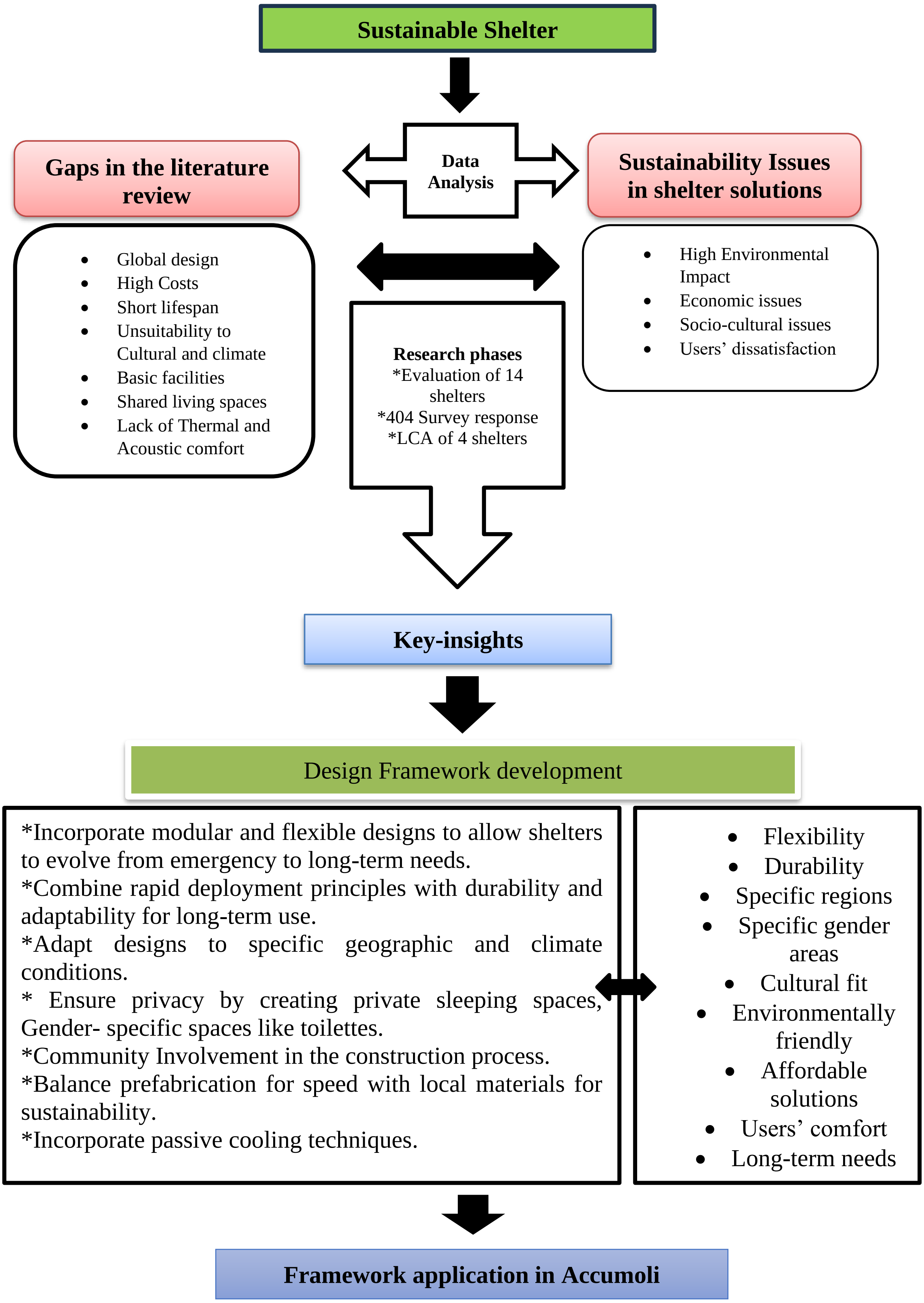


Figure 50: The proposed design framework

5.3 THE APPLICATION OF THE DESIGN FRAMEWORK IN ACCUMOLI (POST-DISASTER SETTLEMENT)

The Design Framework previously mentioned is applied to suggest a more sustainable shelter in the village of Accumoli, a post-disaster settlement. This implementation demonstrates how the Design Framework addresses both the immediate needs and into permanent housing is addressed. The design process consists of two fundamental phases: the emergency quick assembly phase and the transition phase for long-term shelter over time.

- ✓ **Considerations:**

Location: Accumoli is situated in a basin in the Umbrian-Marchigian Apennines in central Italy, approximately 810 meters above the sea.

Demographic needs: about 551 persons [131].

Geographic and Climatic needs: The towns have a typical Apennine climate. Summers aren't too hot, but winters are chilly and snowy.

1. Emergency phase: immediate response

Purpose: To provide emergency and quick response shelter for displaced populations, ensuring easy and quick assembly shelter within days by the inhabitants themselves.

Inspiration: Ikea better shelter' kit of parts construction techniques that is easy to assemble and ensures low transportation costs and environmental impact alike.

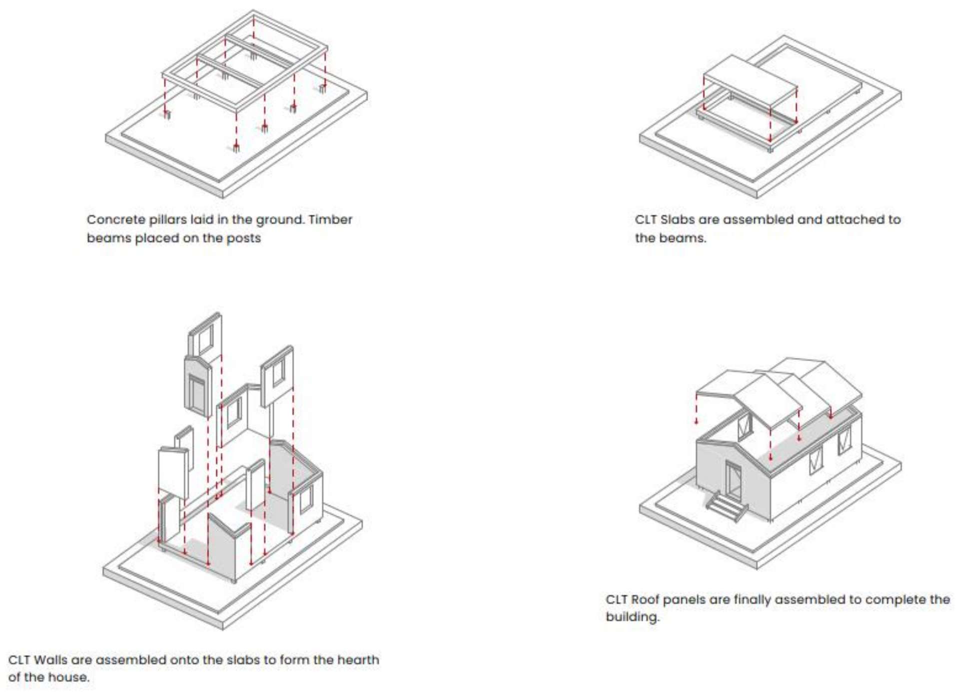


Figure 51: the proposed shelter guide of Assembly (first phase).

The foundation is constructed with Ground screws which are an innovative foundation solution that serve the work of traditional foundations like concrete foundations. they were chosen due to their quick assembly, seismic resistance, and suitability on sloping, uneven ground.

Partition: The separation between the spaces can be done using removable (foldable) walls like fabric walls to ensure more privacy within this phase.

Layout: Open area with sleeping pods or shared mats. With a communual outdoor cooking area.

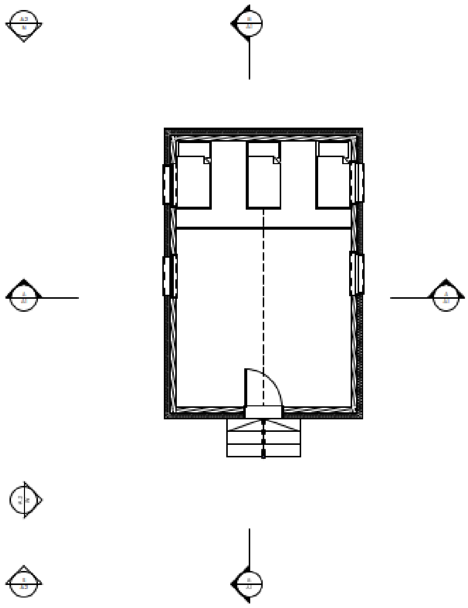


Figure 52: First phase plan

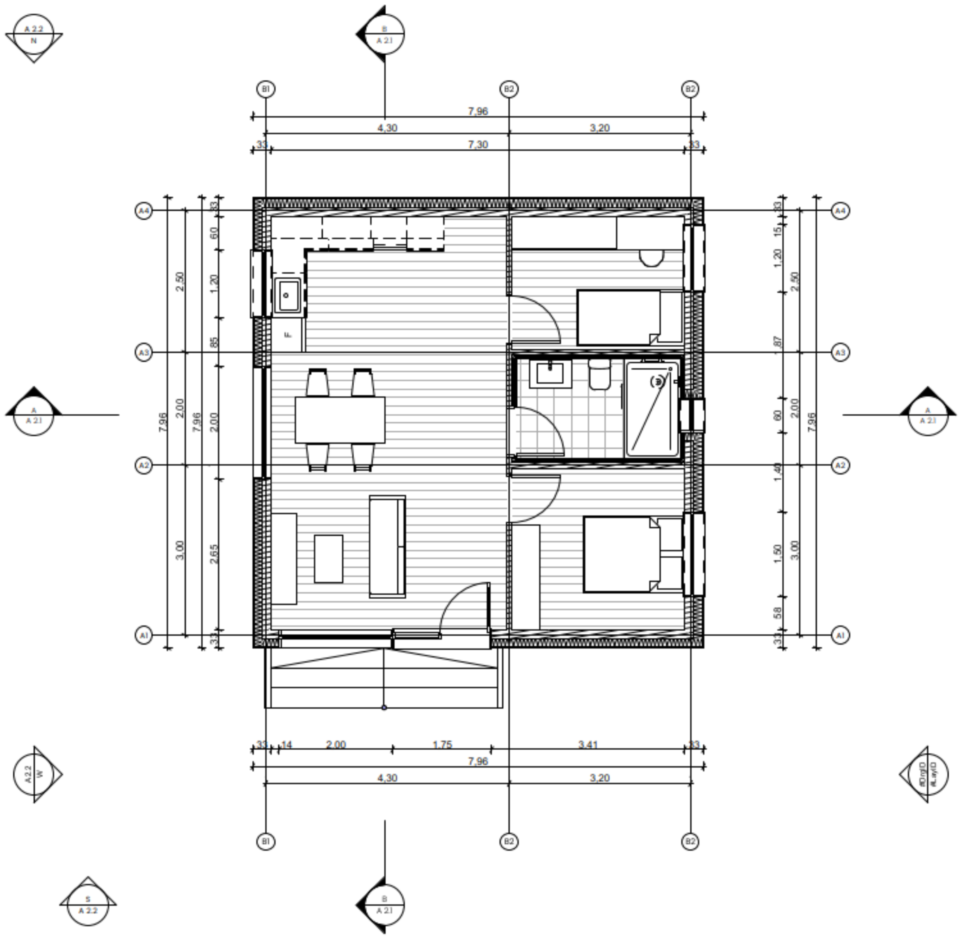


Figure 53: Second phase plan

Dimensions: family units designed for 3 to 4 people (Parents with children).

Materials:

- **Exterior Wall:** The proposed external wall system for Accumoli consists of three layers: 7mm lime plaster, 160mm hemp-fiber insulation, and 120 mm of Stora Enso Sylva CLT. On one hand, Lime plaster provides weather resistance and breathability, and reduces carbon emissions compared to cement plaster. On the other hand, Hemp fiber insulation provides thermal efficiency and environmental sustainability, while at the same time being sourced locally to reduce the transportation cost and emissions. In addition to the use of prefabricated CLT panels that are locally or regionally produced to reduce their transportation cost and emissions. At the same time provides structural strength and seismic resilience.

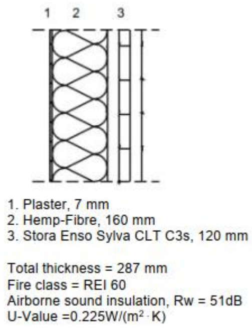


Figure 54: Exterior wall details of the proposed shelter.

