
**Modular Emergency Relief:
A Proposal for Integrating Modular Buildings into Post-Flood
Reconstruction and Recovery**

Master's Thesis

International Master of Science in Construction and Real Estate Management

Faculty 2

from

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Yours truly,

Zeemam Abdur Rehman

Conceptual Formulation



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Conceptual Formulation

**Master Thesis for Mr. Zeemam Abdur Rehman
Student Number S585950**

**Topic: Modular Emergency Relief: A Proposal for integrating Modular
Buildings into Post-Flood Reconstruction and Recovery**

A handwritten signature in black ink, appearing to read 'Rajan', written above a horizontal line.

Signature of the 1st Supervisor

A handwritten signature in black ink, reading 'Richa Srivastava', written above a horizontal line.

Signature of the 2nd Supervisor

M.Sc.,M.Eng. Richa Srivastava



– Introduction

According to the (Federal Flood Commission, 2021), Pakistan (case study country) has witnessed 29 super riverine, urban, and flash floods in its 75-year history, with a record of a flood every year since 2010. Each year, floods wreak havoc on the people of Pakistan, leading to millions of dollars of damage, causing loss of life, cattle, crops, displacement, destruction of property and livelihoods. The worst flood in decade (from 14 June to October 2022) affected 33 million people and more than 1,730 lost their lives (National Disaster Management Authority, 2022). More than 8 million displaced people now facing a health crisis. Flood damages and economic losses over USD 30 billion and reconstruction needs over USD 16 billion (The World Bank (Press Release), 2022). The immediate causes of the floods were heavier than usual monsoon rains and melting glaciers that followed a severe heat wave, both of which are linked to climate change (Kara Fox CNN, 2022).

Today, Pakistan Flood 2022 victims are facing a severe housing crisis. The heavy rainfall, floods and landslides have led to the largest housing loss in any disaster this century. According to the recent report of NDMA, nearly 2.3 million houses have been damaged or destroyed/ washed away across Pakistan (National Disaster Management Authority, 2022). There are at least 598,000 displaced people living in collective centres, along displacement sites, and in camps (UNOCHA, 2022).

Shelter Kits, plastic sheeting, tents, and cash assistance are some of the sheltering solutions used in shelter programmes (UNHCR Emergency Handbook, 2022). Modular construction has a considerable potential to improve the construction time gap drastically and provide a holistic approach (Ghannad et al., 2020). The research gap identified is that little research has been done yet for the implementation of modular houses for Post-Flood/ Post-disaster recovery. Therefore, in this study, we shall explore the potential of using modular emergency relief as a better alternative for post-flood reconstruction and recovery for our case study in Pakistan.

– Research Objective

This research aims to:

- Explore the potential of using modular emergency relief as a solution for post-flood reconstruction and recovery in Pakistan.
- Examine the design and construction process of modular buildings, its cost, speed of deployment, use of eco-friendly materials, stability and integrity of components and transportation challenges.
- Propose a design of a modular house using 6D-BIM model and study its feasibility. This will provide a comprehensive overview of the feasibility of modular emergency relief Proposal.

– Methodology

The used methods would be:

- The proposed model design will be the primary data of this thesis. This modular house model will be designed from the information learned by the literature review to reduce the construction time and use of smart and eco-friendly materials.
- Examination of secondary data collection methods will involve data collection from books, journals, recorded videos, online internet sources, reports etc by intensive literature review on Modular construction, designing, specific features and requirements, use of eco-friendly materials and transportation.
- These findings will then be used to make a proposal with 6D-BIM Modelling for the use of these modular housing in emergency cases. 3D-Architectural Model, 4D-Scheduling, 5D-Cost Estimation, 6D-Energy Analysis will be performed.



- Resources

Softwares to be used: Autodesk Revit Architecture, Primavera P6 Professional, Autodesk Navisworks Manage, Autodesk Insight 360 and Microsoft Office Suite.

Sources for Literature review: Google Scholar, Science Direct, Metropolia Library, HTW Library, etc.

- Timetable

| Time and period | Anticipated Activity |
|--------------------------------|--|
| February 2023 to June 2023 | Comprehensive and thorough reading of the research topic |
| July 2023 to September 2023 | Identify and learn key software and review previous publications |
| October 2023 to November 2023 | Gathering primary data |
| November 2023 to December 2023 | Examining secondary data and writing subtopics |
| January 2024 to March 2024 | Develop the BIM model |
| March 2024 to April 2024 | Data analysis and proposal and writing subtopics |
| April 2024 to May 2024 | Research conclusion |

- References

- Ghannad, P., Lee, Y.-C., & Choi, J. O. (2020). Feasibility and Implications of the Modular Construction Approach for Rapid Post-Disaster Recovery. *International Journal of Industrialized Construction*, 1(1), 64–75. <https://doi.org/10.29173/ijic220>
- Federal Flood Commission. (2021). *Federal Flood Commission, Government of Pakistan, Annual Report*. www.ffc.gov.pk
- Kara Fox CNN. (2022). *Pakistan's melting glaciers are 'erupting' and worsening floods*. <https://edition.cnn.com/2022/09/01/asia/pakistan-flooding-glacier-outbursts-climate-intl/index.html>
- National Disaster Management Authority. (2022). *NDMA Floods (2022) SITREP - 2022 (Daily SITREP No 158 Dated 18th November 2022)*. <http://cms.ndma.gov.pk/>
- The World Bank (Press Release). (2022, October 28). *Pakistan: Flood Damages and Economic Losses Over USD 30 billion and Reconstruction Needs Over USD 16 billion - New Assessment*. <https://www.worldbank.org/en/news/press-release/2022/10/28/pakistan-flood-damages-and-economic-losses-over-usd-30-billion-and-reconstruction-needs-over-usd-16-billion-new-assessme>
- UNHCR Emergency Handbook. (2022). *Shelter Cluster*. <https://emergency.unhcr.org/coordination-and-communication/cluster-system/shelter-cluster>
- UNOCHA. (2022). *Revised Pakistan 2022 Floods Response Plan: 01 Sep 2022 - 31 May 2023 (04 Oct 2022)*. <https://reliefweb.int/report/pakistan/revised-pakistan-2022-floods-response-plan-01-sep-2022-31-may-2023-04-oct-2022>

Abstract

Recurring floods in Pakistan have created a pressing need for post-disaster reconstruction and recovery solutions. Modular emergency relief could be a viable solution to this research's housing crisis caused by recurrent floods. In this context, the study aims to comprehensively examine the modular building design, construction processes, cost-effectiveness, the use of energy-efficient materials, structural integrity, and transportation challenges from various case study projects. Furthermore, it proposes a modular house design that utilises a 6D-BIM model to assess the feasibility of the design comprehensively. Using primary model design data and a secondary literature review, of the findings from the case studies, the research integrates cost-effective and energy-efficient materials with standard modular construction techniques along with a transportation and deployment plan. A disaster-relief Colony Plan of 200 Modular houses with Amenity structures is also proposed. This 6D-BIM modelling is performed which allows for a comprehensive design feasibility assessment, by integrating the 3D model with Project Timeline Scheduling (4D), Cost Estimation and Simulation (5D), and Energy Analysis (6D) assessment. This 6D BIM design and analysis provides a comprehensive analysis and argues for the viability of the project in the future. By filling this research gap, the findings are expected to inform the stakeholders involved to facilitate the adoption of efficient and sustainable solutions for mitigating the impact of the housing crisis due to floods in Pakistan and similar disaster-prone regions worldwide by providing a modular design approach for rapid deployment disaster-relief Modular housing solution.

Keywords: Modular Building, Post-Flood Reconstruction, Design Proposal, 6-D BIM Model, Pakistan

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List of Abbreviations

| | |
|--------|---|
| 6D-BIM | 6-Dimensional Building Information Modeling |
| AEC | Architecture, Engineering, & Construction |
| AISC | American Institute of Steel Construction |
| AVI | Audio Video Interleave |
| BIM | Building Information Modeling |
| BMB | Better Business Bureau |
| CAD | Computer-Aided Design |
| CAGR | Compound Annual Growth Rate |
| CLT | Cross-Laminated Timber |
| CNN | Cable News Network |
| COP | Conference of the Parties |
| CSV | comma-separated values |
| M'DAM | Monnickendam |
| DIN | Deutsches Institut für Normung e.V. |
| EPC | Energy performance coefficient |
| EPS | Expanded Polystyrene foam |
| EU | European Union |
| FEMA | Federal Emergency Management Agency |
| FIFA | Fédération Internationale de Football Association |
| FRP | Fiber Reinforced Polymer |
| GFRP | Glass Fiber Reinforced Plastics |
| GHG | Greenhouse Gas Emissions |
| GmbH | Gesellschaft mit beschränkter Haftung |
| GoP | Government of Pakistan |

| | |
|---------|---|
| GSAS | Global Sustainability Assessment System |
| HSS | Hollow Structural Sections |
| HTW | Hochschule für Technik und Wirtschaft |
| ICC | International Cricket Council |
| IKEA | Ingvar Kamprad Elmtaryd Agunnaryd |
| IMF | International Monetary Fund |
| IPCC | Intergovernmental Panel on Climate Change |
| IPR | Intellectual property rights |
| KWh | Kilowatt hours |
| LEGO | Leg Godt |
| LOG | Lari Octa Green |
| Low-E | Low Emissivity |
| MEP | Mechanical, electrical and plumbing |
| MgO | Magnesium Oxide |
| MPa | Mega Pascal |
| NASA | National Aeronautics and Space Administration |
| NDMA | National Disaster Management Authority |
| NGOs | Non-Governmental Organization |
| OECD | Organization for Economic Cooperation and Development |
| PEB | Pre-Engineered Building |
| PUR | Polyurethane Foam |
| PKR | Pakistani rupee |
| PPS | Paper Partition System |
| PV | Photo Voltaics |
| PVC | Polyvinyl Chloride |
| R-Value | Thermal Resistance Value |

| | |
|---------|--|
| RHU | Relief Housing Unit |
| SDGs | Sustainable Development Goals |
| SIP | Structural Insulated Panels |
| U-Value | Thermal Transmittance Value |
| UAE | United Arab Emirates |
| UAS | University of Applied Sciences |
| UN | United Nations |
| UNHCR | United Nations High Commissioner for Refugees |
| UNICEF | United Nations Children's Fund |
| UNOCHA | United Nations Office for the Coordination of Humanitarian Affairs |
| UNSDG | United Nations Sustainable Development Goals |
| UPVC | unplasticized polyvinyl chloride |
| US | United States |
| USA | United States of America |
| USD | United States Dollar |
| WBS | Work Breakdown Structures |
| WHO | World Health Organization |

1. Introduction

1.1. Background

The need for emergency response solutions to flood disasters is pressing. Various researchers have defined and studied the disaster from different perspectives. They defined the catastrophe as an unpredicted event that resulted in massive fatalities and considerable properties being destroyed. The Federal Emergency Management Agency (FEMA) has stated that mitigation, preparedness, response, and recovery are the four phases of a disaster. Quick and efficient response of government agencies in the aftermath of a disaster to facilitate housing efforts post-disaster and commit reasonable resources for temporary houses for near-term disaster response and rebuilding lost homes for a complete reconstruction. (Ghannad et al., 2020; Smith, n.d.)

Temporary housing accommodation is necessary shortly after the disaster as a short-term housing response. It will take years to build new infrastructures using customary construction methods. In an emergency response, time will be limited to fulfil the requirement of a building, which is the most important of all, and thus faster construction technology is required. This may vary from five years or even more than 10 years, depending on the scale of the disaster. Indeed, it takes decades for communities and people to restore normal livelihoods. (Shahzad et al., 2022)

Time also counts as a significant variable in the reconstruction process to reduce the people's impact. Therefore, time is critical for rehabilitating and building projects to do away with future devastating social and economic influences in the lags and overruns for the affected regions. Modular offsite construction is increasingly gaining popularity as a solution to the time factor of other technologies among all new technologies in post-disaster recovery. (Shahzad et al., 2022)

The lack of affordable housing is increasingly becoming a global crisis. According to estimations of the UN special rapporteur on the right to adequate housing, 1.6 billion people, a fifth of humanity, lack access to adequate housing with essential services. By 2030, this number may double to 3 billion. For most of the past decade, housing prices have been growing at a faster rate than incomes in most countries of the Organization for Economic Cooperation and Development (OECD). (Solf et al., 2024)

1.2. Problem Statement

According to the (Federal Flood Commission, 2021), Pakistan (case study country) has had 29 severe urban, riverine, and flash floods in its seventy-five-year history, with a record of a flood every year since 2010. Each year, floods wreak havoc on the people of Pakistan, leading to millions of dollars of damage, causing loss of life, cattle, crops, displacement, and destruction of property and livelihoods. The worst flood in a decade (from 14 June to October 2022) impacted 33 million individuals, with over 1,730 fatalities and injured more than 12,860 people (National Disaster Management Authority, 2022). Over 8 million displaced persons are currently experiencing a health crisis. Over USD 16 billion is needed for reconstruction after floods caused over USD 30 billion in damages and economic losses. (The World Bank, 2022).

The floods were directly caused by melting glaciers after a particularly strong heat wave and much higher than-normal monsoon rains, both of which are related to climate change. (Kara Fox CNN, 2022). Today, Pakistan Flood 2022 victims are facing a severe housing crisis. An intense low-pressure system that developed over the land area due to the summer heat waves in May and June, coupled with several days of extremely high rainfall on wet antecedent soil conditions, which increases the likelihood of flooding, and the glacial melt, all contributed to this unprecedented climate-induced disaster. The greatest loss of homes in any disaster this century in the world is the result of the intense rains, flooding, and landslides in Pakistan. (UNOCHA, 2022)

The Government of Pakistan has declared 84 districts (Figure 1) in the country as "calamity hit," the bulk of which were in Khyber Pakhtunkhwa (17), Sindh (23) and Balochistan (32) (UNOCHA, 2022). According to a recent report by NDMA, there have been about 2.3 million damaged or destroyed homes/ washed away across Pakistan as shown in Figure 2 (National Disaster Management Authority, 2022). Living in camps, along displacement sites, and in collective centres are at least 598,000 displaced persons. Over USD 30 billion in economic losses due to flooding and farmlands covering 1,540,000 acres were washed away. This flood affected two-thirds of the country; therefore, the supply of goods and transportation of aid underwent major issues as well (UNOCHA, 2022).

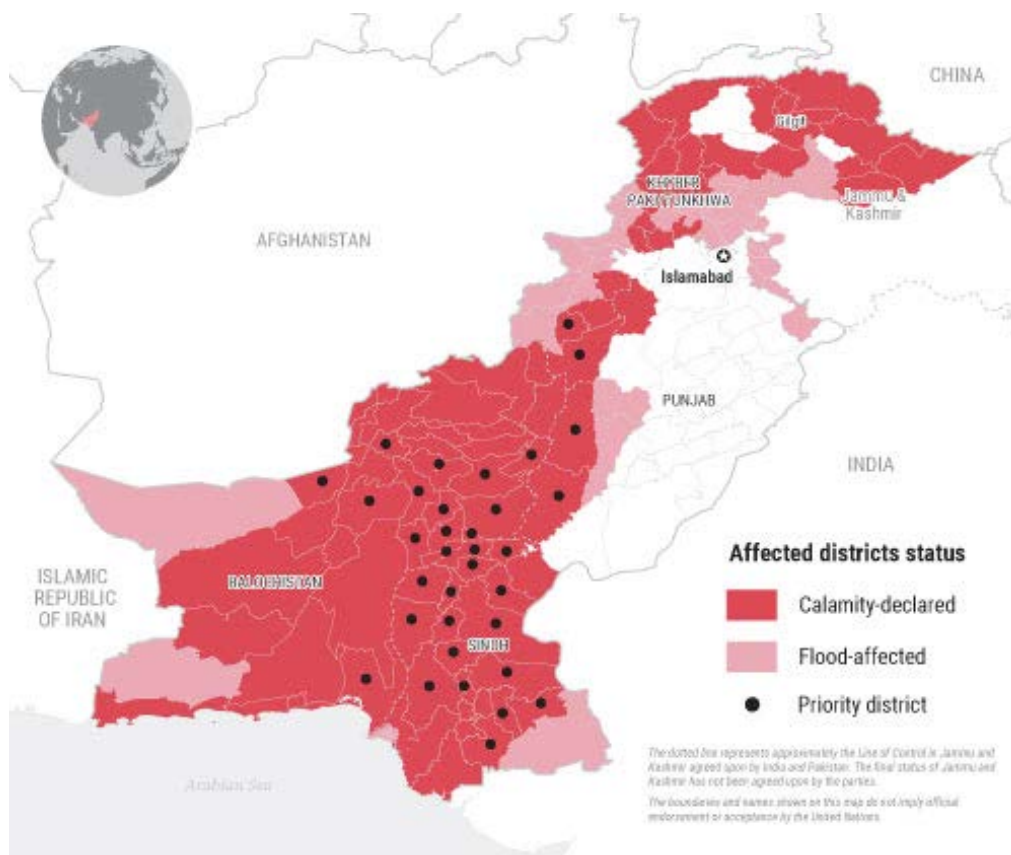


Figure 1: Flood-affected districts in Pakistan Flood 2022

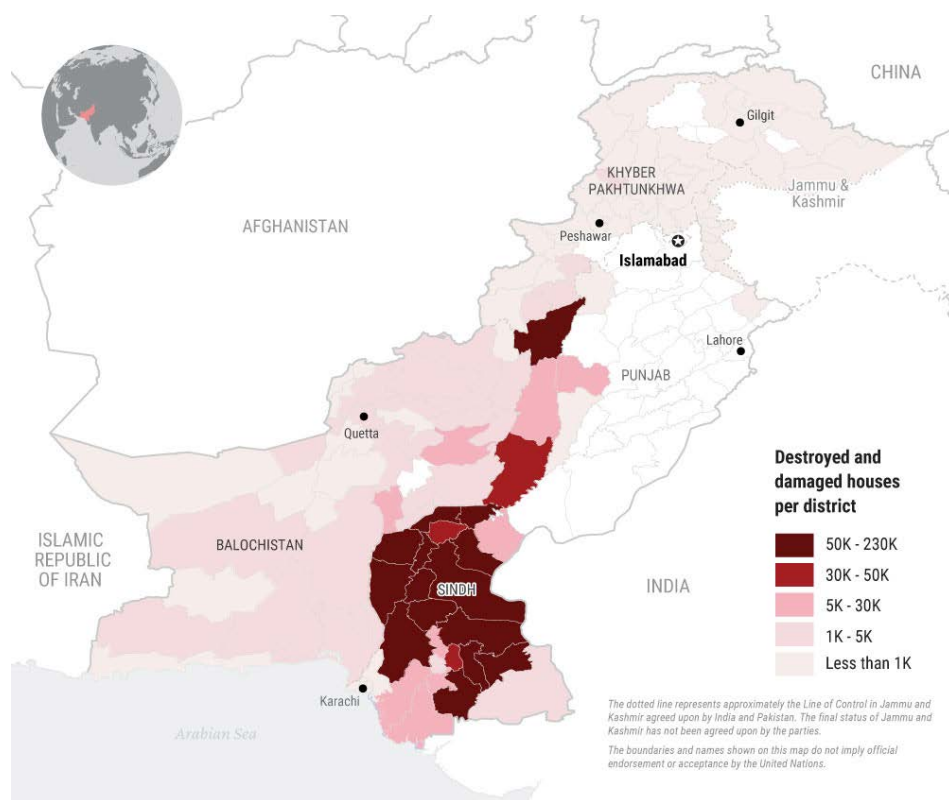


Figure 2: Damaged and destroyed houses per district due to Pakistan Flood 2022

Statistics show that heavy falls and floods have severely hit Sindh and Baluchistan provinces in those districts that are generally affected by drought. Before the flood on August 4, 2022, it shows the regions of Punjab, Sindh, and Baluchistan lining the Indus River, before August 4, 2022, after the flood of August 28, 2022 in the first and second images in Figure 3 respectively. The images are taken using NASA Landsat 8 and 9 satellites, describing the catastrophic floods in Qamber, Shikarpur, Larkana, and Shadadkot. Furthermore, the Sindh and Punjab provinces received six times the normal monsoon precipitation compared to their 10-year average rainfall history. For example, Qamber and Shikarpur districts have, in the recent past, received 500 times their average rainfall as shown in Figure 4. (Saifi et al., 2022)

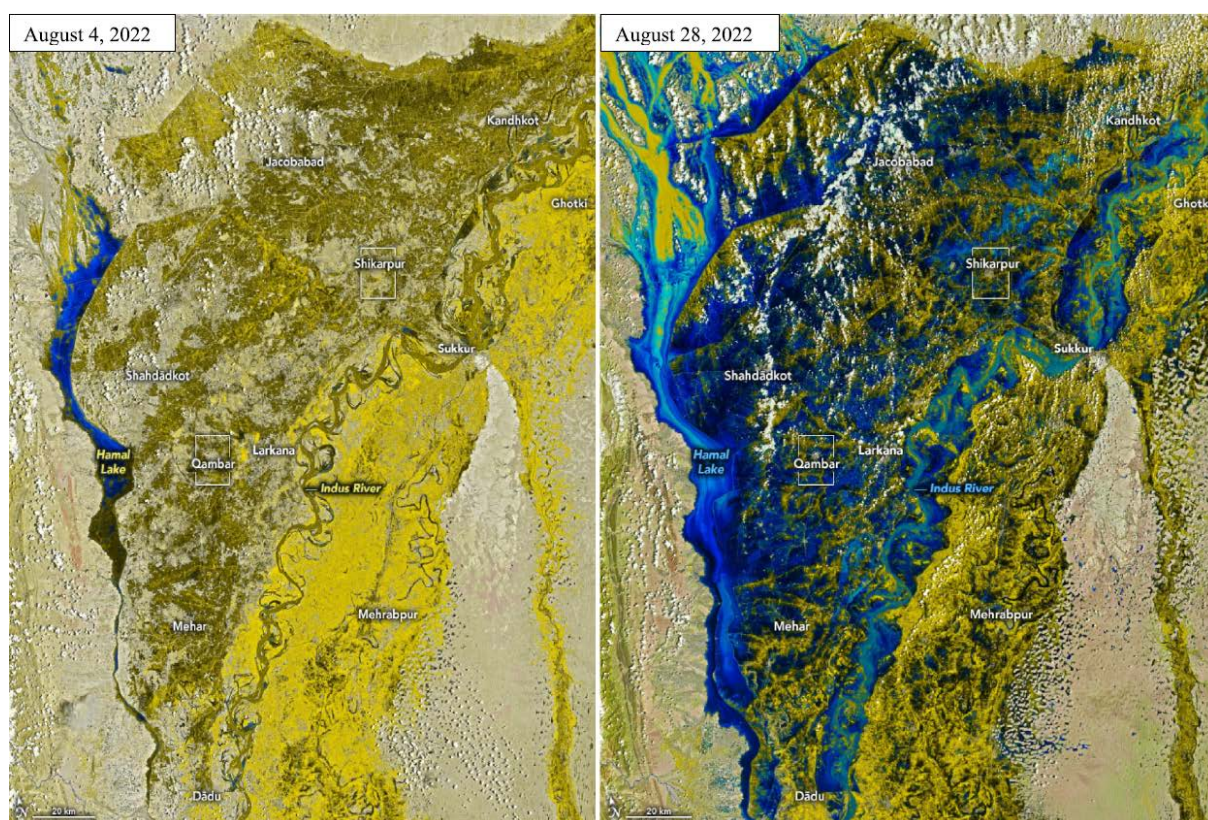


Figure 3: Flood Situation from Satellite images on 4th August 2022, and 28th August 2022 in Pakistan

These effects are a clear indicator of a worsening climate emergency. However, it is regrettable that Pakistan, which is contributing only 0.9% of the world's greenhouse gas emissions (GHG), the nation where climate change is having some of its harshest consequences. The country has been ranked among the Global Climate Risk Index's top 10 nations most impacted by climate change for the past two decades. (GoP, 2021) Speaking to the Nation, the UN humanitarian coordinator in Pakistan, Julien Harneis

stated that Climate change is the primary cause of this massive flood; its causes are global. Pakistan has become the latest nation to suffer from a global calamity which it has not contributed to in any way, owing to the high carbon emissions from developed countries and other polluting nations. Such unfairness has therefore been increasing the demand for climate reparations from Pakistan and the rest of the Global South. Also, climate-impacted countries like Bangladesh, Ethiopia, and Tuvalu are demanding payment from developed nations for disasters they are suffering. This demand, also known as 'Loss and Damage', is still not officially included in the list of topics for negotiations at the UN climate change conference, the COP. Climate-vulnerable nations have continuously sought climate reparations from the developed nations and companies that caused climate change, but their pleas have always been rejected (International Monetary Fund (IMF), 2024).

Shelter Kits, plastic sheeting, tents, and cash assistance are some of the sheltering solutions used in shelter programmes in Pakistan (UNHCR Emergency Handbook, 2022). There is a great opportunity for Modular construction to provide a comprehensive plan and significantly reduce the construction time gap. (Ghannad et al., 2020).

In this research, 3 Nos. of goals by The United Nations Sustainable Development Goals (UNSDG) are targeted which were issued and created by the United Nations in 2015 (The 2030 Agenda for Sustainable Development's 17 Sustainable Development Goals (SDGs), n.d.). The pursued SDGs include:

- Goal# 9: Industry Innovation and Infrastructure
- Goal# 11: Sustainable cities & communities
- Goal# 13: Climate Action

The research gap identified is that little research has been done yet for the implementation of modular houses for Post-Flood/ Post-disaster recovery in Pakistan. Therefore, in this study, we shall explore the potential of using modular emergency relief as a better alternative for post-flood reconstruction and recovery for our case study in Pakistan.

Therefore, the objective of this research is to assess and evaluate the viability of implementing Modular Construction practices as a possible solution for people of flood-affected region in Pakistan. The proposed temporary Modular housing unit will provide

a safe shelter for the people to live in and to recover until more permanent housing is constructed.