- **Interior Wall:** it is made of Stora Enso Sylva CLT panels

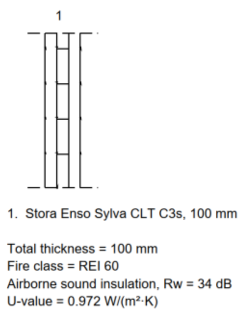
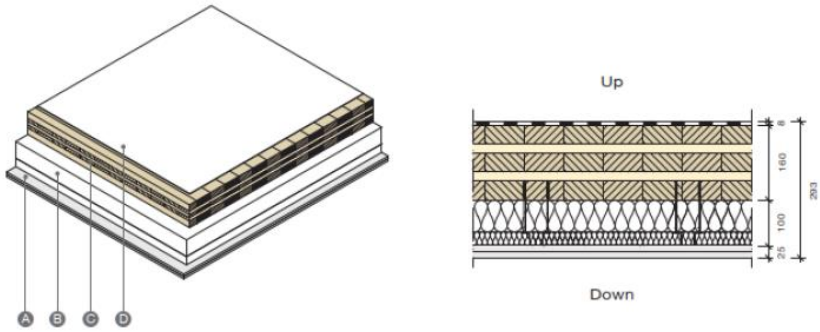


Figure 55: Interior wall details of the proposed shelter.

- **Solar Panels:** can be added to provide a sustainable source of energy that ensures lighting and device charging.
- **Elevated floor details:** the details are as follows



	mm	Materials
A	2x12,5	Cement plasterboard with spreadable waterproofing
B	100	Resilient suspension with mineral wool
C	160	Sylva CLT Floor type 160 L5s
D	8	PVC floor

Figure 56: Elevated floor details

1. first phase: quick assembly

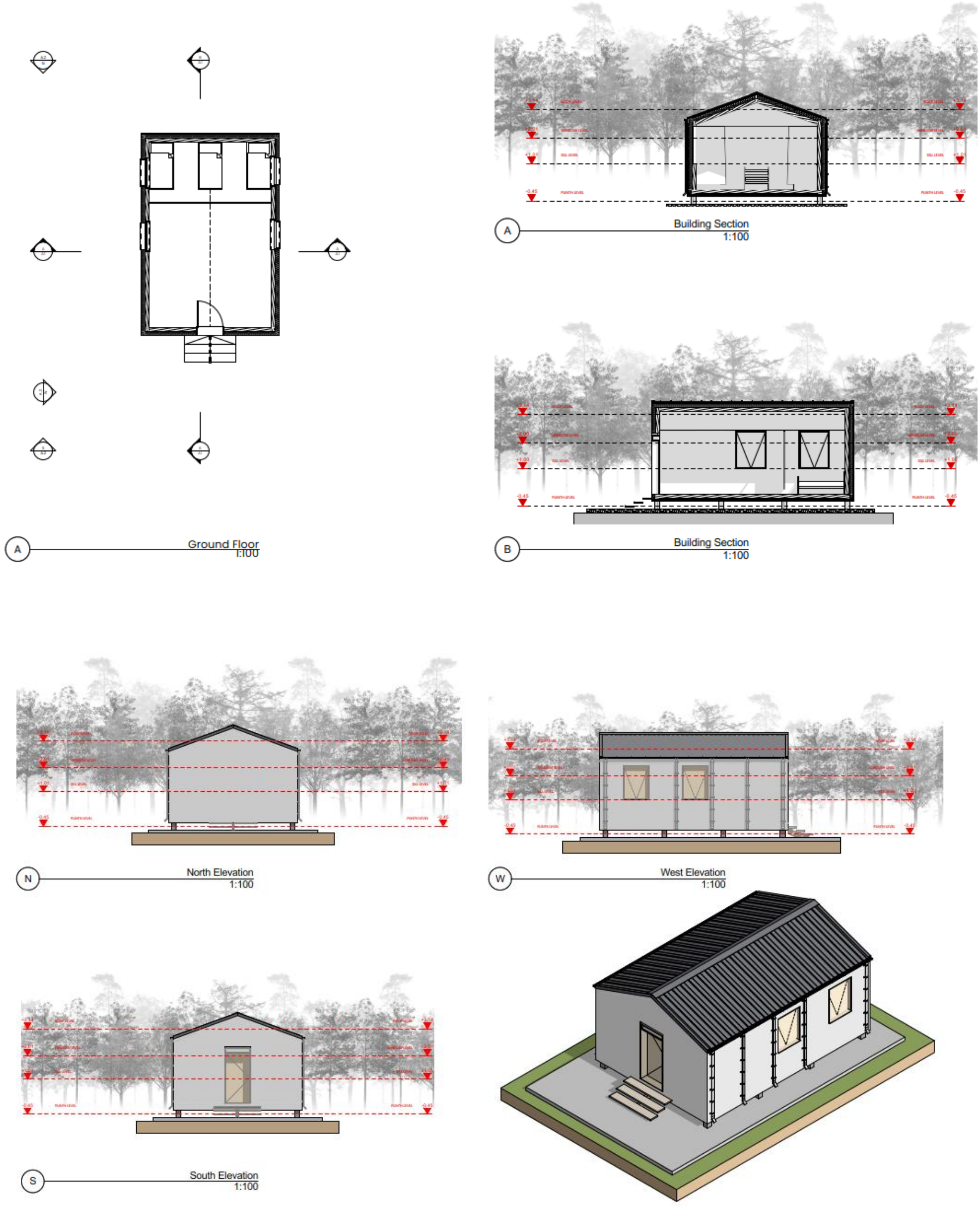


Figure 57: First phase drawings (It includes plan, elevations, sections, and 3d model)

2. Transition Phase Adaptation and extension

Purpose: Transition from short-term shelter to long-term shelter which can be achieved by expanding the modular units to offer more interior living areas and functional spaces like: kitchen, and separate bedrooms that make the living conditions more comfortable, thanks to the shelter's modular construction that allows for removing and adding sections easily.

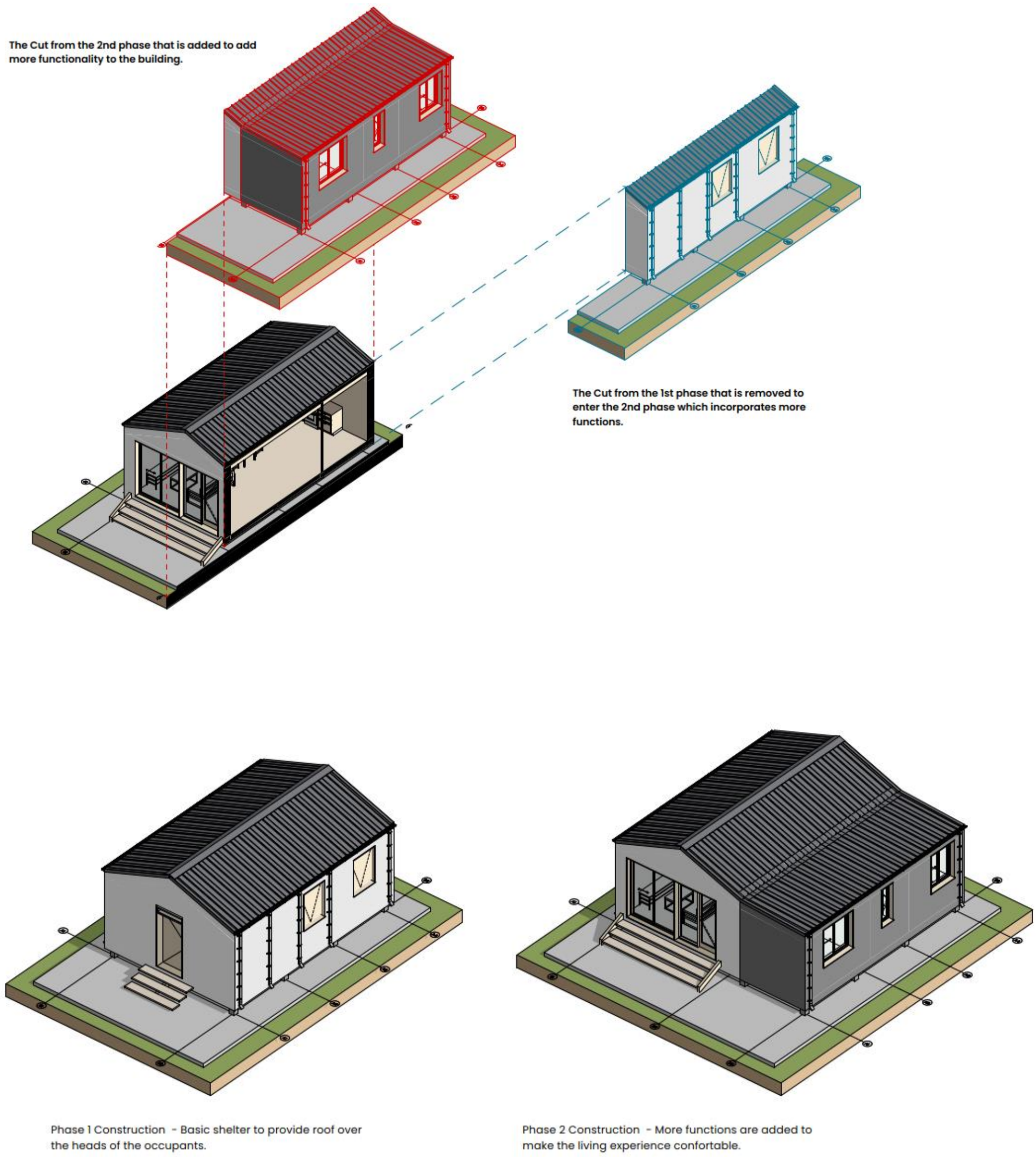


Figure 58: showing the transition from the short-term to the long-term phase.

2. long-term phase

In this phase, the shelter offers more spaces like a kitchen, toilet, and separate bedrooms which make it more permanent housing, separated using permanent walls, with upgrades for openings like adding more windows to ensure natural lightness and ventilation. It has an aesthetic appearance and the roof type with the use of wood reflects Italian architectural styles which ensures cultural suitability and user acceptance.

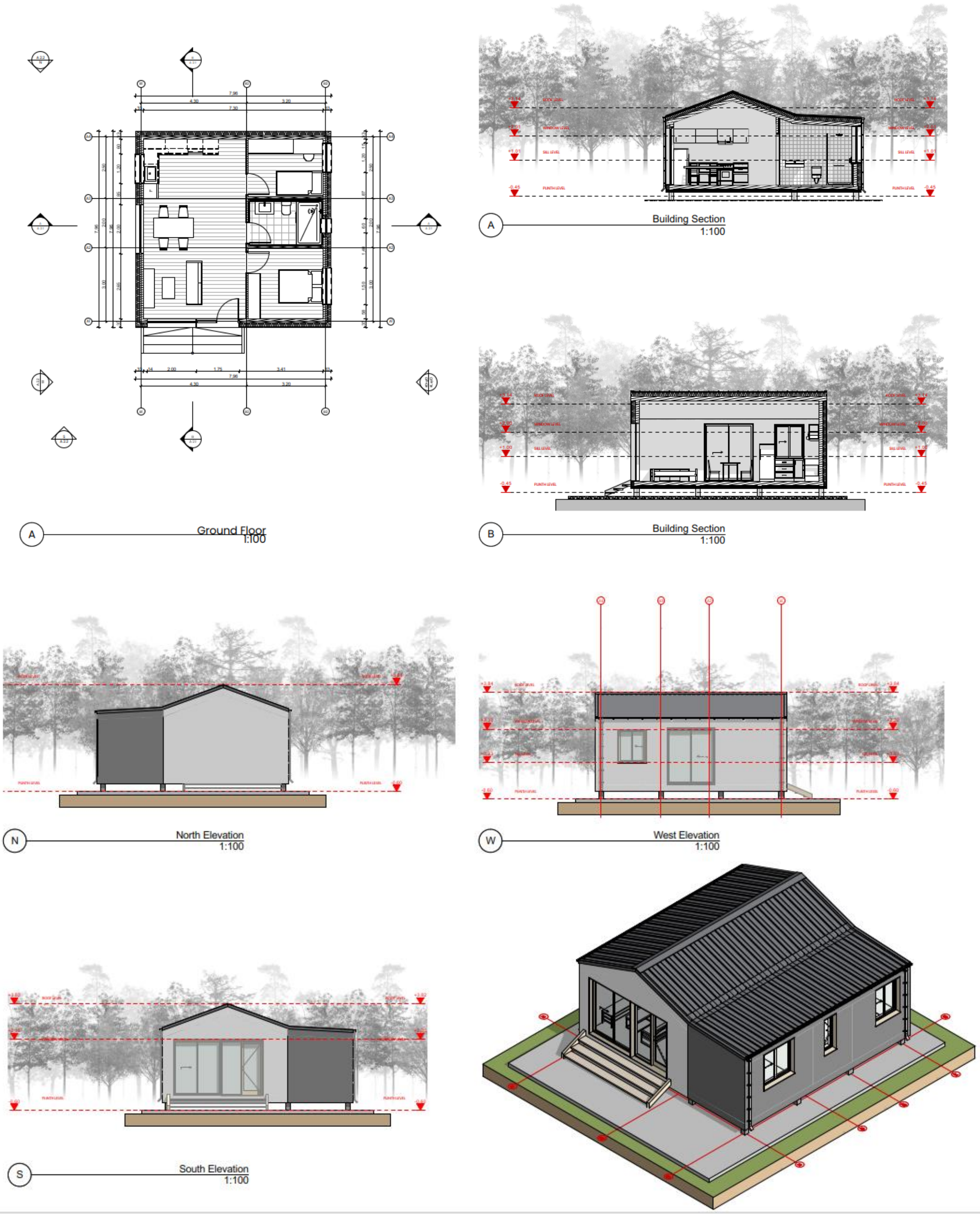


Figure 59: The long-term phase of the proposed shelter.

This shelter presents a new generation of shelter designs that combine rapid deployment with the capability of expansion over time to meet long-term needs. It allows easily the transition from an emergency shelter to a more permanent one, by cutting and adding modular units. These units offer more spaces like kitchens and toilets, it is made of locally manufactured clt panels combined with natural materials like hemp for insulation. It can be assembled by users themselves with the guide provided within days.

The structure uses locally sourced cross-laminated timber (CLT), a material known for its strength, thermal efficiency, and minimal carbon footprint. combined with natural hemp insulation, which ensures thermal and acoustic comfort. The design prioritizes simple assembly and disassembly that enable inhabitants to build their shelters with an assembly simple guide within days. By using local materials and customizable designs, the shelter can adapt to cultural needs and regional specifics, making it a highly flexible solution for various situations. Its durability, resistance to seismic activity, and environmental resilience ensure safety and comfort, while the modular, scalable design supports long-term recovery and development in both post-disaster and refugee contexts. This shelter represents a sustainable and inclusive approach to emergency housing, bridging the divide between immediate relief and lasting resilience.
However, the Development of supporting infrastructure is necessary to implement households with integrated WC (toilet) and kitchen facilities. These initiatives include reliable water supply, sewage management, proper waste disposal, and electricity connectivity. Without these systems, it will be difficult to ensure the proper and safe operation of these critical infrastructures, especially in the case of emergency or temporary housing. Therefore, further research regarding the shelter settlement, improvement is required. However, if the goal is to ensure sustainability, it is recommended to install a Rainwater Harvesting system and a Greywater Recycling system.

Chapter 6: Conclusion

This research covers a critical and growing global issue which could be summarized as the urgent need for sustainable and long-term needs shelter solutions to accommodate displaced populations in response to rising global disasters and crises. By adopting a comprehensive and interdisciplinary approach, the study evaluates the sustainability of this type of housing option based on social, cultural, economic, and environmental aspects, that enable the identification of key shortcomings alongside best practices and effective strategies employed. Furthermore, it highlights the importance of considering users' comfort and satisfaction in shelter design which are essential in the architecture field but unfortunately often neglected in the humanitarian architecture sector. This holistic approach bridges the main gaps discussed in the literature review chapter, offering valuable insights and practical guidelines in the form of a design framework to enhance sustainability that becomes a global priority and improve users' well-being in future shelter designs at both academic and implementation levels.

Key Findings

The results gathered from the literature review analysis that reflects both the 1^{st} and 2^{nd} research objectives show that most of the provided emergency shelters are predominantly designed as globally standardized solutions to facilitate rapid deployment in diverse contexts. While this approach ensures mass production and ease of transportation, it often fails to accommodate the specific cultural, social, climate, and environmental requirements of the regions where they are deployed. Which leads to user discomfort and dissatisfaction as presented in the survey results.

Another critical issue found based on the literature review analysis is that these shelters which are designed for short-term periods are often used for long periods beyond their intended use, which makes the inhabitants suffer more and results in dissatisfaction and abundance as reported by users themselves in the survey responses. After a critical review and analysis of existing studies and data, it can be concluded that the most critical issue in housing families after a disaster is the gap between short-term needs (emergency or temporary shelter) and long-term needs (permanent housing) that must be addressed.

Reflecting on the 3rd research objective which is to identify best practices and common challenges in existing shelter design that may encourage the improvement of shelter solutions in future crises, an evaluation of 14 different shelter solutions across various contexts and geographical regions, was made based on key factors like cost, construction time, durability, sustainability, cultural suitability, weather protection, mobility, and overall comfort. The findings are as follows:

- Prefabricated shelters are good as rapid deployment solutions but are not culturally suitable or environmentally friendly solutions.
- Locally constructed shelters are culturally suitable and environmentally friendly but need more time and effort for construction.
- Shelters constructed with local materials present a better balance between affordability and durability and are more sustainable than prefabricated solutions.

These findings underscore the need for hybrid shelter designs that combine rapid deployment with long-term adaptability, which means integrating prefabrication with local materials and construction techniques.

Addressing the persistent gap between short-term and long-term housing solutions requires rethinking shelter design to prioritize flexibility, sustainability, and user satisfaction. By bridging this gap, future shelter solutions can better serve displaced populations and contribute to building resilient communities in post-disaster and refugee contexts.

Reflecting on the 4th objective, the survey method and results present the users' level of satisfaction, experiences, and the main factors that affect their well-being within the shelter environment.

The survey findings underscore the importance of integrating sociocultural factors in shelter design and environment, including the availability of communal spaces and culturally suitable facilities in ensuring the acceptability and functionality of temporary shelters. Most of the respondents who reported a lack of social and cultural spaces felt socially isolated. Furthermore, the majority of them who lived in tents and prefabricated shelters showed dissatisfaction with privacy, and area and cited the issues with basic and communal facilities like kitchens and bathrooms. Moreover, Thermal and acoustic comfort are primary aspects of shelter design that affect daily well-being and user comfort. Contributing to Objectives 4 and 5, which focus on meeting inhabitants' needs, including thermal and acoustic comfort. Survey results indicate dissatisfaction among respondents due to inadequate insulation, poor ventilation, and lack of soundproofing measures, with 55% reporting extreme summer heat, 37.5% poor winter heating, and over 90% experiencing noise disturbances. These results show that existing shelter solutions failed to ensure the user's satisfaction and highlight the need for improved design strategies that prioritize comfort. Additionally, privacy and culturally suitable facilities, such as communal spaces for socializing, were found to be integral to enhancing shelter functionality and acceptability, which addresses Objective 6.

To address Objective 7, which seeks to identify materials and construction methods that reduce environmental impact., The environmental impact of the IKEA Better Shelter, Tuareg Tent, Eco-Dome, and Mahama Durable Shelter is assessed based on the Life Cycle Assessment (LCA) method. This LCA analysis underscores the importance of selecting materials and construction techniques that combine the intended use and lifespan of each shelter type. Short-term emergency shelters like the IKEA Better Shelter and Tuareg Tent prioritize rapid deployment but have a higher environmental impact when assessed over time. In contrast, shelters such as the Eco-Dome and Mahama Durable Shelter, which employ earth-based or locally sourced materials, exhibit lower annual environmental impacts due to their extended lifespans and design efficiency.

As a final goal a proposed framework design that aims to bridge the gap between immediate disaster response and long-term housing needs. By integrating insights from research findings, it ensures that shelters are adaptable, sustainable, and culturally appropriate. The framework provides a practical and scalable solution to diverse disaster contexts, addressing both short-term relief and long-term stability.

It highlights a hybrid design method that combines modular prefabricated components with locally sourced materials, reflecting Objective 8. This approach balances rapid deployment, cultural relevance, affordability, and environmental sustainability. By integrating the lessons learned from the comparative study of shelter types (linked to Objective 3), the design framework incorporates modularity, socio-cultural sensitivity, structural resilience, and environmental considerations. Such a framework ensures that emergency shelters not only address immediate needs but also foster long-term sustainability and adaptability.

Novel Contributions

- The first novelty of this research is that it considers all three pillars of sustainability, including economic, socio-cultural, and environmental aspects simultaneously in the humanitarian architecture. Addressing a gap in existing studies that typically focus on only one or two aspects.
- The second is: the proposed design framework which is a novel synthesis of findings from comparative studies, user surveys, and environmental impact assessments. It serves as a practical guide in designing shelters that are not only sustainable but also adaptable to diverse contexts and needs.
- The third is: integrating the socio-cultural factors as well as considering users' satisfaction and comfort which are usually neglected or partially addressed in the shelter design.
- A novel approach that balances rapid deployment with long-term needs which is a unique contribution, combining prefabrication with local materials to balance efficiency and sustainability.
- Integration of findings from real case studies such as Accumoli, Tindouf, and Mahama settlements contributes to an in-depth understanding that bridges between theory and practice.

Limitation

While the study offers a robust foundation, areas like end-of-life impacts and operational energy use which are excluded from the environmental impact assessment due to lack of data require further investigation. Moreover, Some LCA data regarding the factors taken relied on secondary sources, which may introduce variability in results. This study focused on assessing and solving the sustainability issues in the shelter unit, however, it is recommended to assess and solve the sustainability issues in the shelter settlement alike.

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Appendices

Appendix A

Title: A comparative study about the shelters based on qualitative factors

The best solution | The worse solution | The good solution

Study on the issues and successes of temporary housing solutions

		Emergency Shelter		Temporary houses				
		Preparedness plans		ready-made houses			houses constructed in place	
		Canvas Tent	Plastic sheeting	modular houses	kit-of-parts houses	A mobile home	Vernacular house	Recycled Materials house
		Tent	Tarpaulin	The Exo Shelter	the better shelter	The FEMA trailer	the sandbag shelter	the PAPER LOG shelter
								