1.3. Research Objectives

The research aims to:

- Explore the potential of using Modular emergency relief as a solution for post-flood reconstruction and recovery in Pakistan.
- Examine the design and construction process of modular buildings, their cost, speed of deployment, use of eco-friendly materials, stability and integrity of components and transportation challenges.
- Propose a design of a modular house using the 6D-BIM model and study its feasibility. This will provide a comprehensive overview of the feasibility of a modular emergency relief Proposal.

1.4. Research Questions

The following are the research questions of this research:

1. Is Modular house a viable solution to be adopted for post-flood recovery in Pakistan?
2. How are modular houses being adopted into post-disaster reconstruction practices around the world and which of their best practices can be adopted into the proposed design of the Modular House?
3. Is the proposed Modular House feasible to solve the need for housing for the flood victims in Pakistan in the future?

1.5. Methodology

The following steps comprise the study methodology, which is based on employing various stages to address the research objectives of the study:

Stage 1: Comprehensive analysis of the literature to address the possibilities of modular building, covering its background, types, advantages, and implementation issues

from case studies projects and the role of BIM. Moreover, to answer the 1st and 2nd research questions.

Stage 2: The development of a proposed 3D Modular house design is the primary data of this thesis. This model is designed from the information learned in 1st stage considering its scope-specific features and deployment requirements.

Stage 3: Further development of 6D BIM models including 4D Scheduling, 5D Simulation and 6D Energy Analysis of this proposed Modular house in the 2nd stage to validate its implementation in Pakistan, in addition to answering the 3rd research question.

Stage 4: A conclusion of the study's results and suggestions for future development based on all the earlier phases.

1.6. Organisation of Chapters

The chapters are organised in the following order:

Chapter 1: includes the study background, problem statement, research objectives and questions and the adopted method of research.

Chapter 2: discusses the current disaster responses in Pakistan, the history of modular construction, its types, example projects, advantages and challenges, using BIM and its related concepts.

Chapter 3: discusses the development of the 3D BIM Modular house by researching on disaster-relief housing solutions case studies projects around the world. Furthermore, its related selection of energy efficient materials and flood relief implementation by proposing a transportation methodology and a Colony planning of these Modular Houses for flood relief.

Chapter 4: discusses a detailed 6D BIM Analysis of the proposed Modular houses for the development of a Colony for flood-relief. The detailed analysis includes 4D Scheduling, 5D Simulation and 6D Energy Analysis. It provides an in-depth understanding of the implementation and viability of proposed Modular house as a flood relief solution.

Chapter 5: summarizes the previous chapters and concludes with the feasibility of the proposal for a Modular relief solution for the flood victims and answering the research questions. It also discusses the recommendations to be considered in future development.

2. Literature Review

This literature review consists of in-depth research and analysis of the Common flood relief housing solutions in Pakistan and then how is this issue handled around the world. Then the lessons learned from how this issue is handled around the world and how it can be implemented in Pakistan.

Modular construction, its types, advantages and disadvantages. Then some modular construction examples for housing around the world. The lessons learned from the various modular construction practices and their reliability.

BIM and its role in modular construction practice. The dimensions of BIM and the various tools used for the development of the 6D BIM Model and its analysis phase for this research.

2.1 Introduction

It is pertinent to mention that the recent floods in Pakistan are attributed to climatologists, in which global warming is considered one of the major factors that has changed the atmosphere (Shehzad et al., 2021). Pakistan has already gone through the weather astrophysics, with abnormally high temperatures before the floods. In April and May 2022, the temperatures were above 40°C, with Jacobabad registering 51°C; far beyond the usual average (Mallapaty, 2022). According to the IPCC, Pakistan's temperature is rising at a rate quicker than the global average, especially in the northern area (Pachauri et al., 2014). More moisture is produced as the temperature rises, and intense events lead to significant precipitation (Clarke et al., 2022).

In the current year, monsoon rains have been more severe in Sindh where 142 mm of rain was recorded on 11-Aug-2022 and 16 days of continuous rains. The rainfall received in Padaidan town in August was 1228mm as evident from Figure 4. (GoP Pakistan Meteorological Department, 2022)

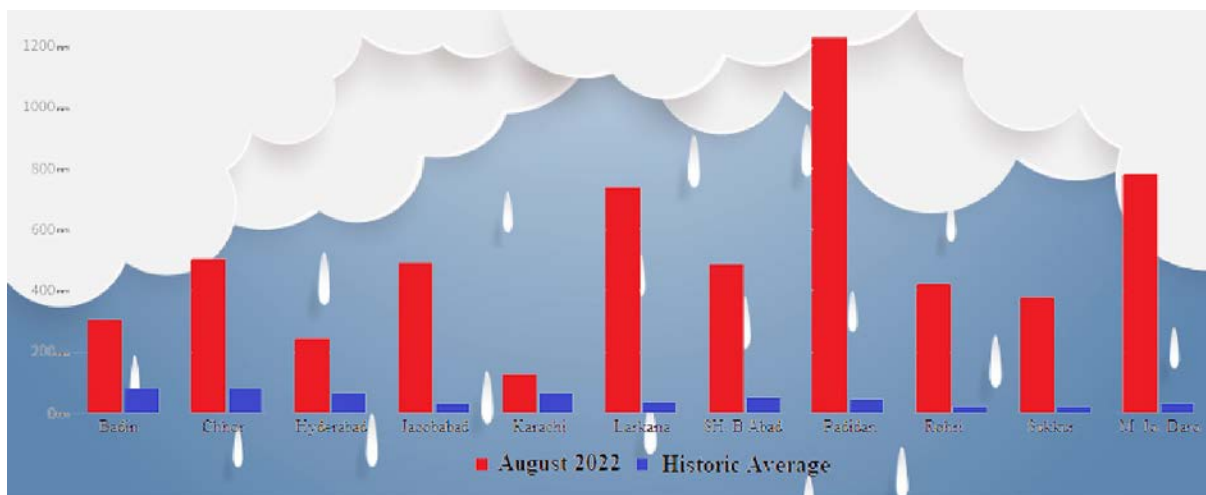


Figure 4: Comparison of Rainfall in August 2022 vs. Historical Average in Sindh, Pakistan. Source: Meteorological Department Pakistan

Also, glacier melt in the northern areas made the water levels of the tributaries go up significantly leading to the enhancement of floods (Mallapaty, 2022) (Figure 5: Flood-affected village in Sindh Province, Pakistan. UNICEF/Asad Zaidi). Lack of water utilisation and poor political stability exacerbated the situation (Bangash, 2022). Other factors include uncontrolled construction, increased rate of urbanization, and alteration of land use in the rate of climate change (Arif et al., 2022).



Figure 5: Flood-affected village in Sindh Province, Pakistan. UNICEF/Asad Zaidi

Climate change affects human existence by causing food shortages, severe weather conditions and species loss. In fact, Pakistan contributes less than 1% to global GHG emissions yet it ranks among the top 10 most climate-vulnerable countries. Temperatures above 40 degrees centigrade and torrential rains have led to the recent floods, which have been estimated to have claimed more than \$10 billion from the economy. The loss of lives was 1280, crop damage and losses, and destruction of infrastructure such as roads; 2000 km of roads were destroyed (Shehzad et al., 2021).

2.2 Stages of Disaster Relief

Disaster management is a very complex process that generally, the national, local, and international bodies, including the United Nations and Red Cross, should respond to in a well-coordinated manner. This implies that disaster management is an area where multi-organizational and multi-agency coordination strategies are put into practice. Strategic planning remains critical in identifying who are the most severely affected people. Disasters are unique phenomena, and what comes out is that they affect different communities differently. Relief and recovery processes also take a long time. In real life, there is no scheduled recovery with the exact timeline of stages. Still, some steps should be taken while affected communities begin to recover and set their lives in motion after disasters. (Dialameh, 2017)

Phase 1 and 2: Preliminary Damage Assessment and Search & Rescue

Post-crisis, both international and national humanitarian organizations undertake rapid needs assessments to gather important information about the victims and other vital populations. The most critical phase is the search and rescue, meant to save lives by emergency services and sometimes by ordinary citizens, local authorities, and emergency response teams. This period lasts from hours to days, after which more organizations focus on supporting the survivors. (Dialameh, 2017)

Phase 3, 4, and 5: Emergency Relief, Early Recovery, and Long-Term Recovery

Emergency relief immediately starts, offering food, water, shelter, and medicine. The phase lasts several months, much longer for more prepared countries like Chile or

Japan but years in case of less equipped ones like Haiti. The early recovery phase introduces stability: people gain access to basic needs and begin to return to their daily routines. Lastly, long-term recovery involves the construction of permanent structures and restoring social systems so that the families are re-stabilized and the social and livelihood is improved. (Dialameh, 2017)



Figure 6: Real-world case studies demonstrating that survivors of natural catastrophes spend more than five years living in makeshift shelters like tents

Figure 6 shows four different cases of disaster response in terms of these phases of recovery in Pakistan, Haiti, Japan and Iran. Usually, it is seen that emergency shelters like tents are the most common survival methods initially that last approximately more than 5 years in these countries. Although this is not the ideal response, this reflects the reality on the ground. (Dialameh, 2017)

2.3 Common Disaster Relief Housing Solutions in Pakistan

There is a vast amount of literature on the topic of shelters in disasters, and different ideas and frameworks have been proposed, but there is no universally correct one. Solutions proposed in a project may vary in terms of design, material, and even how they are assembled. Still, the lack of these ideas, these shelters could not beat the tents that are most popular in the market regarding the ease of assemble and transport (Dobias, 2022).

The following topic analyses examples of solutions that have been utilized after a disaster in Pakistan. Each case is discussed to focus on the best practices and components applicable to the design. These learnings are then used to design and propose a modular house model as per the scope of this thesis.

For flood relief temporary housing solutions, Pakistan has been using Disaster Relief Tents, Lari Octa Green (LOG) shelters, and cash assistance provided by the government and NGOs for reconstruction for sheltering solutions for the disaster-affected people. On the government level, several flood relief programs were announced, flood relief funds were allocated, and several donations were collected from all over the world. Several international Organisations including The World Bank, United Nations, WHO and International Rescue Committee and several countries including the EU, USA, Saudi Arabia, China, UAE, Qatar etc. allocated relief funds and deployed emergency response teams.

The housing relief methods adopted over the affected regions are discussed in detail below.

2.3.1.1 Disaster Relief Tents

Shelter is very important during the post-disaster phase as some people are made homeless by the flooding and loss of their livelihood and property. These tents are usually the initial kind of aid provided to the affected area, which is intended to prevent the loss of life and provide the initial support. Tents for example are foldable, affordable, and can be easily carried from one place to another and can also be easily erected in case of an emergency. But they are designed for temporary use and if applied in the

long-term, they cause many problems such as insecurity, lack of privacy, poor sanitation, and poor insulation. (Dialameh, 2017)

The flood has affected or completely wiped out more than 1.5 million homes. They slept in the rain and the sun without any protection for weeks on end as they tried to get help. However, thousands of Pakistanis have contributed tents and tarpaulin to help the affected people in need. Omar and his team of volunteers managed to raise more than \$40,000 and bought several dozens of tents that were delivered to the affected regions by lorries, helicopters and boats. These areas are Keti Bunder, Kachee, Jhal Magsi, Gandakha, Sukkur, and Khairpur in the southern province of Sindh most affected by the floods. (Bin Javed, 2022)

A flood relief plan by the Pakistan government and UN calls for an immediate \$160 million in international funding, and aid is already arriving. UNHCR donated tents and tarpaulins for temporary shelter for the victims (Figure 7: UNHCR tent at a camp in Sukkur, Sindh, 8th September 2022. AFPPIX).



Figure 7: UNHCR tent at a camp in Sukkur, Sindh, 8th September 2022. AFPPIX

Several Tents were also donated by China for flood relief aid in Matli town of Badin District in southern Pakistan's Sindh province. (Figure 8: A shelter erected with tents provided by China Photo: Xinhua) (Xinhua, 2022)



Figure 8: A shelter erected with tents provided by China Photo: Xinhua

Critical Analysis:

Although the initial conditions of emergency shelters are relatively advantageous, a variety of issues arise when they are utilized as long-term solutions. Most are sub-standard and can easily be torn apart posing a challenge to environmental factors and security issues. Also, these shelters normally do not contain basic amenities such as bathrooms, kitchens, or proper ventilation; hence, living conditions are pitiable, which worsens the psychological and physical health of the occupants. (Dialameh, 2017)

To overcome these deficits, it is necessary to move from the emergency shelters to more permanent or temporary housing. This phase involves the establishment of permanent structures which are more comfortable to live in than the previous structures, for instance, better insulation, sanitation and cooking. The end outcome is to make sure that people can get back to normal and start their lives over in a secure place, thereby minimizing the long-term effects of the disaster on the well-being of affected persons. (Dialameh, 2017)

2.3.1.2 Lari Octa Green (LOG) shelters by Yasmeen Lari

Yasmeen Lari, the first female architect in Pakistan, constructed a branded disaster bamboo house for flood-affected people called Lari Octa Green (LOG) shelter in 2005 after an earthquake devastated Pakistan-administered Kashmir. These homes have been developed by the Heritage Foundation of Pakistan and the structure of these houses is made from locally available bamboo and lime plaster (Figure 9: Lari Octa Green (LOG) one-room shelter designed by Heritage Foundation Pakistan). They are cheap, easily deployable, and eco-friendly, providing temporary shelter and rehabilitation while encouraging sustainable living in disaster-sensitive regions. Lari's initiative is to provide and promote these homes based on the local people's participation and skills to assemble on-site (Jamal, 2023).



Figure 9: Lari Octa Green (LOG) one-room shelter designed by Heritage Foundation Pakistan

These bamboo structures provided by Lari, have been tested to be effective in flood-prone areas as it is more durable when it comes to construction and is environmentally

friendly than the other materials. The design comprises the elevated platforms and the porous pavement to reduce the flood risk. Every house cost around \$89 (PKR 25,000) and it takes only 10 days to construct with local materials such as mud and rice husk. The foundations are made from lime bricks and concrete. The prefabricated Wall Panel, Roof and Door structure is made from locally available bamboo (Figure 10: Locally assembled LOG Shelter bamboo structure construction). While it offers direct protection it is also effective in a way that empowers the community since it involves the people in the construction in addition to promoting local resources. (Hafeez, 2023; Jamal, 2023)

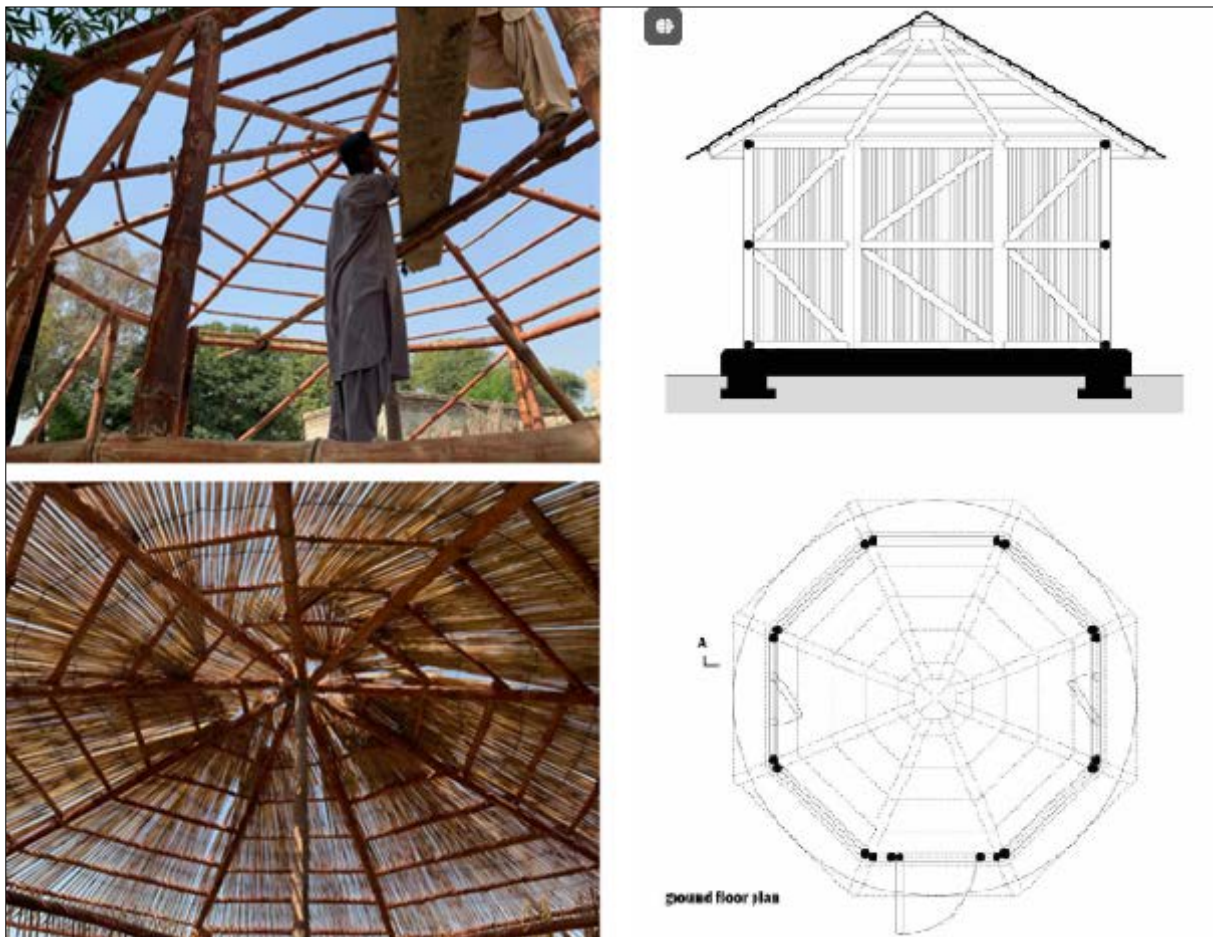


Figure 10: Locally assembled LOG Shelter bamboo structure construction

Critical Analysis:

However, these bamboo structures have some constraints in the context of flood housing, especially when it is most needed in the long term. Although bamboo has many

advantages compared with other materials, it is vulnerable to pests such as termites which can weaken the structure of the homes in the long run. Furthermore, for longevity, suitable foundations for extra sturdiness, the reinforced concrete, are absent, and, thus, such houses may not endure severe storms for long as the walls are made of mud. This makes them more appropriate for those who need a house for a short period of time. (Hafeez, 2023; Jamal, 2023)

However, the problem of housing and the need for structures that are both sustainable and long-lasting persists with bamboo homes being a quick and affordable option. While the use of local materials and involving the community is well appreciated, the homes are still vulnerable to pests' attacks, they are prone to degradation and therefore the need to work harder to address the issue of flood-resistant homes for the needy. (Hafeez, 2023; Jamal, 2023)

2.4 Modular Construction

Modular construction can be defined as the construction methods where building elements are made in piece by piece or sections in indoor factory condition. They are then conveyed to sites and connected in building units. Thus, the quality is ascertained to be high, while the time spent on the construction process is minimized and productivity is as well enhanced by virtue of maximum structural build off-site. Also, the client is benefited from time from minimized site labour and limited disruption, reduction in wastage of material, adaptive design. This is especially so in housing that is provided after the occurrence of the disaster since this comes with the added advantage of easy setup as well as the fact that the end product is strong housing units that are flexible. (Zhou, 2023)

James Garrison, the head of Garrison Architects proclaims that the primary strength of the Modular units is diversification. It can be piled up like toy Lego's to make row housing or can be located in between structures. Each of these modules is meant to meet the most stringent zoning ordinances in the country and can easily be deployed across the country. (NYC Emergency Management et al., n.d.)

Architectural units can be constructed in hours to weeks, with opportunity of less waste and costs compared to conventional homes. They are also often designed highly that

it is amazing to think they could perform, or that the people in them could move and/or speak. These are flexible units which are constructed in the factory, then relocatable for assembly at the intended location as shown in Figure 11.

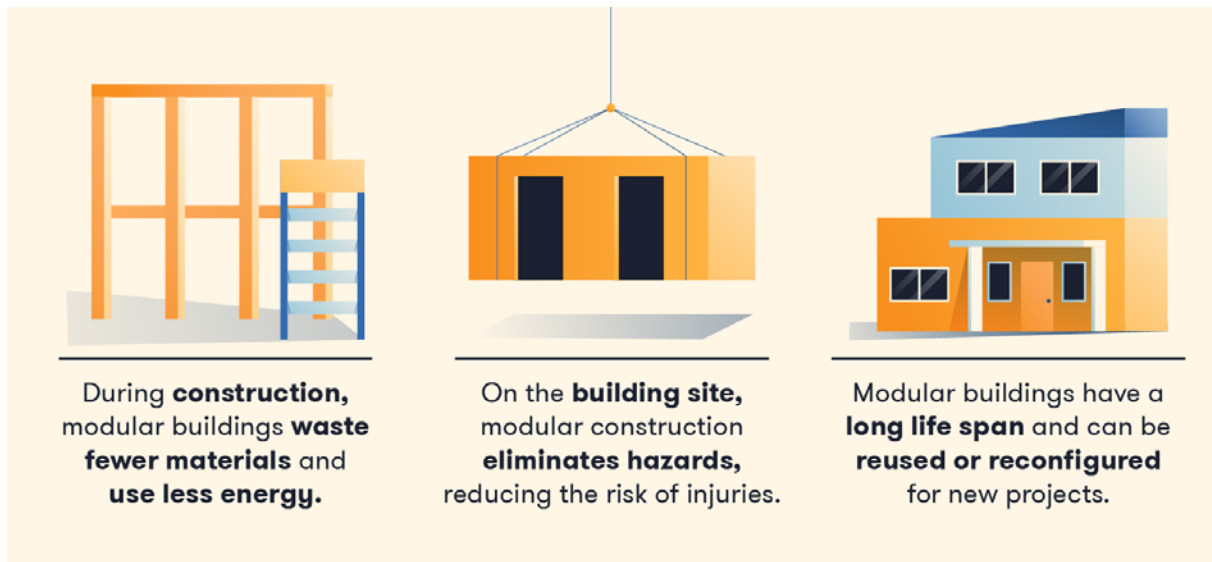


Figure 11: Modular Construction

2.4.1 Types of Modular Prefabricated Building Systems

Modular and prefabricated construction are related concepts because both entail manufacturing structures off site, but they are not synonyms for each other. Modular construction involves the creation of full building sections or modules in a factory environment and transported to the actual construction site and joined, this leads to quick construction and high standard quality assurance. The other one is known as off-site fabrication where little unique parts like walls and roofs are fabricated off site and then transported and assembled at the construction site. In this method, efficiency is the main theme, and it aims at improving the output by optimizing the manufacturing of part production. For instance, although modular construction best fits the deployment concept, prefabrication seeks to eliminate as much work as possible at the building site to enhance the construction process. (Keeth, 2022; Zhou, 2023)

On-site construction is a labour-intensive process, that greatly affects construction time and project costs. There are several types of Modular Prefabricated Building Systems in use today. They are mentioned below:

2.4.1.1 Panelised Systems

Panelised systems involve the fabrication of building panels which is followed by transporting them to the construction site in order to be assembled. The Structural Insulated Panels (SIPs) are typical in this case, and it is composed of an insulating foam core and two structural skins as shown in Figure 12. These panels give good thermal insulation and can be applied to walls, roofs and flooring. Another kind of cladding is pre-cast concrete panels, which have high level of sturdiness, and are frequently applied in business and industrial structures. These systems enable faster construction by assembling structures on-site. (Panjehpour et al., 2012)

The other type is prefabricated concrete panel which has a central insulation layer, and a layer of cement or mortar is applied on both sides as shown in Figure 12. These boards are used for constructing various types of exterior and interior bearing and non-bearing walls and floors. The panel's strength and rigidity come from diagonal cross wires welded to the welded-wire mesh on both sides. Installation of the panel system is quick, requiring minimal tools. When the steel wall sections are attached to the facade, the bearer profiles with pre-settled sections and spacers or stringers slide over the wall sections and are easily secured with a bolt connection. The C-shaped panels, in full length, are then fixed onto the sections. (Baghchesaraei & Reza Baghchesaraei, 2015)

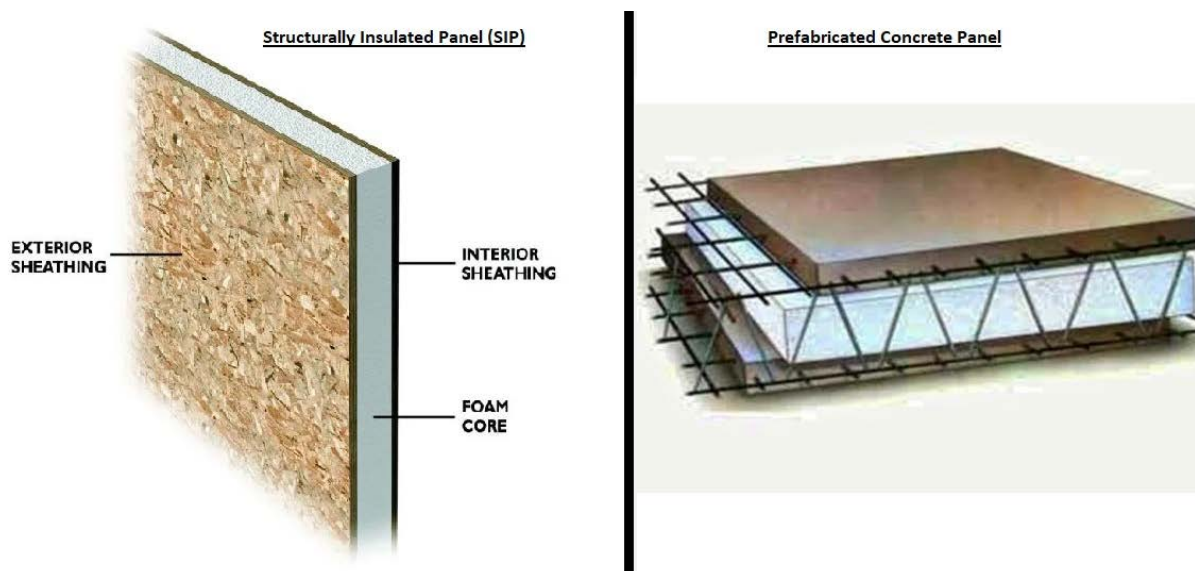


Figure 12: SIP and Prefabricated Concrete Panel

2.4.1.2 Volumetric System:

The volumetric systems involve the manufacture of 3D units ready for use, where interior works including the fit out are also completed off site (Figure 13). These modules are then taken to site where they are connected to make up a whole building. Fully volumetric modules can be applied for hotels, apartments, classrooms, and etc it provides absolute uniformity in the quality of work and tremendous amount of time saving. The hybrid volumetric systems incorporate the volumetric modules with other prefabricated parts like panels, hence making its construction even more flexible. (Podder et al., 2020)