Time	short construction time	Tents are typically stockpiled as part of disaster preparedness plans in many countries.	Plastic sheeting is also known as plastic tarpaulin, tarp or polythene sheet is a part of disaster preparedness plans	it is one of prepardness solution and the installation of the shelter is very easy, it takes less time to set up than a tent(2 minutes or less).	it is one of prepardness solution.The shelter is delivered in two cardboard boxes which can be lifted by four people and also contain all necessary tools and instruction manuals.	it is one of prepardness solution.the shelter is a prefabricated structure,which built in a factory before being transported to the site.	Every five incoming refugees put up a simple structure in five days. but the structure with bedroom, bathroom, kitchen, and entry can be put up in about four weeks, by one skilled and four unskilled people	the process of building this house is very quick with no machines even needed. One house can be finished by eight local students in two days when all materials are prepared.
	quick response	They are usually the very first things distributed among the victims of natural disasters.It is provided from the 1st day, and just few hours after the disaster.	Together with the tents, they are the first things distributed to the victims from the 1st day after the disaster.	it is a rapid response emergency housing which can be available to shelter thousands of people in under 24 hours , depending on the distance between the storage facilities and deployment location.	the shelter can be available to shelter thousands of families in refugee camps in days depending on the distance between the storage facilities and deployment location.	the Response was slow , innefficient and costly	the shelter can be available to shelter number of families in weeks.	it can be available in two days because the process of construction helps victims to find shelters quickly.therefore, the people do not need to wait for the material to be delivered from another area.
	longer shelf life	the majority of tents have the life span of under a year	tarpaulin last about 5 to 6 months however people should not stay under plastic sheeting for more than a few days	this type of shelter have long shelf life about 10 years	The Better Shelter is designed to last for at least three years	the life of the fema trailer on an average is about 10-12 years minimum. But FEMA policy generally allows residents to live in a FEMA trailer for a period of 18 months	It's an emergency shelter, but if we cover it with waterproofing and stucco, it will last for 30 or more years.	they were expected to last approximately five years.
Cost	Innexpensive Construction	Tents are usually made of either thin layers of fabric or plastic which are cheap .A UN tent costs around $500	they're generally cheap and available anywhere.	They cost an astounding $5,000.For comparison, each unit costs a quarter of the price of a traditional trailer, the likes of which were used following Hurricane Katrina and a third of the price of a modified shipping container	The Better Shelter minimises overhead costs, as everything required to build it is included.It costs arround $ 1000	this type is Very expensive to build & Install. a FEMA trailer costs around $24,000	the structure is very cheap, it costs about $150 - $300 per m2 or more depending on the proportions of the ingredients (cement, gravel, ...)	this type is used inexpensive recycled materials like cardboard.The cost is also very economical of about $2,000.
	Innexpensive Transportation	Tents are a very cost-efficient solution.they can be easily transported to and installed at the desired locations. But Tents are heavier and bulkier compared to tarps	They're way cheaper than a tentt because Unlike tents, tarps don't need tent poles to set up. You'll just need some cordage (preferably some paracord that you carry in your pack anyway) and pegs for most configurations.	the Exo's design makes it stackable, meaning that it can be easily transported in bulk with low cost, making more units accessible to disaster sites more quickly.	Its design is optimised for high volume production and fl at pack logistics, which makes it even more efficient and affordable	The units could be transported to their installation sites via truck and rail which make their transportation very expensive.	the shelter is constructed in place with local materials, which saves transportation costs	The materials of the Paper Log House are easy and cheap to store and transport to the site, as well as many materials, including the paper tubes, could be made on site
	Low cost infrastructures	No infrastructures	No infrastructures	This shelter can only use on grid. the infrastructure is needed to have access to clean water.	there is infrastructures	this type of shelter Needs infrastructure to utilize.	this type of shelter Needs infrastructure to utilize.	The architect used sand-filled beer cases for the foundation of the houses which are not expensive.
Mobile	Easy Assembling and dismantling	They can be easily installed and removed at and from the desired locations. They're easier and faster to set up	the installation of tarpaulins is not easy like tents because they require a considerable amount of skill to set up.	assembly is very simple, One: set the shell down onto a base, and it latches into place. Just like that, you've got a secure, locked connection. Two: fold the built-in beds down from the walls. Three: plug the unit in.	Assembling a 17,5 m2 Better Shelter requires a team of four people and takes around four hours depending on experience, conditions and location.	several private contractors are hired to install FEMA. A subcontractor installs the trailer. Another contractor installs the stairs andramps, furniture, appliances, and water. Then the power company installs a power line and meter.	The system of the shelter allows buildings to be quickly erected by hand by the occupants themselves with a minimum of training.	The shelter is easy and fast to put up; it takes less than six hours to construct.
	Lightweight mobile dwelling	They are light-weight structure but sometimes they come with other parts like poles, pegs, and accessories which make them heavier compared to tarps	They're very lightweight and compact structure.They weigh less than a tent and are easy to carry.	Each Exo shelter is a portable, light enough to be moved by four persons	The shelter is delivered in two cardboard boxes	This type of shelter is not lightweight dwelling.	This type of shelter is not lightweight dwelling.	the paper log houses are not mobile.
	Easy Transportable Units	They can be easily transported	their transportation is easier than tents because tarps don't need tent poles to set up.	Four people can move and assemble one shelter in just a few minutes.	The two boxes can be lifted by four people and also contain all necessary tools and instruction manuals.	the transportation of the fema trailers is difficult and expensive.	the system passes the transportation difficulties because it is constructed in place.	the system passes the transportation difficulties because it is constructed in place only the components which can be segregated and transported to the zone.
Weather protection	water proof	They are not water proof either and they easily get wet during the rainy seasons of the year.	It is water resistant solution . It is completely waterproof and has a very low moisture vapour permeability.	They are water proof shelter.	The Better Shelter Housing Unit is a weatherproof temporary shelter.	They are water proof shelter.	Although initially designed for hot arid climates, this structure can also be made waterproof for cold wet climates.	They are water proof shelter.
	Thermal insulation	Tents are not thermally insulated. They can get very hot during the day and very cold at nights	they're not the warmest shelters around. Most tarp configurations don't come with a ground sheet or are not very effective in trapping heat in.	Exo Housing Units sleep four adults, are climate controlled	this type of shelter does not include insulation.	FEMA trailers are known for having very poor insulation. They offer little sound insulation, and are known to sway in high winds.	the Building mass, which is earth in this case, is used as natural insulation.	For the insulation, an adhesive waterproof sponge tape is sandwiched between the tubes.but the shelter only meets the requirements of a short term temporary shelter by not being properly insulated
	ventilation	In tents there is Inadequate ventilation, poor air circulation, humidity, which often lead to serious health issues and respiratory problems.	most open tarp configurations have great ventilation with none of that damp, stuffy, humid air. And with great airflow no condensation problems.	the units are remotely monitored for temperature, making fire detection and prevention far more feasible.	It has four windows and a high ceiling, enabling residents to stand upright inside	it has 4-6 small windows which are placed on the sides of this trailer to let in daylight. The windows can also be opened for cross ventilation.	the dome shape structure with a hollow in the center of the roof provide air ventilation in the shelter. Also, it has 8 windows which are used for daylighting and cross ventilation	the shelter has 3 windows which are used for daylighting and cross ventilation.Also,the roofing is kept separate from the rest of the shelter so that when summertime comes air can circulate and in winter it better allows the shelter to hold warm air
Sustainability	in term of cost	They are not sustainable solution in term of cost.	They are not sustainable solution in term of cost.	They are sustainable solution in term of cost.	They are sustainable solution in term of cost.	They are sustainable solution in term of cost.	They are sustainable solution in term of cost.	They are sustainable solution in term of cost.
	in term of Environmental consequences	They are not sustainable solution in term of environmental consequences.	They are not sustainable solution in term of environmental consequences.	They are not sustainable solution in term of environmental consequences.	They are not sustainable solution in term of environmental consequences.	They are not sustainable solution in term of environmental consequences.	They are sustainable solution in term of environmental consequences.	They are sustainable solution in term of environmental consequences.
Cultural Suitability	Cultural and Local conditions	They do not provide cultural and local conditions.	They do not provide cultural and local conditions.	They do not provide cultural and local conditions.	They do not provide cultural and local conditions.	They do not provide cultural and local conditions.	They provide cultural and local conditions.	They provide cultural and local conditions.
	Users's need	They do not provide user's basic needs	They do not provide user's basic needs	They do not provide all the user's basic needs	The Better Shelter meets the basic needs for the activities of basic living	The Fema trailer provides the most needs of the users.	The Eco dome provides the basic needs of the users.	the shelter lack the most basic living conditions and users'needs.
	Local architecture and Materials	They are not made from local materials	They are not made from local materials	They are not made from local materials	They are not made from local materials	They are not made from local materials	They are made from local materials.	They are not completly made from local materials
Social Suitability	community participation	No community participation for the construction of the tents	No community participation for the construction of the Tarps	No community participation for the construction of the Exo shelter	No community participation for the construction of the better shelter	No community participation for the construction of the fema shelter	the people participate in the construction of the shelter 100%.	The simplicity of the structure allowed the affected community to take part in the construction process.
	users'satisfaction	They are not satisfied because tents are unhealthy overcrowded temporary house with absolutely no sanitary facilities, privacy, and safety.	They are not satisfied because tarps don"t offer protection from insects or External dangers also there is no sanitary facilities, privacy, and safety.	The users are not satisfied because the Exo's design do not provide all their needs	The users are satisfied because the Better Shelter Housing Unit do not provide all their needs	The users are not satisfied because of the health issues relating to Katrina-issue FEMA trailers	The users are satisfied because they shared in the construction of the shelter.	The users are satisfied because the paper log cabins are very comfortable. In addition to the temperature comfort applied by the roofing system.
	Social needs	they make people live in Social isolation	they make people live in Social isolation	this shelter meets the needs for the familiarity.	The Better Shelter meets the needs for the social activities and familiarity.	The fema traailer meets the needs for the social activities and familiarity.	The eco dome meets the basic needs for the social activities and familiarity.	The paper log house meets the basic needs for the social activities and familiarity.
Facilities	Sanitary Facilities	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Gaz and Electricity	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Services	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Possibility of Reuse and recycle the Shelter	for the same fuction without any Modification	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	for the same fuction with Modification	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	for different functions	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Flexibility	Expandable Possibilities	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	adaptable to the climate change	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	adaptable to the geography	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Comfort	Security	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Privacy	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Temperature comfort	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Properties	Durability	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	strength	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Disaster Proof	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Others	Environmentally friendly	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Efficiency	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Aesthetic appeal	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	production capacities	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Long term effects of the shelter and issues	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix B

Title: The Digital flyer about the questionnaire that has been distributed to the refugees

PhD Research Survey Invitation

Purpose of the Survey:

Dear Participants,

I am doing a PhD research study about the general living conditions within a shelter or camps. Your participation is important in helping me understand the real needs of refugees from an architectural point of view. your answer will help to gather more knowledge in this field.

Who Can Participate: Individuals (Refugees, Asylum Seeker, Natural Disaster affected Population...)

How to Participate:

- The survey is completely anonymous and will take approximately **[5-10]** minutes to complete.
- You can participate by selecting your preferred language and scanning the QR code below.

Survey Links:

English Version:

Arabic Version:

Turkish Version:

Confidentiality:

Please be assured that all responses are anonymous and will be used solely for research purposes. Your participation is entirely voluntary, and you can withdraw at any time without any consequence.

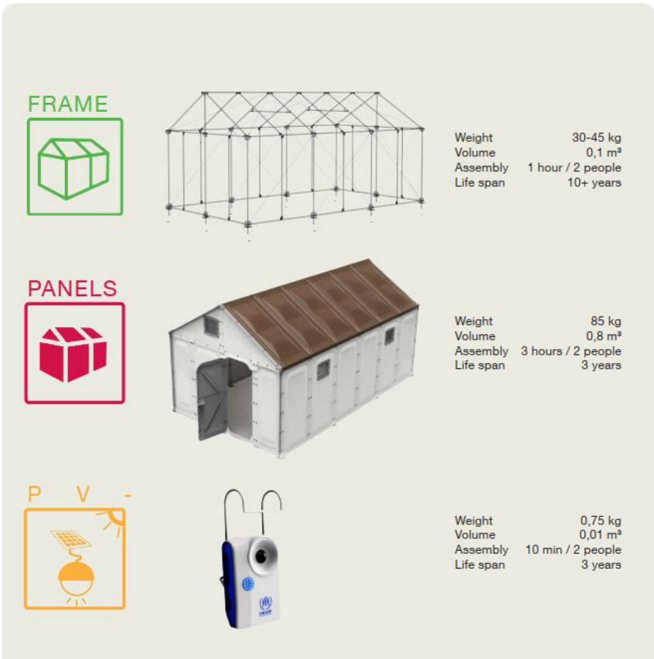
Thank You for Your Participation!

Appendix C

Environmental impact Calculation (Hand calculation details)

4.4.1 First shelter: Ikea Better Shelter (Refugee Housing Units)

(A)



(B)

Figure 60(A, B): Ikea better shelter used in Jordan.

Source : [87]

A. Material Emissions phase (from cradle to Gate):

✓ **General Information and Data (more Info about the shelter can be found in 3.1 section)**

- The Materials used in the shelter are gathered from the bill of quantity details in the UNHCR 2016 Report [60]. The main materials used are: Steel Frame, Plastic Panels (Polypropylene), PV System (Solar Panels), and Other Components (Steel, Glass, and Aluminium) as shown in the figure below.