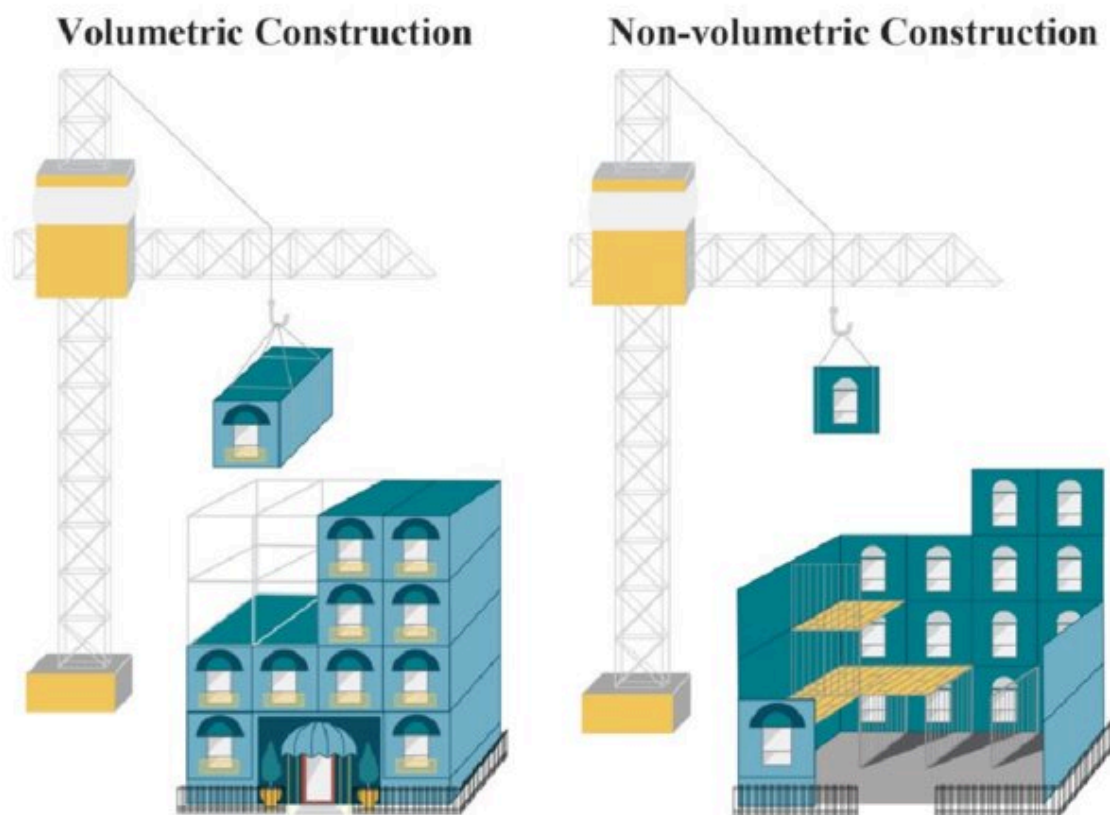


Figure 13: Volumetric Vs. Non-Volumetric Construction

2.4.1.3 Component systems

Component systems deal with the manufacture of single building elements to be assembled on construction site. An example of this system is the kit and package homes like IKEA – Better Shelter, where most of the fixing is done in the factory, and the home components are delivered at the site where they are fitted together in the required style. Steel frame systems are another example, in which prefabricated steel parts are

erected on the construction site to give a skeletal frame of the construction (Figure 14). These systems are robust, versatile and ideal for all classes of buildings from residential buildings to the commercial ones. (SI-MODULAR, n.d.)

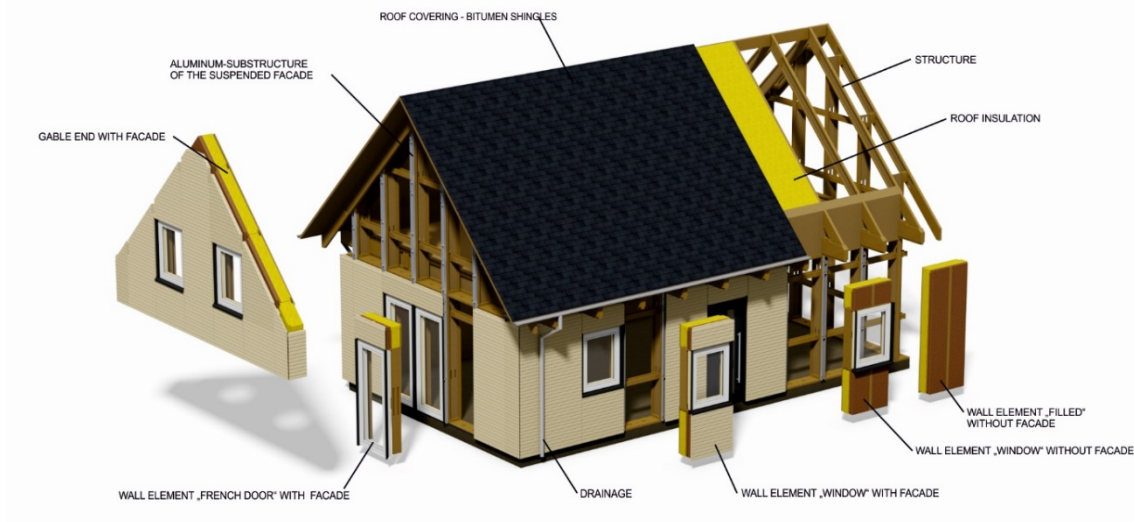


Figure 14: Component Modular System

2.4.1.4 Hybrid Modular Systems:

Hybrid Modular systems include the application of both panelised and volumetric systems in generating hybrid modular systems as they complement the strengths that each one offers optimize construction flexibility and efficiency. It also extends the ability to design and manipulate a building form and plan to a higher level can also increase the constructional and economic benefits of construction. For example, there is a technique that involves the use of volumetric modules which can be used in manufacturing or providing certain standardized units such as the washroom or the kitchen arrangement. This way is possible to create complicated constructions and meet requirements of different designs of the buildings employing the benefits of prefabrication. (Lawson & Ogden, 2008)

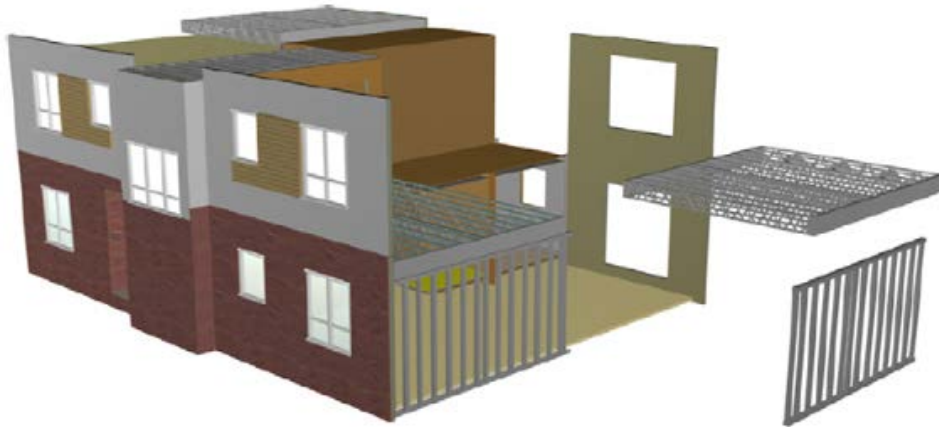


Figure 15: Hybrid Modular System by Corus

2.4.1.5 Flat Pack Systems

Flat-pack systems are structures that are transported in flat packages as ready-made sections of the building components (Figure 16). Simple bolt-together structures, they are perfect when construction requires minimal tools; the systems decrease the shipment size and expenses for regions with poor access. Flat-pack systems are frequently employed for non-residential and low-rise constructions such as temporary structures or emergency shelters or small houses due to their ease of assembly and disassembly characteristics of the system and thus being perfect for modular and relocatable buildings. (MoneyBox Modular Housing, n.d.)



Figure 16: Flat-Pack Modular system from MoneyBox

2.4.2 Advantages of Modular Construction

According to (Riztria Adinda et al., 2021; Zhou, 2023), following are the advantages and benefits of using Modular construction techniques in a construction project:

- **Speed and Efficiency:** Modular construction can be 30% to 50% quicker because of concurrent site development and standardized module assembling in a factory which is not vulnerable to climatic conditions and/or hindrances. Due to fast construction time, it generated revenue quicker once it is occupied therefore being beneficial for both the manufacturer and customer.
- **Cost Savings:** The combined costs in modular constructions, therefore, signify that material acquisitions for a specific building project are more efficient as well as thrifty to purchase in large quantities and the general demand of labour is minimal as most construction projects are standardized hence making modular construction cheaper than on-site constructions.
- **Quality Control:** Factory system in off-site construction has a better standardized quality of modules, and safety issues are less compared to normal construction sites.
- **BIM Integration:** Modular construction cuts its costs through the implementation of Building Information Modeling (BIM) which improve planning and implementation precision as well as quality, innovative materials, and methods in the manufacturing environment.
- **Design Flexibility and Reliability:** Modular buildings provide design flexibility and high reliability due to its process predictability. Since these can be changed customised to suit requirements; it can be expanded/ condensed or changed by adding/ removing modules. Modular construction entails a higher level of certainty in delivery and projects timely with efficient provision and minimal disruptions.
- **Sustainability:** Modular construction is environmentally friendly since most of the construction work is done in a controlled factory environment with little to no wastage of construction materials and little to no interruption of the surrounding environment. The problems of sustainability are solved in modular construction by using energy-efficient materials and systems and the possibility of recycling and using renewable power resources while manufacturing the modules.

- **Improved Health and Safety:** Enclosed factory fabrication also results in overall reduction in compromise health and safety by preventing the contact with site work hazards and other on-site risks and having streamlined construction processes due to repeated steps.

2.4.3 Examples of Modular Construction Projects around the World

Some notable buildings that have utilized modular construction techniques and reaped its benefits are listed below:

2.4.3.1 Casita by Boxabl (USA)

Boxabl is a U.S.-based company that focuses on the production of collapsible housing units. These units are fabricated and supplied as a single unit on site and can be erected in a few hours using a crane. Regardless of the configuration, the dimensions of the unit are 2.90 meters in height, 5.90 meters in length, 2.60 meters in width when folded and 5.90 meters when expanded. When the unit is expanded, it occupies a surface area of 34.80 square meters (Figure 17: The stages of deployment of the Boxabl housing unit). The sandwich wall panels have various configurations of window and door frame sizes and placement. These units can be stacked one on top of the other or connected side by side to create as many layouts as one can imagine (Boxabl, n.d.).

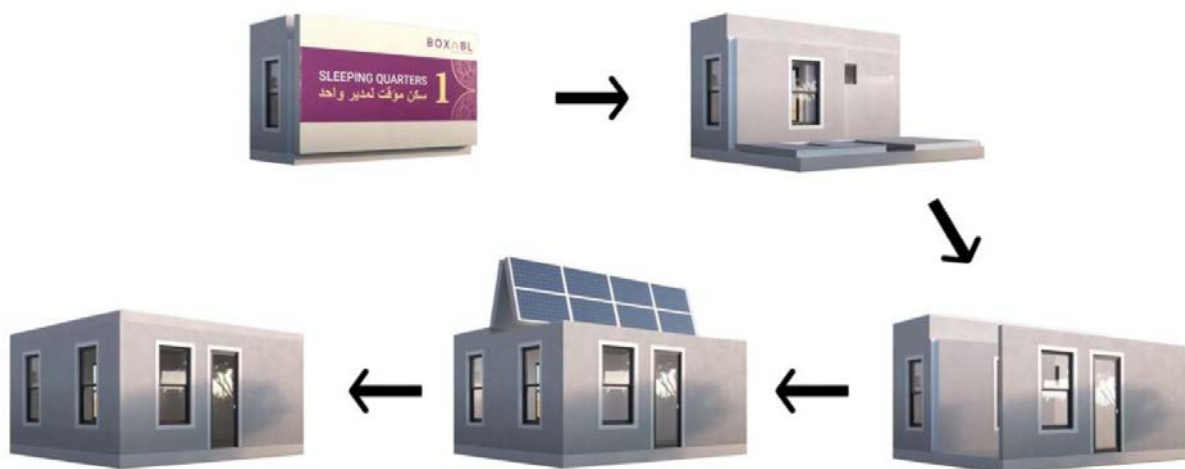


Figure 17: The stages of deployment of the Boxabl housing unit

The units are built in a factory with a highly organized production line and separated areas until the building is finally finished. During the assembly process of the structure, provisions for plumbing and electrical installations are incorporated. This approach leads to lower expenses on homes and eliminates the necessity of hiring specific professionals like an electrician or a plumber after assembly on-site. Every part is then incorporated based on the engineering and calculated planning that goes into it. It consists of prefabricated wall, ceiling, and floor panels, which take approximately 20 minutes to construct, and the structure is built like a Lego set. (Boxabl, n.d.)



Figure 18: Boxabl housing unit assembly on site

Boxabl uses Structural Insulated Panels in their construction. SIP is a modern construction material used for wall, ceiling, and floor construction. These panels consist of three layers, including a central EPS (Expanded Polystyrene foam) foam core, sandwiched between an external steel face and an internal magnesium oxide (MgO) face. (Figure 19: Boxabl panel construction and its staggered seam location). These Structural Insulated Panels (SIP) are 152.4 mm (6 inch) thick wall panels and 190.5 mm (7.5 inch) thick roof and floor panels. (ICC-ES, 2023)

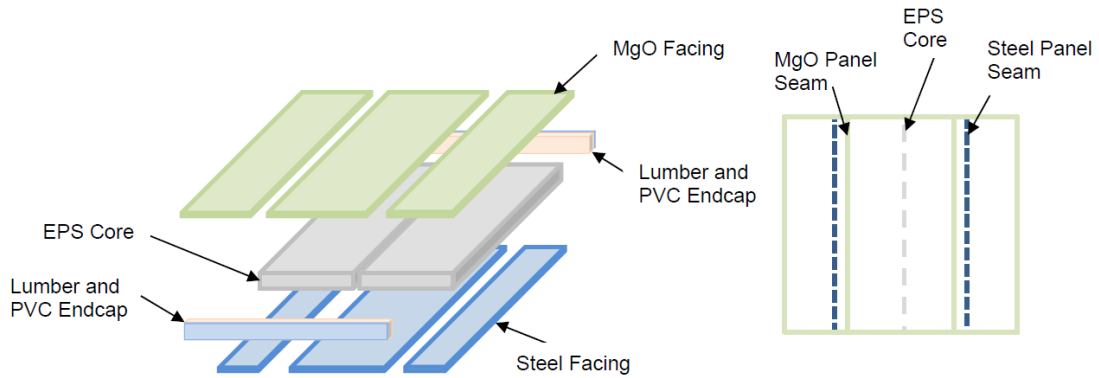


Figure 19: Boxabl panel construction and its staggered seam location

This EPS insulation material improves the energy efficiency of the building by reducing the thermal conductivity of the panel.

2.4.3.2 Moneybox Modular Housing

This container house can be erected by a team of at least five people, and there is no need to use a crane for deployment purpose. Nevertheless, the transportation of the object will necessitate the use of a crane. When transported in a single unit it is 5.80 meters in length, height of 2.50 meters, and 2.20 meters wide when folded and 6.30 meters when deployed (Figure 20). The expanded covered area is 36.50 square meters. It uses 15mm fibre reinforced concrete panels for the flooring. (MoneyBox Modular Housing, n.d.)



Figure 20: The stages of deployment of Moneybox Modular container housing unit

2.4.3.3 Puukuokka Apartment Building (Jyväskylä, Finland)

It is the first 8-storey high, wooden apartment building in Finland completed in 2015 (Figure 21). Prefabricated modules with Cross-laminated Timber (CLT) construction have been utilized for this building. Cross-laminated timber (CLT) (Figure 22) is a mass timber product that is a sustainable alternative (cutting emissions by up to 70%) to concrete and steel in modern construction. CLT is popular due to its strength, appearance, and versatility, acoustic, fire, seismic and thermal performance.



Figure 21: Puukuokka Apartment Building using CLT

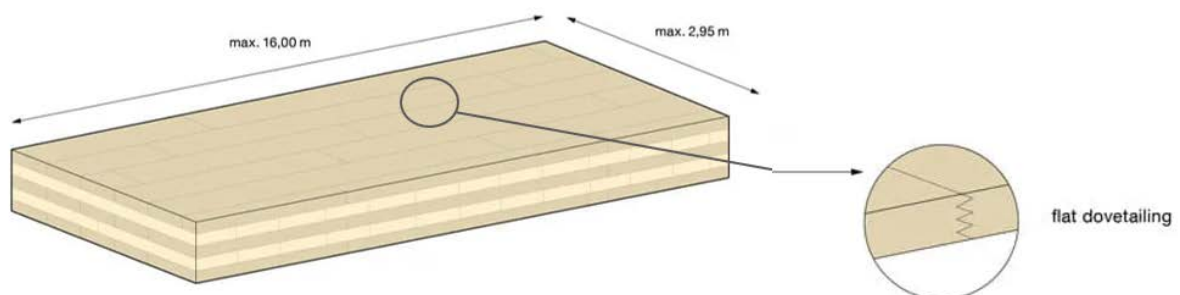


Figure 22: Cross-Laminated Timber (CLT) Module

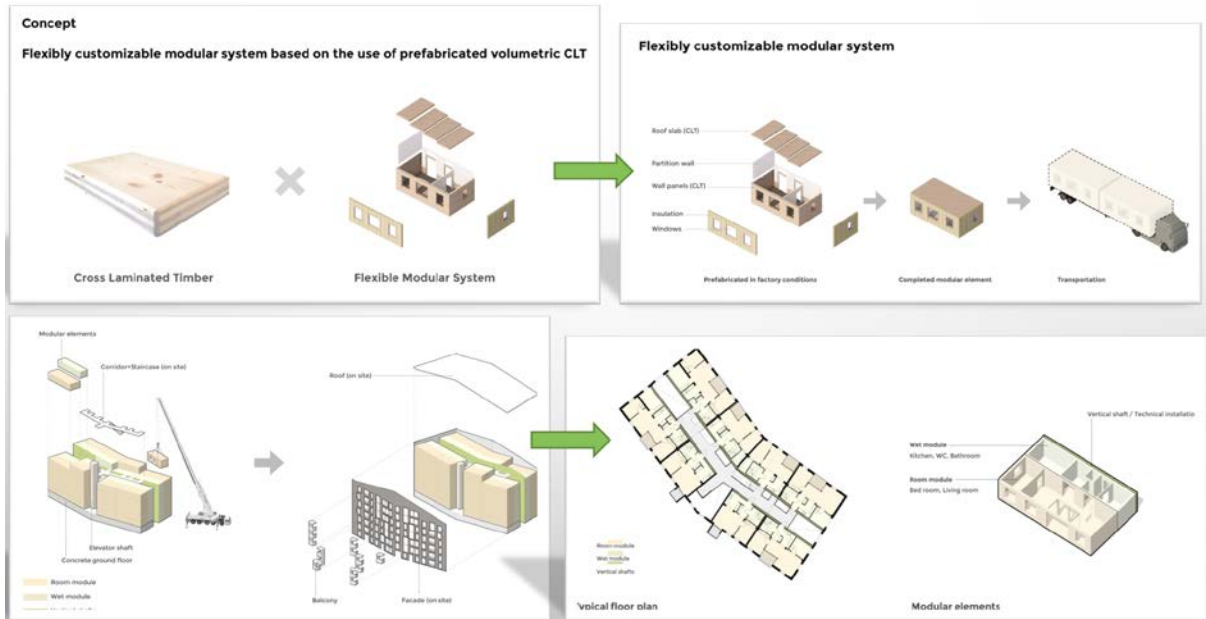


Figure 23: Construction, transportation and assembly of CLT

The construction, transportation and assembly of these CLT based modules used in the construction of this building is shown in Figure 23.

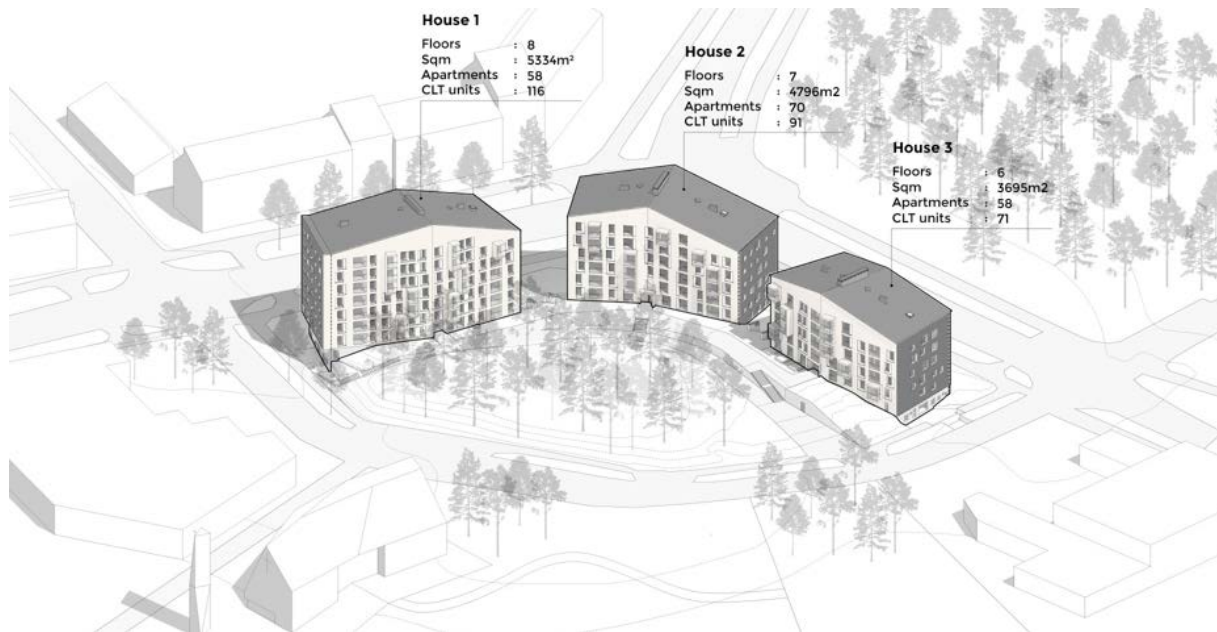


Figure 24: Final constructed Puukuokka Apartment Buildings

The Final constructed Puukuokka Apartment Buildings are shown in Figure 24.

2.4.3.4 LA Trobe Tower (Melbourne, Australia)

At 133 meters, La Trobe Tower is a 44-level tower residence in central Melbourne. The Rothelowman-designed and Longriver Investments-developed project at 323 La Trobe Street was built in 19 months (26 months in traditional construction methods), finished in November 2016 (Figure 25). There are 206 apartments within, the design of which was influenced by musical elements, the company says, resulting in a unique glass façade. The 15th floor includes a common area with a lounge, terrace, kitchenette, and gym. Floor-to-ceiling windows in the one and two-bedroom units provide city views and plenty of natural light. (Hickory Group, n.d.)



Figure 25: La Trobe Tower Melbourne (Rendered)

Hickory said it used innovative construction methods, including integrated prefabrication, Hot-rolled steel box frames incorporating an engineered concrete floor. These boxes came in varying sizes of up to 4.2m x 16.4m, with pre-fitted bathroom pods and a pre-attached facade. Its construction time is also remarkably short, Two floors in a week were constructed (four floors a week should be possible in traditional construction) to cut 30% off its timeline. BIM software was used for 3D modeling and design validation. Hickory installed these large, prefabricated units at night after consulting

with the community and planned it very carefully in order not to disrupt traffic and the operating hours of the tram service in the city. (Hickory Group, n.d.)