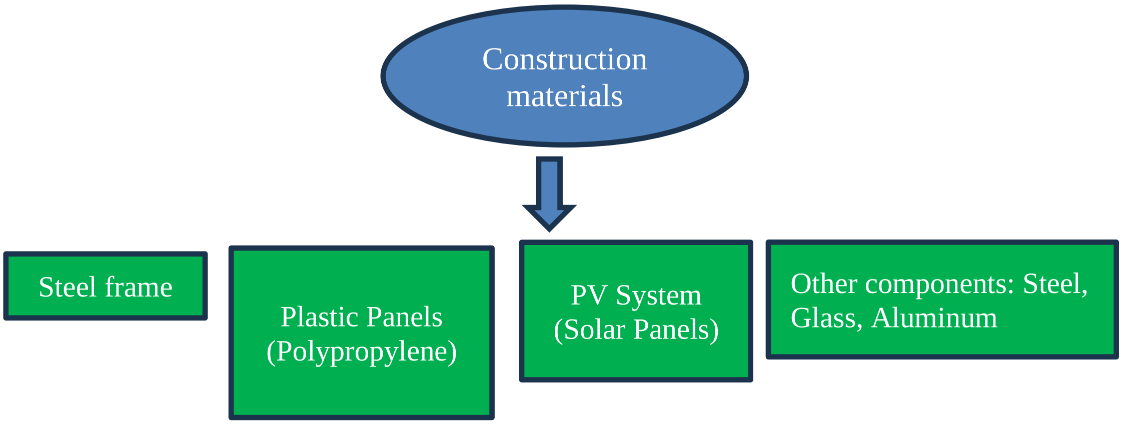


Figure 61: The total materials used to build the Ikea better shelter.

- The Use and End of life phases are excluded from this calculation due to the lack of Data.
- The Embodied Carbon factor of Materials is gathered from the Ice Database [88] and research papers: for Steel is equal to 1.99 kg CO_2/kg, while for polypropylene panels is taken as 4.49 co2 embodied carbon [88], other component embodied carbon is taken from the database. However, the embodied carbon of the Pv system is taken from a research paper [89].
- The Embodied Energy factor of Materials is gathered from different sources: Steel is equal to: 30 MJ/kg [90] While plastic is taken as 73 MJ/kg [69], for other components is taken as follows: glass: 28MJ/kg [91], for Aluminium is considered equal to 190 MJ/kg [92].
- The Weight of Materials is as follows [52]: steel is equal to 45kg, plastic is taken as 85kg, While for Pv system is equal to 0.75 kg. It is mentioned in the Unhcr report that the total weight of the components materials is 29.25 kg but not in detail, however, due to a lack of data, an assumption was made based on similar structures, considering 20kg is the weight of steel/5 kg for glass/4.25 kg for aluminum.

- ✓ **The hand calculation of Material emissions (considering Global warming potential and Embodied Energy from cradle to Gate):**

  - ❖ **Steel Frame**

- ➢ **GWP**: 45 kg×1.99 kg CO_2/kg=89.55 kg CO_2
- ➢ **Embodied Energy**: 45×30 MJ/kg=1350 MJ

  - ❖ **Plastic Panels GWP**:

- ➢ **GWP**: 85 kg×4.49 kg CO_2/kg=381.65 kg CO_2
- ➢ **Embodied Energy**: 85×73 MJ/kg=6205 MJ

  - ❖ **PV System GWP**:

- ➢ **GWP**: 0.75 kg×6 kg CO_2/kg=4.5 kg CO_2
- ➢ **Embodied Energy**: exempted from the study due to lack of information.

  - ❖ **Other Components**:

    - ➢ **Steel**
      - **GWP:** 20×1.99 kg CO_2/kg=39.8 kg CO_2
      - **Embodied Energy**: 20×30 MJ/kg=600 MJ

    - ➢ **Glass:**
      - **GWP**: 5×1.44 kg CO_2/kg=**7.2 kg CO_2**
      - **Embodied Energy**: 5×28MJ/kg=140MJ

    - ➢ **Aluminium**
      - **GWP:** 4.25 ×5.58 kg CO_2/kg=**23.715 kg CO_2**
      - **Embodied Energy**: 4.25×190 MJ/kg=807.5 MJ

Other components total emission GWP: 70.71 kg CO_2

Total EE for Other Components =600+140+807.5=1547.5MJ

- **Total Material emissions**

Total (GWP): 89.55 +381.65+4.5+70.71 = **546.41kg CO_2**

Total Embodied energy: 1350 MJ+ 6205 MJ+ 1547.5 MJ=9102.5 MJ

- **The following table and figures below present a summary of the material emissions:**

Materials	Weight (kg)	EE (MJ)	GWP (kg CO_2)	Source
Steel Frame	45	1350	89.55	Weight from UNHCR catalogue/EC, EE Factors from ICE Database
Plastic Panels	85	6205	381.65	Weight from UNHCR catalogue/EC from ICE Database
PV System	0.75	-	4.5	(Nils Holger Reich, paper, DOI: 10.1002/pip.1066)
Other Components (Steel)	20	600	39.8	weight assumed, EC from ICE Database
Other Components (Glass)	5	140	7.2	weight assumed, EC from ICE Database
Other Components (Aluminium)	4.25	807.5	23.715	weight assumed, EC from ICE Database
Total	160	9102.5	546.415	Calculated

Table 13: summary of the material emission phase (from cradle to Gate).

Source: created by Author.

B. Transport Emissions phase (from Gate to Site):

✓ **General Information and Data**

- Based on the UNHCR Catalogue and literature review: Better Shelter (RHU) is designed and manufactured in Sweden Stockholm and transported to the employment site, in this study considering the site is Azraq Refugee camp in Jordan. Based on that, an estimated distance is calculated.
- The total weight of the package is 0.16 tons.
- The transport Emissions are calculated using standard emission factors for road and sea transport gathered from Ecoinvent.
- the distance by sea from the port of Gothenburg in Sweden to Aqaba port in Jordan is determined using the online ports website [93]

- the distance by truck from the better shelter factory in Stockholm to the port of Gothenburg is approximately 496 km, and From Jordan port to the camp location is about 422 km (estimated using Google Maps).

- **Sea Transport emissions**:

  - **Sea Transport emissions**:

    8843,3 km×0.02 kg CO_2/ton-km×0.16 tons=**28.29 kg CO_2**

  - **Truck (Land) Transport emissions**:

    - **Truck Transport emissions:**

    (496+422) km ×0.08 kg CO_2/ton-km×0.16 tons=**11.75 kg CO_2**

  - **Total Transport Emissions = 40.04 kg CO_2LCA results Summary:**

Materials emissions (Gwp): 546.41kg CO_2e.

Transportation emissions: 40.03 kg CO_2e.

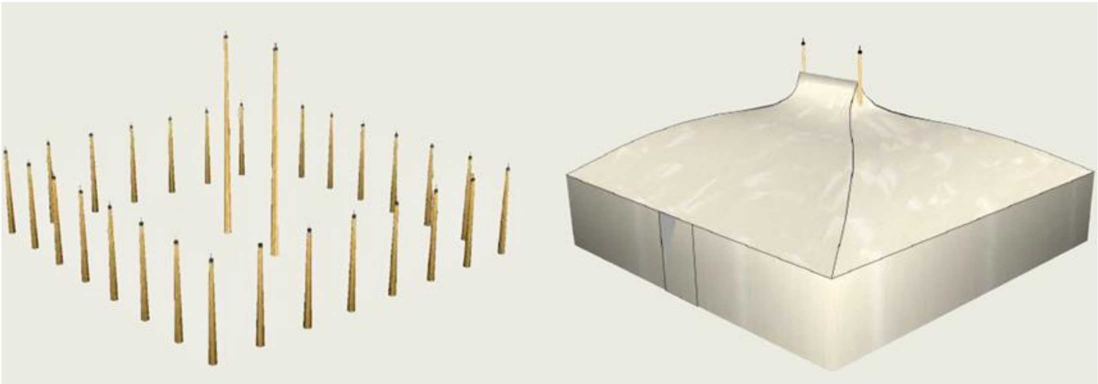
Total GWP for the Better Shelter in Jordan (from cradle to Site): 586.44 kg CO_2e per shelter.

The comparative metric (GWP/lifespan/Area):

GWP/ Lifespan/Area: 586.44 kg CO_2e /1.5 year/17.5 m^2=22.34 kg CO_2e/Year/ m^2

4.2.4.2 <u>Second shelter: Tuareg Tent (emergency shelter type)</u>

(A)



(B)

Figure 62 (A, B): A model of the Tuareg tent shelter

Source : [25]

A. Material Emissions phase (from cradle to Gate):

✓ **General Information and Data (more Info about the shelter can be found in the 3.1 section)**

• The Materials bill of quantity gathered from the UNHCR 2016 Report [25] used in the shelter are Cotton Canvas (cotton for covering), Blended Cloth (60% Polyester, 40% Cotton), Cotton Rope, Bamboo Poles, Rivet Pins and Iron Pegs (steel or iron) as shown in the figure below.

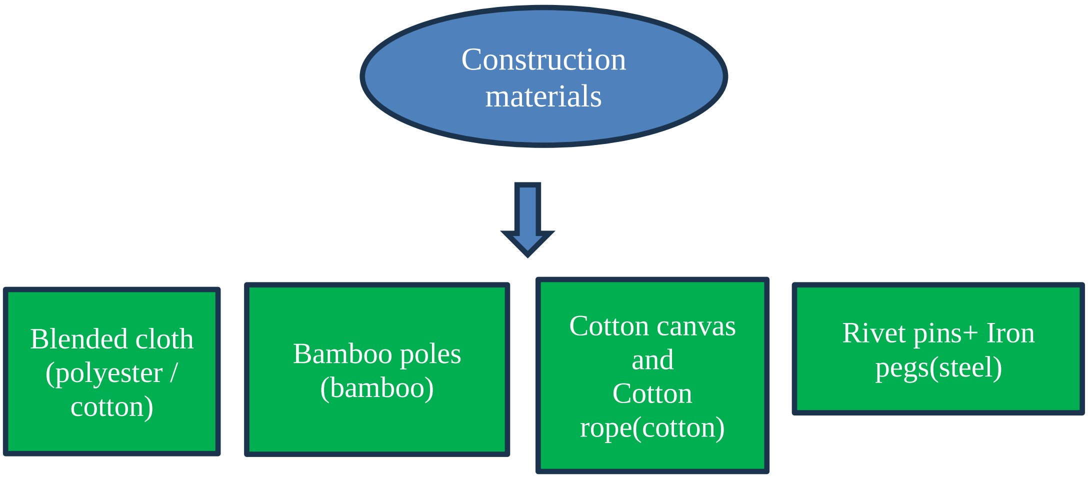


Figure 63: The total materials used to build the Tuareg Tent.

- The weight of each material is calculated or estimated in some cases based on its volume [25]and density which are gathered from different sources.
- The Embodied Carbon of Materials is gathered from the Ice Database (Ecology).

✓ **Determine the weight of each material**

❖ **Cotton canvas**:

➢ Each piece is 1.5 m x 70 m, so the total material is:

2 pieces × (1.5 m×70 m) =210 m^2

➢ The weight of cotton canvas [94] is calculated based on the material density [95], 14 oz = 475 g/m^2 [96] :

➢ Mass: 210 m^2×0.475 kg/m^2=99.75 kg

❖ **Blended cloth**:

➢ Each piece is 1.5 m x 70 m, so total material is: 2× (1.5 m×70 m) = 210 m^2

➢ Weight of blended cloth (assuming based on similar material, Density: 250 g/m^2) [97]:

➢ Mass: 210 m^2×0.25 kg/m^2=52.5 kg

❖ **Cotton rope**:

➢ It is 50 m in length and 12 mm in diameter, estimated weight of 6.5 kg. [98].

❖ **Bamboo Poles (4 meters in length, 2 pieces):**

➢ It is 2 pieces, each 4 meters in length, and 4 cm (0.04 m) diameter

- According to ISO Standard (ISO 22157) [99] which provides guidelines for bamboo as a structural material: Density of Bamboo: Bamboo has a density of approximately 500–1000 kg/m³, depending on species and moisture content. 700 kg/m³ as chosen based on the research paper [100].
- The volume of bamboo poles is calculated using the following equation: Volume of a cylinder= $\pi \times r^2 \times h$

Where: $\pi \approx 3.14$

r is the radius of the cylinder (half the diameter).

h is the height (or length) of the cylinder.

Volume of one pole=$\pi \times (0.04 \div 2)^2 \times 4$ m=0.005024m³

  - The weight of one pole is calculated using the following equation: (Weight=Density × Volume)

  Weight =700 kg/m³×0.005024 m³=3.52 kg

  - Total weight of two 4 m poles: 2×3.52=7.04 kg

- **Bamboo Poles (1.8 meters in length, 28 pieces):**
  - Dimensions of the material [25]: Length = 1.8 m, Diameter = 4-7 cm (assumed diameter = 4 cm or 0.04 m).
  - Volume of one pole: Volume of one pole=$\pi \times (0.04 \div 2)^2 \times 1.8$ m=0.00226 m³
  - Weight of one pole: Weight of one pole=700 kg/m³×0.00226 m³=1.58 kg
  - Total weight of 28 bamboo poles: 28×1.58=44.24 kg
- **Rivet pins (30 pieces)**:
  - Rivet Pin Dimensions according to the UNHCR 2016 Report are as follows: Length is equal to 12 cm (0.12 meters), Diameter (assumed based on similar constructions due to lack of information [101]), taken as 1.2 cm (0.012 meters).
  - The material is steel or iron, The Density of Steel/Iron is approximately 7,850 kg/m³ [102].
  - Volume of One Rivet Pin=$3.14 \times (0.012 \div 2)^2 \times 0.12$=0.0000136m³
  - Weight of One Rivet Pin=7,850kg/m³×0.0000136m³=0.1067kg
  - Total Weight=0.1067kg×30=3.20kg
- **Iron pegs**:
  - According to ISO Standard: ISO 1461, iron or steel in galvanizing, is commonly used for tent pegs.

- Density of Steel/Iron: Approximately 7,850 kg/m^3.
- Dimensions of Each Peg: Length = 50 cm (0.5m), Diameter = 1.5 cm (0.015m) (assumed to be solid iron pegs).
- Volume of one peg=$\pi \times (0.015 \div 2)^2 \times 0.5m = 0.000088 m^3$
- Weight of one peg=$7,850 kg/m^3 \times 0.000088 m^3 = 0.69 kg$
- Total weight of 28 iron pegs: 28×0.69=19.32kg

✓ **Material Production Emissions:**

❖ **Cotton Canvas**:

- Weight: 99.75 kg.
- GWP factor (Embodied carbon) for Cotton Canvas: Based on [103], the GWP is around 6.78 kg CO_2/kg
- Embodied Energy: 12 MJ/kg [103].

GWP of Canvas: 99.75kg×6.78kg CO_2/kg=676.82kg CO_2

Embodied Energy of Canvas: 99.75kg×12 MJ/kg= 1197 MJ

❖ **Blended Cloth** (assumed 60% polyester/40% cotton):

- Weight: 52.5 kg.
- Embodied Energy factor of Polyester: 125 MJ/kg [104].
- Embodied Energy factor of Cotton: 12 MJ/kg.
- GWP [105]:9.14 kg CO_2/kg for polyester and 6.78 kg CO_2/kg for cotton

- GWP of Blended Cloth= (0.6×GWP of Polyester/nylon) +(0.4×GWP of Cotton)

GWP of Blended Cloth= (0.6×9.14kg CO_2/kg) +(0.4×6.78kg CO_2/kg)

GWP of Blended Cloth: 52.5 kg× 8.196kg CO_2/kg=430.29 kg CO_2

Embodied Energy of Blended Cloth

52.5 kg× ((0.6×125 MJ/kg for polyester) +(0.4×12MJ/kg for cotton)) =4189.5 MJ

- **Cotton Rope**:

  - Weight: 6.5 kg.
  - Embodied Energy of cotton: 12 MJ/kg [103].
  - GWP factor (embodied carbon): 6.78 kg CO_2/kg [103].

GWP of Cotton Rope= 6.5kg×6.78kg CO_2/kg=44.04kg CO_2

Embodied Energy of Cotton Rope=6.5 kg×12 MJ/kg=78 MJ

- **Bamboo Poles (4 m)**:

  - Weight: 7.04 kg.
  - Embodied Energy: 1 MJ/kg.
  - GWP [106]: 0.2 kg CO_2/kg.

GWP of Bamboo Poles (4 m):7.04 kg×0.2 kg CO_2/kg=1.41 kg CO_2

Embodied Energy of Bamboo Poles (4 m): 7.04 kg×1 MJ/kg=7.04 MJ

- **Bamboo Poles (1.8 m)**:

  - Weight: 44.24 kg.
  - Embodied Energy: 1 MJ/kg.
  - GWP: 0.2 kg CO_2/kg.

GWP of Bamboo Poles (1.8 m): 44.24 kg×0.2 kg CO_2/kg=8.85 kg CO_2

Embodied Energy of Bamboo Poles (1.8 m): 44.24 kg×1 MJ/kg=44.24 MJ

- **Rivet Pins (3.2 kg)**:

GWP: 3.2 kg×1.99 kg CO_2/kg=6.37 kg CO_2

Embodied Energy of Rivet pins=3.2 kg×30 MJ/kg=96 MJ

- **Iron Pegs**:

  - Weight: 19.32 kg.

- Embodied Energy: 30 MJ/kg [107].
- GWP: 1.99 kg CO_2/kg [103].

GWP of Iron Pegs=19.32 kg×1.99 kg CO_2/kg=38.45 kg CO_2

Embodied Energy of Iron Pegs=19.32 kg×30 MJ/kg=579.6 MJ

- **Total Material Emissions:**

GWP: 676.82+430.29+44.04+1.41+8.85+6.37+38.45=1206.23 kg CO_2

Embodied energy: 1197 + 4189.5+ 78 + 7.04 + 44.24 + 96+ 579.6 = 6191.38MJ

- The table below presents a summary of the material emissions:

Material	Weight (kg)	EC factor kg CO_2/kg	GWP Emissions kg CO_2	EE Factor MJ/kg	EE MJ
Cotton Canvas	99.75	6.78	676.82	12	1197
Blended Cloth	52.5	8.196	430.29	125 polyester/12 cotton	4189.5
Cotton Rope	6.5	6.78	44.04	12	78
Bamboo Poles (4m)	7.04	0.2	1.41	1	7.04
Bamboo Poles (1.8m)	44.24	0.2	8.85	1	44.24
Rivet Pins	3.2	1.99	6.37	30	96
Iron Pegs	19.32	1.99	38.45	30	579.6
total	232.55	-	1206.23	-	6191.38

Table 14: A summary of the Material emissions phase (GWP Embodied Energy).

Source: Created by the author.

Transportation Calculations (from Gate to Site):

Assuming the materials (Cotton Canvas, Blended Cloth, Cotton Rope, and bamboo poles) were transported from China which is one of the Leading cotton and bamboo producing countries worldwide with 6684 thousand metrics of cotton in 2022/2023 to Algeria**.** [108]**,** [109]

- Total Distance by sea (from shanghai port to port of Algiers): 8,754 nautical miles = 16,208 km (1 nautical mile = 1.852 km).

- Assuming the materials are transported from the UNHCR Center located in Beijing to Shanghai Port which is the busiest shipping port in China by truck [110] According to google maps the distance is 1427 Km
- Assuming the materials are transported from the port of Algiers to the Sahrawi refugee camps in Tindouf by truck, according to google maps the distance is 1991Km
- Assuming that Rivet Pins and Iron Pegs are produced locally in Algeria, Tindouf city, therefore considers their transportation Negligible.

❖ **Transport Mode by Sea**

Total weight: **99.75kg+52.5kg+6.5kg+7.04kg+44.24kg=210.03kg (0.21003 tons).**

GWP=Weight (tons)×Distance (km)×GWP per ton-km (by sea)

GWP (China to Algiers) =0.21003 ×16,208 km×0.02kg CO_2/ton-km =68.06kg CO_2

❖ **Transport Mode By land (Truck)**

GWP (Truck Transport) =0.21003tons×1,427km×0.08kg CO_2/ton-km

GWP =23.96kg CO_2

GWP (Truck Transport) =0.21003tons×1,991km×0.08kg CO_2/ton-km

GWP=33.47kg CO_2

Total GWP (Transport)=68.06kg CO_2(Sea)+23.96kg CO_2(Truck, Beijing to Shanghai)+33.47kg CO_2(Truck, Algiers to Tindouf)

Total GWP (Transport)=125.49 kg CO_2**Final GWP Calculation:**

Material Emissions: 1206.22 kg CO_2

Transportation Emissions: 125.49 kg CO_2

Total GWP = 1206.22 kg CO_2 +125.49kg CO_2 =1331.71kg CO_2

Total GWP for the Tuareg Tent Shelter in Algeria (from cradle to site): 1331.71kg CO_2e per shelter.

GWP/ Lifespan/Area: 1331.71kg CO_2e /2 year/49 m^2=13.58 kg CO_2e/Year/ m^2

4.2.4.3 <u>Third Shelter: Eco dome by nadir Khalili</u>

Figure 64: A sample of the sandbag house in California designed by Nader Khalili source: [111]

✓ **General Information and Data (more Info about the shelter can be found in the 3.1 section)**

- The Eco-Dome is a 400 square foot structure with four apses (kitchen, bedrooms, and bathroom) featured on HGTV Tiny House Hunters and CNN. The main dome is 15 feet in diameter, with 15-inch-thick walls. It is a spacious and energy-efficient "tiny" home that includes a rocket mass heater and a passive cooling system called a wind scoop. The Eco-Dome is engineered to surpass all structural building codes, has been permitted and built in various locations worldwide, and exceeded all requirements of seismic destructive testing for California [66]. Sandbags: Filled with earth and stabilized with materials such as cement, lime, or asphalt emulsion. The sandbags themselves are synthetic (typically polypropylene). The materials used are: Barbed Wire: Galvanized steel wire is laid between sandbag layers for reinforcement, providing both tensile and earthquake resistance.
- Plaster: The exterior is typically plastered with a mix of 85% earth and 15% cement to protect from weathering and erosion. The figure below presents a process tree of the shelter:

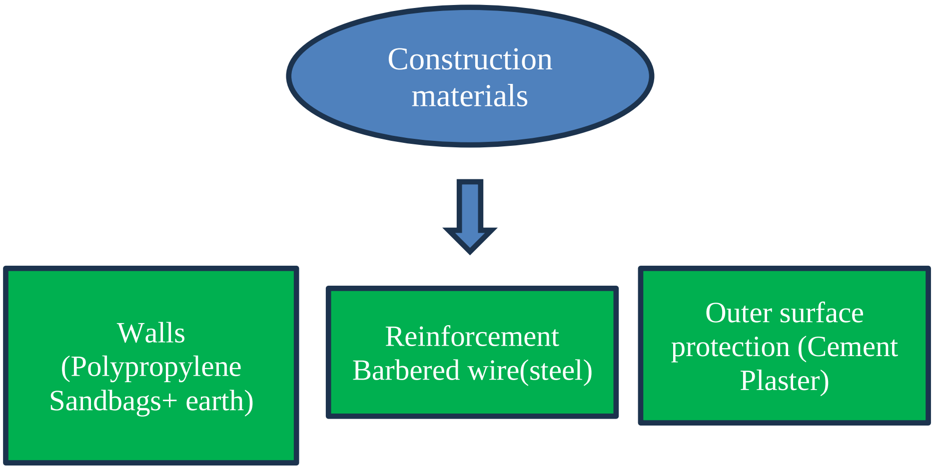


Figure 65: The total materials used to build the Eco-dome shelter.

- Shelter specification is gathered from different papers and websites:
  - Main Dome Diameter: 15 feet (4.57 meters).
  - Wall Thickness: 15 inches (0.38 meters).
  - Total Floor Area: 400 square feet (37.16 square meters).
  - Additional Spaces: Four apses.

*** Calculation of the materials' Weight:**

❖ Sandbags (filled with earth): For the **main dome**:

- Surface Area of Dome=$2\times\pi\times r^2$

  Surface Area of the Main Dome=$2\times 3.14\times (2.285)^2 = 32.8\ m^2$

  The surface of the four apses: $37.16-32.8 = 4.36\ m^2$
- Dome principles: the height of the hemisphere is the radius of the hemisphere.

  The height of the walls would be approximately 2.285 meters (or 7.5 feet).
- The surface of walls: the length of the wall × thick of the wall
- The volume of earth in the wall = Surface Area ×Wall Thickness

  $37.16m^2 \times 0.38m = 14.12\ m^3$
- Weight of Sandbags (filled with earth):

  *Density of sand: $1602 kg/m^3$ [112]

Weight of Sandbags (filled with earth) $=14.12\ m^3 \times 1602 kg/\ m^3 = 22620.24$ kg (22.6 tons).