2.4.3.5 Stadium 974 (Doha, Qatar)

This Stadium 974 was designed as a temporary stadium. Six matches from the FIFA Arab Cup Qatar 2022 served as its inaugural event. Later, during FIFA World Cup Qatar 2022, it played host to seven thrilling matches. This modular stadium in Figure 26: Stadium 974 (Doha, Qatar) has its name from the 974 containers used in construction and is also a symbol of Qatar's dialling code. (VisitQatar, 2021)



Figure 26: Stadium 974 (Doha, Qatar)

This innovative modular football stadium was built by Schlaich Bergermann Partner, Hilson Moran, and Spain's Fenwick Iribarren Architects using recycled steel and re-used shipping containers as shown in Figure 27: Stadium 974 using recycled shipping containers, which resulted in less waste and more economical construction. It is a multipurpose and environmentally friendly sports arena since each container was customised to fit different stadium components, such as seating, refreshments, and bathrooms. (VisitQatar, 2021)



Figure 27: Stadium 974 using recycled shipping containers

The 40,089-seat stadium was digitally launched in November 2021 and held its maiden match at the FIFA Arab Cup Qatar 2021™ on November 30, 2021, with a game between the United Arab Emirates and Syria. The stadium's environmental effect is greatly reduced because of its clever, water-efficient design. Following the event, excess seats will be donated to other nations, and the buildings will be repurposed for hospitals, schools, houses of worship, and hotels, with many materials destined for reuse in Africa and South America. (FIFA, 2021)

As the first FIFA-compliant stadium that can be completely dismantled and recycled, it provides architectural flexibility for either rebuilding the stadium in a different place with the same capacity or creating several smaller venues using the same elements. (FIFA, 2021)

The stadium was awarded 5-star certification from the Global Sustainability Assessment System (GSAS) for both design and construction. The seating bowl is naturally aired, avoiding the need for air conditioning, while the steel construction is meant to be recycled and reused after the event. (FIFA, 2021)

The stadium's smart water systems save water use by 40% compared to traditional stadiums and make it 30% more energy efficient than global norms. This novel technique demonstrates its dedication to sustainability and adaptability. (FIFA, 2021)

2.4.3.6 M'DAM (Monnickendam, Netherlands)

A construction company in The Netherlands namely Finch Buildings has made several innovative sustainable buildings. One of their projects namely M'DAM is made of a Timber-clad, modular, reconfigurable complex of 62 apartments, two-thirds i.e. 20 of which are social housing while the remaining 42 are owner-occupied apartments for their client BMB development as shown in Figure 28: M'DAM project bird's-eye view. (Finch Buildings B.V., 2021)



Figure 28: M'DAM project bird's-eye view

The construction of the M'DAM project started in February 2021 and it took 9 months from foundations to completion of the whole complex on the Pierebaan in Monnickendam, Netherlands as shown in Figure 29: M'DAM project courtyard, Figure 30: M'DAM project front profile view and Figure 32: M'DAM project side profile view. It has been constructed almost totally from CLT (cross-laminated timber) and Glue-Lam (laminated timber) which is energy-neutral and modular with 106 modules of solid wood as shown

in Figure 31: M'DAM project CLT construction inside view. CLT is comprised of at least 3 cross-glued single-plywood panels arranged in a single module. The glue is environmentally friendly as it is free from formaldehyde. (Finch Buildings B.V., 2021)

The traditional concrete and steel building of a comparable size would take at least 18 months for construction.



Figure 29: M'DAM project courtyard



Figure 30: M'DAM project front profile view



Figure 31: M'DAM project CLT construction inside view

The use of wooden structures in the construction of these residential buildings is an example of innovative modular construction techniques. This was manufactured in the Factory of Wooden Buildings operated by De Groot Vroomshoop. These wooden modules' components like cladding, roofs, thermal insulation, floorings, glazing, doors, and sanitary components were assembled in this fully electric factory. For this circular wood construction, the Energy performance coefficient (EPC) of 0.0 was achieved and a completely all-electric building was also implemented in line with the company's sustainability vision. (Finch Buildings B.V., 2021)



Figure 32: M'DAM project side profile view

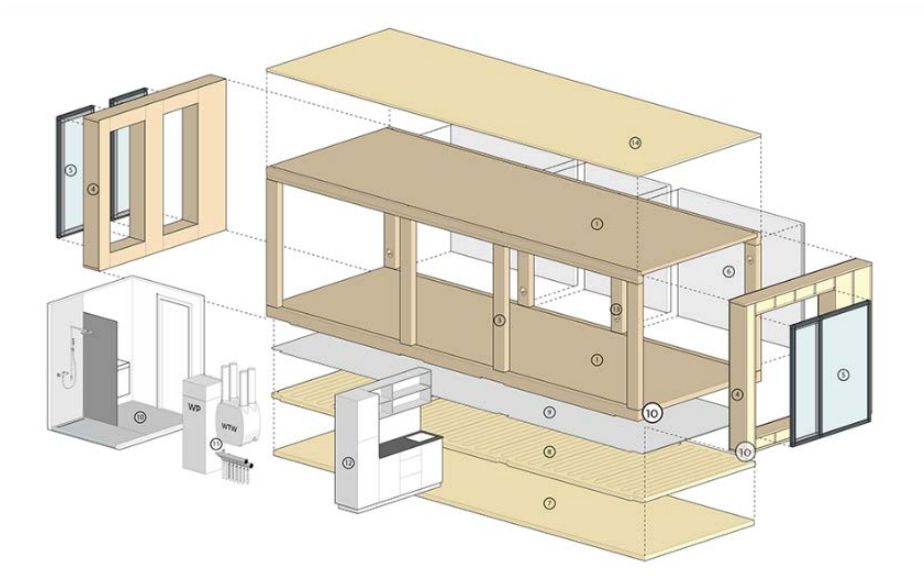


Figure 33: Finch Module design

The above-completed modules as shown in Figure 33: Finch Module design were then transported on the road to Monnickendam where the modules were finally assembled and fitted. (Finch Buildings B.V., 2021)

2.4.3.7 Nassau County International Cricket Stadium (New York, USA)

The Nassau County International Cricket Stadium in New York remains among the most significant constructions of modern stadiums. This 34,000-seater modular stadium is expected to stage eight games during the ICC Men's T20 World Cup 2024, and it was developed by the reputed Populous architectural company. What makes it even more exciting is the application of modular construction, a system commonly utilized in various other sports such as Formula 1, golf, and the Olympics. This is the first-ever attempt to adopt such a plan for a cricket ground. (Spangler, 2024)



Figure 34: The stadium site in Eisenhower Park was marked out in February 2024

The fact that the construction of a modular building is much faster than a traditional building is the reason that the completion of the building is expected within three months. The stadium's design was announced on 17th January 2024 and the construction work started the same week; the stadium site marking is shown in Figure 34: The stadium site in Eisenhower Park was marked out in February 2024. The grandstands are also being borrowed from the Formula 1 Las Vegas Grand Prix, which shows that sustainability and costs are paramount as shown in Figure 35: Construction in progress for the stadium site in Eisenhower Park in March 2024, Figure 36: Construction in progress of T20 World Cup cricket stadium in March 2024 and Figure 37: The Aluminium structure of the stadium in May 2024.

These grandstands will be accompanied by other VIP and hospitality facilities. It will also comprise a party deck, cabanas, and a fan zone with food and drinks services. The media and broadcast firms will find suitable locations to ensure they capture the matches well. The drop-in pitch, which has been sourced from Australia, was cultivated in Florida and then shipped to New York in early May. Although the short turnaround

time of completion of the project in May 2024 and its first match on 3 June 2024 the project was deemed successful. (Gollapudi, 2024a)



Figure 35: Construction in progress for the stadium site in Eisenhower Park in March 2024



Figure 36: Construction in progress of T20 World Cup cricket stadium in March 2024



Figure 37: The Aluminium structure of the stadium in May 2024

The construction of the stadium was completed in May 2024 as shown in Figure 38: The completed stadium project.

The first cricket match was played on June 3, and the two teams were South Africa and Sri Lanka. The most prominent match was between India and Pakistan on June 9. Curtains, seats and modular structures were dismantled after the last match of the tournament between the USA and India on June 12. While the cricket ground part is retained, to make future upkeep easier, artificial turf will be used in place of the drop-in pitch. (Gollapudi, 2024b)



Figure 38: The completed stadium project

Through its modularity, it embodies efficiency, sustainability and flexibility, thereby raising the bar for other cricket stadiums across the globe.

2.4.4 Lessons learned from Modular construction practices

Modular construction is a modern, effective method that significantly speeds up the building process for residential units. This approach, noted for its comprehensive and time-saving nature, addresses several common challenges in current permanent housing reconstruction strategies following disasters. It benefits from reduced construction durations facilitated by automation, concurrent manufacturing activities, decreased overall delivery times, faster returns on investment, shorter planning and design phases, and fewer weather-related delays due to the controlled environment of factories. (Bertram et al., 2019; Shahzad et al., 2022; Thurairajah et al., 2023)

Thus, the inherent time efficiency of modular offsite construction makes it an appealing option for post-disaster housing reconstruction.

2.4.5 Challenges of Implementation

According to (Bertram et al., 2019; Gerrard, 2023; Thurairajah et al., 2023; Zhou, 2023), to lessen the effects, it is vital to determine the obstacles preventing the use of modular offsite construction. Here are the challenges of implementing modular system:

- 1. Initial Costs and Financing:** Owners of modular construction project also experience higher costs of initial investment due to specific manufacturing of the components, cost of transportation and since it is perceived to have higher risks the financing attracts higher interest rates or come with some restrictive conditions.
- 2. Transportation and Logistics:** Transportation and assembly of large modules especially in remote areas is costly, and at times impossibly complex, particularly when carrying out installation in difficult to reach areas; regulation of transport concerning size affects the design process. Also proper planning and coordination is required to ensure that the modular units are deployed promptly and in the right locations.
- 3. Site Preparation and Foundation:** Other issues which are critical are the site preparation, and notably the cleaning and preparing the ground to obtain a level

environment in some cases necessitating huge costs and time to develop the site.

4. **Design Limitations and Stability and Integrity of Components:** Flexibility is provided in modular homes to an extent, but the size and shape of a module is fairly standardized and some variations from other home designs can be expensive. Transportation and erection of the various modular elements may prove difficult since they have to retain stability and structural strength which in essence is a cumbersome process that demands a lot of quality control and professionalism in a bid to overcome any hitches that may be encountered.
5. **Regulatory and Zoning Challenges:** One drawback of modular construction is the challenges that may be encountered in dealing with local building codes and zoning laws or regulatory authorities because such laws may not easily be acquainted with modular construction hence may result in time wastage and extra expenses.
6. **Perception and Market Acceptance:** Modular homes are subjected to a social stigma and are looked down upon as being less than site-built homes, thus their marketability and demand is compromised.

2.4.6 Role of Building Information Modeling (BIM) in Modular Construction

BIM is very relevant to modular construction since it enhances the planning, designing, and coordination of the project. Integrated applications of Building Information modeling for structures make it easy to create Intelligent 3D structural models which contain geometric and non-geometric details of the structure and internal equipment. This capability improves on the collaboration and coordination between architects, engineers and construction contractors in their work; thus, the general construction speed is boosted. BIM is also providing essential advantage to modular construction dealing with MEP systems since this has been realized to be complex. BIM in MEP systems enable effective documentation and proper arrangements of the systems in that, it can help in doing away with or reduce avoidable clashes that may be realized during the design. This reduces the risks of having built distortions and excessive time costs during the construction phase. (Lu & Korman, 2010)

However, the application of BIM in modular construction has some limitations especially to the small-medium scale firms as explained below. Preparation of appropriate

Developing BIM models requires a lot of time, money, specific expertise and skilled workforce. However, there are also legal and organizational consequences that must be taken into consideration regarding the complete BIM implementation, namely, the definition of roles and responsibilities, and the management of IPR. Nonetheless, the increased adoption of the BIM technology in the undertakings of different firms shall continue boosting; efficiency, decreasing costs and enhancing quality in the construction industry. (Lu & Korman, 2010)

2.4.6.1 Dimensions of BIM

For the purpose of this research, 6-Dimensional Building Information Modeling (6D BIM) has been adopted which is discussed in detail below:

3D BIM (Structural + Architectural) Model

A 3D model or design is a well-executed presentation in which the information applicable to constructing a designed object is located. This model also houses 2D documents and starts directly from the model, including parts, views, details, and elevations. The outcomes from 3D models are:

- A comprehensive 3D building model designed to accommodate a variety of industries.
- A library of used materials.
- 2D drawings (Jankowski et al., 2015)

4D Scheduling

The 4D model starts with the geometrical description in the model from where the process of construction can begin, and the enumeration of construction elements can directly implement the information for making a schedule. In the process, suitable implementation technologies can be chosen and at the same time, the planning of the construction site can be done, and the division of work centres is possible. This data is reflected in the model. Once all the data is in, it is possible to generate a schedule where each item is associated with the amount of time needed to perform it, as well as

any connection and execution order. In a 4D model, information can be seen that provides both the date and place in which different activities will occur. The principal outputs from the 4D model are:

- Pre-measures in all industries.
- Table of libraries.
- A schedule indicating areas for optimization (Jankowski et al., 2015)

5D Simulation

5D BIM simulates the investment realization process, and links cost information based on labour, material, and equipment with the model and the elements. The fifth dimension permits rapid execution and cost calculation using allocation programs. Any differences in the newest version of the model could be pre-measured and reflected in the model and the schedule. Differences can be calculated automatically according to previous iterations. If such a process does not get to be scrutinized by a quote controller, it will quickly lead to faults. Outputs from the 5D model include:

- Cost estimates.
- Projections for cash flow.
- A basis for the change management process (Jankowski et al., 2015)

6D Energy Analysis

It is an added motivation to perform this energy analysis through 6D-BIM technology. Using 6D BIM technology would enable more accurate energy estimates earlier during design. It also allows measurement and verification during building operations and can improve processes for incorporating lessons learned in high-performance facilities. The model's simulation with the connection of BIM to 6D CAD simulates the model toward presenting a comprehensive view of energy consumption (Charef et al., 2018).