Number of sandbags

- The volume of earth in the wall $=14.12\ m^3$
- the length of the circular wall of the main dome $=\pi \times$Diameter

  the length of the main dome wall $= 3.14 \times 4.57m = 14.35$meters

  Length of the Wall for the Apses: we have four apses let's assume each two form a hemisphere, and each hemisphere has a surface equal to $2.18\ m^2$ (0.58m radius, 1.16 diameter): Length of the Two Apses wall $= \pi \times$Diameter$= 3.64$m

  Length of the four Apses wall $=3.64 \times 2 = 7.28$m

  Total Length of Wall=Main Dome Wall Length+Four Apses Wall Length

  Total Length of Wall=14.35 m+7.28 m=21.63 meters.
- The number of earthbags is calculated based on the following information provided in [67]:

  Each bag covers approximately 0.075 square meters.
- Number of Bags in the eco shelter: $37.16\ m^2 \div 0.075 m^2$ /bag=496 bags
- Weight of empty bags: 0.2-0.5 kg
- Total weight of empty sandbags: $0.5 kg \times 496$ bags=248kg

- **Sand (Filling Material for Sandbags):**
  - Since sand is sourced locally, we often exclude it from the LCA's total weight but it is important for structural purposes.
  - The volume of sand or earth: 14.12 cubic meters (calculated based on the total surface area of $37.16\ m^2$ and wall thickness of 0.38 m).
  - Weight of Sandbags (filled with earth): 22620.24 kg (22.6 tons).
  - Total weight of empty sandbags: 248kg
  - Total weight of sand: weight of filled sandbags-weight of empty sandbags

    Total weight of sand: 22620.24kg-248 kg=22372.24kg
- **Barbed Wire (Galvanized Steel):**
  - It is used between sandbag layers for reinforcement. Estimated based on a similar structure and calculated by surface area ratio. [64]

Ratio= Surface Area of Eco-dome ÷ Surface Area of Similar structure Dome

Ratio=5.25

Estimated Steel Wire for Eco-dome:46.2kg×5.25=242 kg

- **Plaster (Cement Mix):**
  - The plaster covers the outer surface of the dome, including the apses.
  - Surface Area for Plaster=37.16m
  - Assume a 20 mm thickness of plaster (0.02 m) [68].
  - Volume of Plaster=37.16 m^2×0.02m=0.74 m^3
  - The plaster is 15% cement by weight, with cement having a density of 1,440 kg/m^3 [113].
  - Weight of Cement=0.74 m^3×1440kg/ m^3×0.15=159.84kg

Total Weight=248kg (Sandbags)+242kg (Barbed Wire) + 159.84kg (Cement)=649.84kg

A. Material Emissions phase (from Cradle to Gate):

- Empty Plastic Sandbags (Polypropylene)
  - number of Polypropylene bags: 496 bags
  - total Weight of empty Polypropylene Sandbag: 248 kg.
  - Embodied Energy and GWP of Polypropylene (from the ICE Database):
    - Embodied Energy: 73 MJ/kg [69].
    - GWP (Embodied Factor): 4.49 kg CO_2/kg [103].

Total Embodied Energy of Sandbags=248kg×73MJ/kg=18104MJ

Total GWP of plastic Sandbags=248 kg×4.49 kg CO_2/kg=1113.52 kg CO_2

- Sand or earth
  - total Weight of Sand: 22372.24kg
  - Embodied Energy and GWP of sand (from the ICE Database) [105]:
    - Embodied carbon of Sand: 0.007 kg CO_2/kg
    - Embodied Energy factor: 0.081 MJ/kg [114]

Total Embodied Energy of Sand=22372.24kg×0.081MJ/kg=1812.15MJ

Total GWP of Sand=22372.24 kg×0.007 kg CO_2/kg=156.60 kg CO_2

- **Barbed Wire (Galvanized Steel)**
  - Total Weight of Barbed Wire: 242kg(0.24 tons).
  - Embodied Energy and GWP of Galvanized Steel (from the ICE Database):
    - Embodied Energy: 34.8=35 MJ/kg.
    - GWP: 2.27 kg CO_2/kg.

Embodied Energy of Barbed Wire=242kg×35MJ/kg=8470MJ

Total GWP of Barbed Wire=242 kg×2.27 kg CO_2/kg=549.34 kg CO_2

- **Plaster (Cement Mix)**
  - Surface Area of Plaster: 37.16 m².
  - The thickness of the Plaster: is 2 cm (0.02 m).
  - The volume of Plaster: is calculated using the equation:

    The volume of plaster = Surface area × Thickness

    Volume = 0.7432 m³.
  - Cement Content: 15% by weight.

    The density of Cement: is 1440 kg/m³.
  - Weight of Cement:

    Weight of Cement: 0.7432m3(volume)×1440kg/m3(Density)×0.15(15% cement content) =160kg
  - Embodied Energy and GWP of Cement (from the ICE Database):
    - Embodied Energy: 5.6 MJ/kg [115].
    - GWP: 0.91 kg CO_2/kg [103].

The 85% of sand or earth that is mixed with cement is considered neglected in this study (GWP: 7 kgCO_2, EE:82 MJ).

Total Embodied Energy of Cement=160kg×5.6 MJ/kg=896 MJ

Total GWP of Cement=160 kg×0.91 kg CO_2/kg=145.6 kg CO_2

- **Total Material emissions:**

Total Embodied Energy: 1812.15(sand) +18104(empty plastic-bags) +8470(barbered wire) +896(plaster)=29282.15MJ

Total GWP: 1113.52(plastic-bags) +156.60 (sand)+549.34(barbered wire) +145.6(cement plaster) =1965.06kg CO_2

Material	Weight (kg)	EC Factor kg CO_2/kg	EE Factor MJ/kg	Total GWP kg CO_2	Total EE MJ
Polypropylene Sandbags	248	4.49	75	**1113.52**	18104
Sand	22372.24	0.007	0.081	**156.60**	1812.15
Barbed Wire (Galvanized Steel)	242	2.27	35	549.34	8470
Cement-Stabilized Plaster	160	0.91	5.6	145.6	896
Total				1965.06kg CO_2	29282.15MJ

Table 15: A summary of the material emissions (GWP and Embodied energy)

Source: Created by the author.

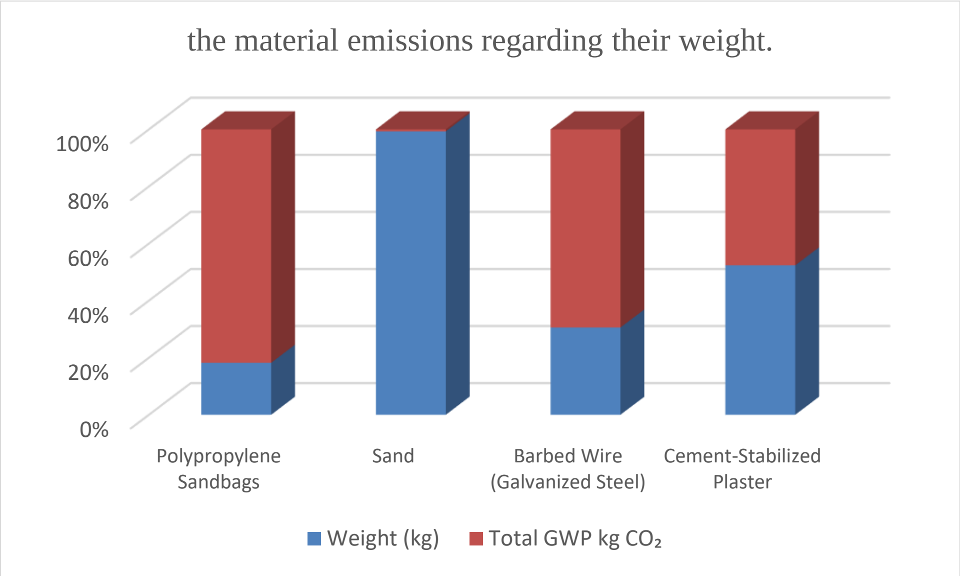


Figure 66: Eco-dome shelter materials emissions regarding their weight.

Source: created by the Author.

B. Transportation Emissions (from Gate to Site)

Calculated using the equation:

- CO_2 transport Emissions=Distance ×Weight ×Emission Factor

Assume the materials are locally transported or within the same country (Iran)

- Truck transport Mode (by land)
  - **Assume transport distances for polypropylene** from the petrochemical production company in Iran called: Bandar Imam Petrochemical Complex which is located in Mahshahr to the Bam City is 1219 km by road (calculated using google maps).

    CO_2 Emissions=1219 km×0.248tons×0.08kg CO_2/ton-km=24.18 kg CO_2

  - **Assume transport distances for Cement** from Kerman Cement Factory to Bam City is approximately 210 km by road (calculated using google maps).

    CO_2 Emissions=210km×0.16tons×0.08kg CO_2/ton-km=2.69kg CO_2

  - **Assume transport distances for Barbed wire (Galvanized Steel)** from Mobarakeh Steel Company in Isfahan to Bam City is approximately 859 km by road (calculated using google maps).

CO_2 Emissions=859km×0.24tons×0.08kg CO_2/ton-km=16.49kg CO_2

  - Assume that the sand has 0 emissions as it can collected from the site.

Total GWP for Transport=24.18 kg CO_2(polypropylene earthbag)+ 2.69kg CO_2(Cement)+16.49kg CO_2(Barbed wire steel)= 43.36kg CO_2

Overall LCA Summary:

Materials emissions: 1965.06kg CO_2.

Transportation emissions: 43.36 kg CO_2.

Total GWP for the Eco-dome Shelter in Iran (from cradle to Site): 2008.42 kg CO_2e per shelter.

The earthbag shelter can last over 30 years according to the calearth' report [116]

The comparative Metric: GWP/ Lifespan/Area:

2008.42 kg CO_2e /30 year/37.16 m^2=1.80 kg CO_2e/Year/ m^2

Material	EE MJ	GWP kg CO_2	GWP transportation
Polypropylene Sandbags	18104	1113.52	24.18
Sand	1812.15	156.6	0
Barbed Wire (Galvanized Steel)	8470	549.34	16.49
Cement-Stabilized Plaster	896	145.6	2.69
Total	29282.15MJ	1965.06kg CO_2	43.36kg CO_2
		Emissions from cradle to site 2008.42	

Table 16: Present a summary of the life cycle assessment results.

Source: created by the author.

4.2.4.4 <u>Fourth Shelter Durable shelter Mahama settlement, variation A</u>

Figure 67: The Mahama Durable Shelter

Source: [74]

Shelter Overview: it was designed in Mahama settlement by UNHCR and Rwandan governments to transform the settlement which was founded in 2015 from a temporary site into a more durable, integrated settlement through an innovative and long-term response plan, that promotes refugee self-reliance and integration with the host community. Temporary shelters are being replaced by the more durable, brick alternatives, which were designed as twin structures due to the scarce availability of land. One shelter unit can therefore host two households [74]. Following is a detailed bill of quantity of the shelter. See Figure below

Raw materials used[3*]	gum trees	1 m^3
	water[1*]	126 600 liters
	soil	21.5 m^3
	quarry stones	10 m^3
Manmade materials used	plastic (damp course)	0.02 m^3
	steel (nails, CGI, bars)	174 kg
	cement	405 kg
	sand	6 m^3

Figure 68: bill of quantity of Mahama Durable Shelter

Source: [74]

The structure of the shelter is as follows [74]:

- Walls: Cement plastered sun-dried mud-brick.
- Roof: Corrugated iron sheets.
- Footing: 40x70 cm mud-brick foundations.
- Floor: Compacted earth.
- Openings: 2 doors (90x200 cm), 4 windows (60x60 cm), and 4 gable vents (50x30 cm).
- Area: 34.6 m², suitable for 5 occupants.
- Materials:

➢ **Regionally/Locally Sourced Materials**: Water, timber, straw, clay-rich soil, bricks, sand, cement, and cement-based products.

➢ **Imported Materials:** Some steel and plastic-based products are imported, primarily from China.

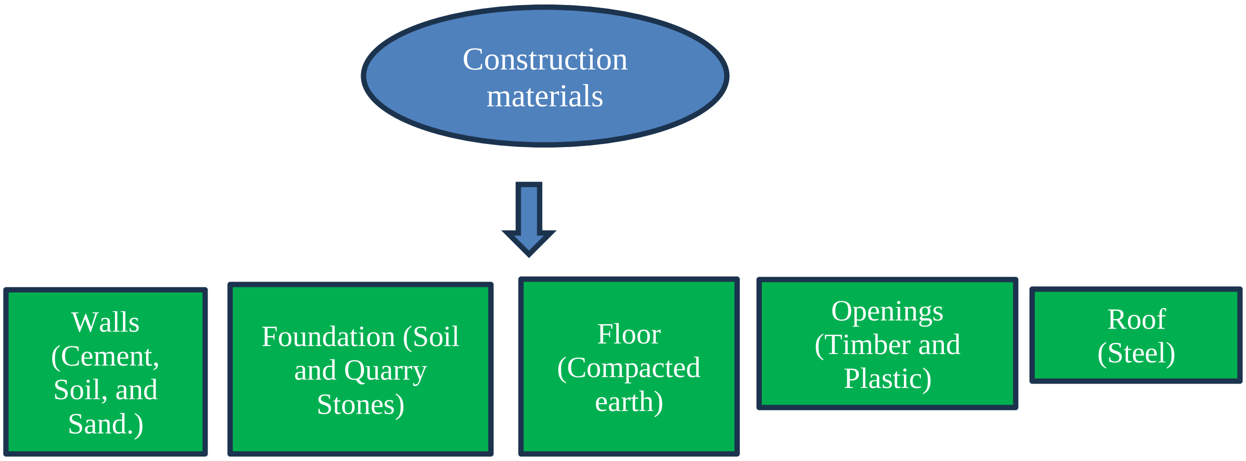


Figure 69: The total materials used to build the Mahama durable shelter.

✓ **Material Emissions:**

❖ **Quarry stones**: Quantity: 10 m³ [74]

➢ The density of stone: 1474 kg/m³ [117]

➢ Mass of quarry stone=10m³×1474kg/m³=14740kg

➢ Embodied carbon of stone: 0.079 kg CO_2-eq/kg (ICE Database)

➢ Embodied energy factor :0.16MJ/Kg [118]

GWP for quarry stone:14740kg×0.079kg CO_2-eq/kg=1164.46kg CO_2-eq

EE for quarry stone: 14740kg×0.16MJ/Kg =2358.4 MJ

- **Gum Trees (1 m^3)**

  - Volume: 1 m^3
  - The density of Gum Wood: The density of wood is 538 kg/m^3 (database)
  - Mass: 1 m^3×538 kg/m^3=820 kg
  - GWP of Gum Wood: 0.263 kg CO_2-eq/kg (database)
  - Embodied energy factor: 9.062 MJ/kg [119]

  (Gwp)Emissions from Gum Wood: 538kg×0.263kg CO_2-eq/kg=141.49 kg CO_2-eq

  EE: 538kg×9.062 MJ/kg =4875.35 MJ

- **Soil (21.5 m^3)**

  - The density of Soil: 1300 kg/m^3 [120]
  - Mass: 21.5 m^3×1300 kg/m^3=27,950 kg
  - GWP for Soil: 0.024 kg CO_2-eq/kg [88]
  - Embodied energy factor: 0.01 MJ/kg

GWP of Soil=27950 kg×0.024 kg CO_2-eq/kg=670.8 kg CO_2-eq

Embodied Energy = 27,950 kg × 0.01 MJ/kg = 279.5 MJ

- **Plastic (Damp Course) (0.02 m^3)**

  - Density of Plastic (LDPE typical for plastic sheeting): 940 kg/m^3 [121]
  - Mass: 0.02 m^3×940 kg/m^3=18.8 kg
  - GWP for Plastic: 2.6 kg CO_2-eq/kg [102]
  - Embodied Energy factor: 73 MJ/kg (Boustead, 2005).

GWP of Plastic=18.8 kg×2.6 kg CO_2-eq/kg=48.8 kg CO_2-eq

EE: 18.8 kg×73MJ/Kg=1372.4MJ

- **Steel (Nails, CGI, Bars) (174 kg)**

- Embodied factor of Steel: 1.99 kg CO_2-eq/kg [102]
- Embodied energy factor: 35 MJ/kg (database)

GWP of Steel: 174 kg×1.99 kg CO_2-eq/kg=346.26 kg CO_2-eq

EE: 174 kg × 35 MJ/kg = 6090 MJ

- **Cement (405 kg)**

  - Embodied carbon of Cement: 0.91 kg CO_2-eq/kg [105]
  - Embodied Energy factor: 5.6 MJ/kg (Concrete and Embodied Energy – Can using concrete be carbon neutral, 2024).

GWP of Cement: 405 kg×0.91 kg CO_2-eq/kg=368.55 kg CO_2-eq

EE: 405 kg×5.6 MJ/kg =2268MJ

- **Sand (6 m^3)**

  - The density of Sand: 1600 kg/m^3 [105]
  - Mass: 6 m^3×1600 kg/m^3=9600 kg
  - Embodied carbon of Sand: 0.007 kg CO_2-eq/kg
  - Embodied Energy factor: 0.081 MJ/kg [114]

GWP of Sand:9600 kg×0.007 kg CO_2-eq/kg=67.2 kg CO_2-eq

EE of sand :9600 kg×0.081 MJ/kg=777.6 MJ

Total GWP (Material Emission Phase): 141.49 (Gum Trees) + 670.8 (Soil) + 1164.46 (Quarry Stones) + 48.8 (Plastic) + 346.26 (Steel) + 368.55 (Cement) + 67.2 (Sand) =2807.56 kg CO_2-eq

Total EE: 2358.4 (Quarry Stone) + 4875.35 (Gum Trees) + 279.5 (Soil) + 1372.4 (Plastic) + 6090 (Steel) + 2268 (Cement) + 777.6 (Sand) = 18021.25 MJ

Material	Weight (kg)	EE Factor (MJ/kg)	EE(MJ)	E C Factor (kg CO2-eq/kg)	GWP (kg CO2-eq)
Quarry Stones	14740	0.16	2358.4	0.079	1164.46
Gum Trees (Wood)	538	9.062	4875.35	0.263	141.49
Soil	27950	0.01	279.5	0.024	670.8
Plastic (Damp Course)	18.8	73	1372.4	2.6	48.8
Steel (Nails, CGI, Bars)	174	35	6090	1.99	346.26
Cement	405	5.6	2268	0.91	368.55
Sand	9600	0.081	777.6	0.007	67.2
Total	53425.8		18021.25		2807.56

Table 17: A summary of the material emissions (GWP and Embodied energy)

Source: created by the author.

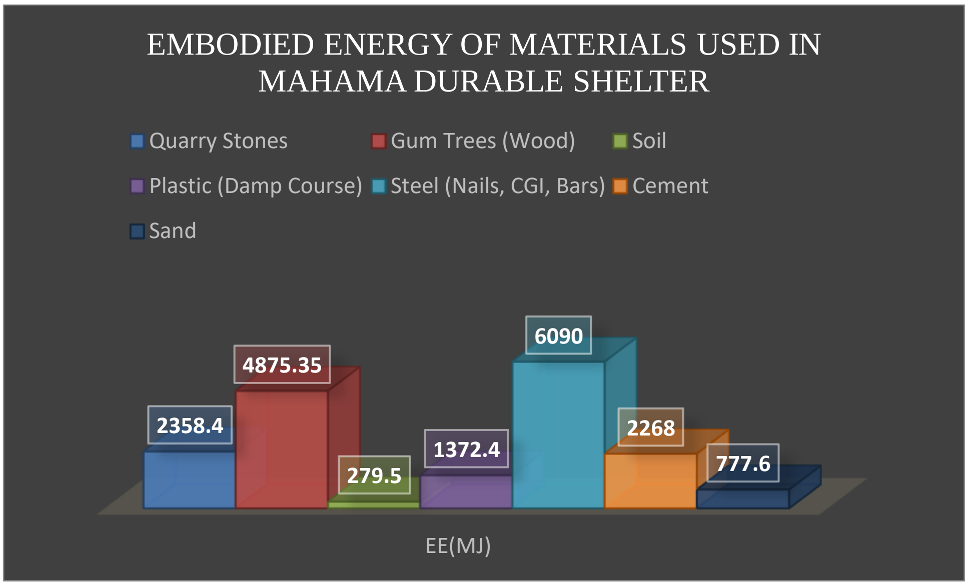


Figure 70: the calculation results of Embodied energy of materials used in Mahama shelter.
Source: created by the author.

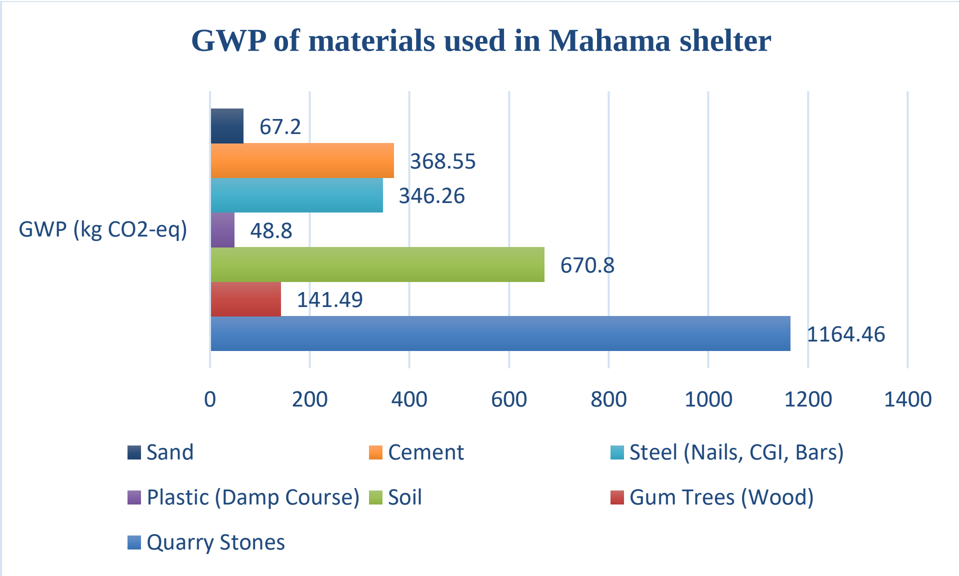


Figure 71: the results of GWP calculation of materials used in Mahama shelter.

Source: created by the author.

✓ **Transportation Phase (from Gate to site):**

•Assuming the imported materials (plastic-based items, some steel, and iron products) are transported from the UNHCR Center located in Beijing to Shanghai port which is the busiest shipping port in China (Chipchura, 2024).

- According to Google Maps, the distance is 1427 Km, assuming half of the steel 87 kg + 18.8 kg of the plastics items are imported. (Total mass 105.8kg=0.1058 tons)

GWP for road transport (Beijing to Shanghai port):0.1058tons×1,427km×0.08kg CO_2-eq/ton-km GWP=12.07kg CO_2-eq

Shanghai Port to Mahama Settlement (Sea and Road):

- Shanghai Port (China) to Dar es Salaam Port (Tanzania), distance 12,967.4 km by Sea [76]

  GWP for sea transport (from china port to Tanzania port):0.1058tons×12,967.4km×0.02kg CO_2-eq/ton-km =27.43kg CO_2-eq

- Dar es Salaam Port (Tanzania) to Mahama settlement in Kirehe District in the Eastern Province of Rwanda, distance 1319 km by road (calculated based on Google Maps)

GWP for transport:0.1058tons×1319 km×0.08kg CO_2-eq/ton-km=11.16kg CO_2-eq

Total GWP for Imported Materials Transport:

Total GWP=12.07kg CO_2-eq+27.43kg CO_2-eq+11.16kg CO_2-eq=50.66kg CO_2-eq

•Assuming the local materials (Timber, Cement, some steel and iron products) are transported from nearby factories within a distance of around 250km - 350km while considering water, soil, sand, and other natural materials are taken from the site which means their transportation is equal to 0.

Total Mass (tons) =0.405tons(cement)+0.087 tons(steel)+0.538(timber) =1.03tons

GWP for transport=1.03×350km×0.08kg CO_2-eq/ton-km=28.84kg CO_2-eq

Total transport: 50.66kg CO_2-eq +28.84 kg CO_2-eq=79.5 kg CO_2-eq

Overall LCA Summary:

Materials emissions: 2807.56 kg CO_2-eq

Transportation emissions: 79.5 kg CO_2-eq

Total GWP for the Mahama durable Shelter (from cradle to site): 2887.06 kg CO_2e per shelter.

GWP/ Lifespan/Area: 2887.06 kg CO_2e /10 year/34.6 m^2=8.34 kg CO_2e/Year/ m^2