3. Materials and Methods

3.1 Introduction

This chapter provides an overview of the working methodology adopted for this research. This is achieved by firstly performing a literature review for the disaster relief housing solutions as similar case studies projects around the world. By using these case studies, best practices for Modular House Design, their specific features, energy efficient material selection were used in the development of the proposed 3D BIM model of the Modular house. Furthermore, Transportation Methodology and then designing a Colony of Modular Houses on site of flooding has also been discussed thoroughly. Then, in Analysis and Results Chapter-4, 4D Project Schedule is developed for the Colony of Modular Houses. Then, for 5D, the Time Simulation is performed and then finally for 6D Energy Analysis is performed.

3.2 Project Methodology

The following Figure 39 represents the adopted Project Methodology:

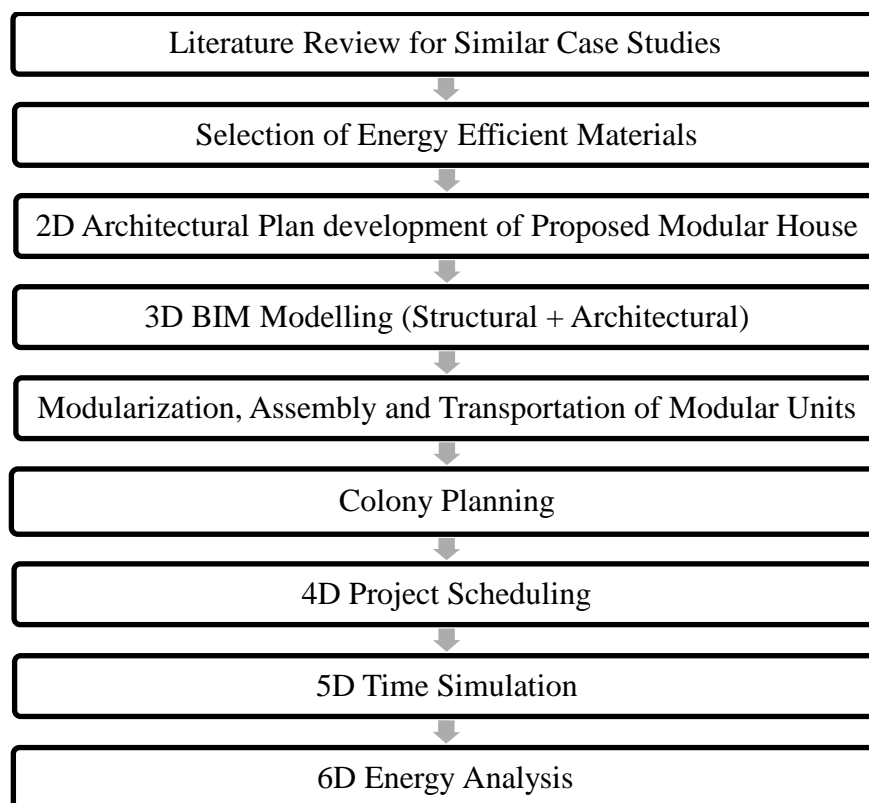


Figure 39: Project Methodology

3.3 Literature Review for Similar Case Studies

As has been noted by (Russell & Potangaroa, 2008), it is not uncommon in most housing reconstruction projects to find that beneficiaries are given standard-sized houses across the board, regardless of the household size or the diverse home-based income-generating activities. Major reconstruction projects heavily put pressure on the natural resources required for construction many times. Some of the problems that people face in resettlement schemes include Deforestation: clearing woodlands for construction affects the environment. Like Indonesia, it was difficult to obtain certified timber after the Tsunami in 2004 since there was a lot of illegal logging and deforestation. This resulted in construction of many brick masonry homes even where wood or fuel for burning bricks was scarce, this worsened deforestation and environmental degradation (Ahmed & O'brien, 2009).

Post-disaster temporary housing is an essential solution during recovery and reconstruction phases that commence a few weeks after the disaster and last until permanent homes are built. Temporary homes can be developed in various ways. In the context of disaster management, they are regarded as part of the emergency-to-home transition stage. The location for temporary housing must be determined as part of the disaster management. Historical data suggests that temporary shelters were erected in forests, coasts, and agricultural zones because of poor planning and preparation. (Johnson, 2002; SÜALP & COŞGÜN, 2023)

Temporary Housings for Post-disaster typically come into these categories:

1. Kit of Parts
2. Modular
3. Mobile
4. Vernacular
5. Use of Recycled Materials

Some of the prominent post-disaster temporary housing practices by category type adopted around the world are discussed in detail as follow:

3.3.1 IKEA – Better Shelter (Kit of Parts)

IKEA came up with the IKEA Foundation, which is a charitable organization involved in the fight against poverty and funding of climate change through grants. IKEA Foundation in line with flat pack furniture of Kit of Parts developed the Better Shelter as shown in Figure 40: IKEA - Better Shelter RHU Prototype (source: courtesy of Better Shelter, www.bettershelter.org), a secure and comfortable home for the families that were displaced, with provisions like washbasins, an adjustable small solar panel and it weighs 65Kg (*Better Shelter - About*, n.d.; *Our Relief Units*, 2021).

Assembling the 17.5m² shelter means 4 people and takes 5-6 hours for construction, after the assembly the interior can be seen in Figure 41: Interior image of Better Shelter RHU Prototype (source: courtesy of Better Shelter, www.bettershelter.org) .

The construction is mainly polyolefin insulated foam sheets, a tarpaulin floor, and steel frame that is fixed to the ground (UNHCR RHU 1.2, 2022). IKEA provides assembly training, either at the furniture's location for two days, or by watching a two-hour streamed video (UNHCR RHU 1.2, 2022).



Figure 40: IKEA - Better Shelter RHU Prototype (source: courtesy of Better Shelter, www.bettershelter.org)



Figure 41: Interior image of Better Shelter RHU Prototype (source: courtesy of Better Shelter, www.better-shelter.org)

The specific features of Better Shelter and its critical analysis is listed in Table 1: IKEA - Better Shelter Specific Features below:

Table 1: IKEA - Better Shelter Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|-------------|--------------------------------|---|
| Dwelling and Size | 5 people | 3.3m (W) X 5.6m (D) X 2.8m (H) | Gives 3.5 m ² per person for a family of five; expandable with more units. |
| Cost | - | \$10,000 reduced to \$1,000 | It is priced at \$1000—more suitable as emergency housing but lacking basic facilities. |
| Installation Manpower | - | - | It takes 4 persons 5-6 hours to assemble |
| Power source | ✓ | Off Grid: Solar powered | Charges only a mobile phone and an LED light for 4 hours. |
| Window & Sunlight | X | 4 Small Windows | Four small windows do not allow sufficient natural light in. |
| Water Source | X | No Water Inlets | It cannot be directly connected to a water source; it has no inlets or outlets. |

| | | | |
|---------------------------|---|------------------------|---|
| Cooking Gas Source | X | No Gas Pipes | Only mini portable stoves that are without exceptions. |
| Kitchen | X | No kitchen | Families must also include cupboards, stoves, sinks, and plumbing. |
| Sanitary Facility | X | No Sanitary Facilities | Toilets and shower facilities should be accessible; families should not have to construct or rely on the few available at public sites. |
| Ventilation | ✓ | 2 Ventilation Openings | Two present vents, but uncertain of the effectiveness. |
| Waterproofing | ✓ | Waterproof | And the design is waterproof for added comfort even when it's raining. |
| Insulation | X | Not Insulated | Without any form of insulation, the shelter becomes very uncomfortable in extreme temperatures. |
| Fireproofing | X | Easily Combustible | IKEA can claim it is UNHCR compliant, but Zurich failed 62 units for fire hazards. |



Figure 42: Better Shelter Housing Units in Türkiye earthquake relief (Source: (Better Shelter, 2023))

Better Shelter has provided RHUs to various countries in need like in Ukraine, Syria, Chile, Panama, Czechia, Iraq, India to name a few. Figure 42: Better Shelter Housing Units in Türkiye earthquake relief shows the deployment of Better Shelter after the

earthquake in Türkiye in 2023. They provided 500 RHUs for the earthquake relief (Better Shelter, 2023).

Summary:

The Better Shelter has been used extensively, particularly in the refugee camps, and the characteristics have been used to design the proposed modular house. However, once the physical components of the design have been put together, the design is rather rigid and can seldom be altered to fit the user requirements. The modularity of the walls means that wall panels can be replaced with windows, doors and solar panels but will come at extra costs and subject to being produced and delivered by IKEA thus having limited options for customization. Tarpaulin floor is a challenge, requires flat and dry prepared site, which is impractical in disaster areas, questions arise about heating, hygiene and safety. The 'upgrade and upcycle' approach by IKEA is compatible with the use of local materials over time, which, even though does not change the functionality of the shelter, has informed the design considerations of this thesis.

3.3.2 Reaction Housing – Exo Shelter (Modular)

Exo Shelter is a modular housing unit created for the safe, climate-controlled, personal living quarters of up to four people. Several of these units can be stacked together to increase the amount of living space. The Exo design is more robust than a tent but cheaper than trailers and containers. After the devastation of Hurricane Katrina in 2005, there was a push for new designs and ideas for post-disaster relief housing. One such design that came to life was the Exo Shelter, and thus, the Reaction housing company was born (Figure 43: Exo Shelter prototype with its founder, Michael McDaniel). Inspired by the stackable design of polystyrene cups (Figure 45: Exo Shelter building stacks), it only takes 15 minutes to assemble on-site, which increases the square meters available for shipment of more shelters (Figure 44: Modular design assembly of Exo Shelter).



Figure 43: Exo Shelter prototype with its founder, Michael McDaniel

For instance, a 53-foot semi-truck trailer or a C-130 Hercules plane can carry twenty nested units. Each unit houses four people in two-fold-out bunk beds that leave a small aisle between them. Made from a recyclable metal and plastic composite, the shelters, while not providing any outside space or any possible design adjustments, take on the possibility of a community when they are placed into groupings called neighbourhoods. (Barney, 2014; Kessler, 2015; The Index Project, 2015)

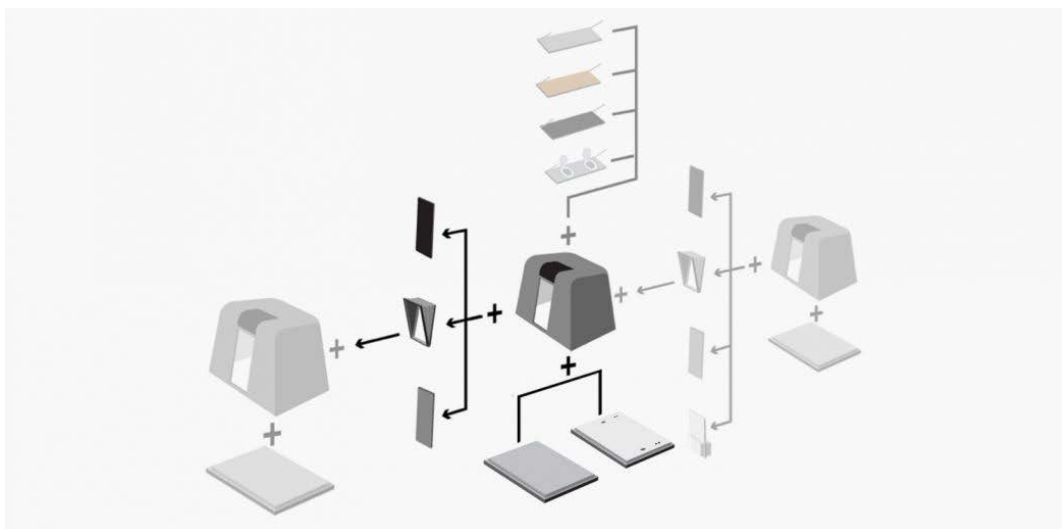


Figure 44: Modular design assembly of Exo Shelter



Figure 45: Exo Shelter building stacks

The specific features of Exo Shelter and its critical analysis is listed in Table 2: Exo Shelter Specific Features and Critical Analysis

Table 2: Exo Shelter Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|-------------|-------------------------------|---|
| Dwelling and Size | 4 people | 2.9m (W) X 2.6m (D) X 2.7 (H) | 7.5 m ² is adequate for two people but is not enough for four people, considering it is against shelter standards where the recommendation requires 3.5 m ² per person. |
| Cost | - | \$5000 | A \$5000 cost is too high for a basic shelter without the amenities. |
| Installation Manpower | - | - | 4 people needed to assemble |
| Power source | ✓ | On Grid: Needs City Power | If infrastructure fails in a disaster, there is no power to rely upon from the grid. |
| Window & Sunlight | ✓ | 1 Window | Small, fixed-roof windows offer no ventilation and no outside view. |
| Water Source | ✓ | On Grid: Needs City Water | No access to clean water without the grid infrastructure. |
| Cooking Gas Source | X | No Gas Pipes | Mini-size portable stoves are only allowed. |
| Kitchen | X | No kitchen | Families must include spaces for cooking and washing, such as cupboards, cookers, sinks, and plumbing. |

| | | | |
|--------------------------|---|------------------------------------|---|
| Sanitary Facility | X | No Sanitary Facilities | Toilets and showers are needed; public or shared facilities must be added. |
| Ventilation | ✓ | Ceiling Fans & Floor Mounted Vents | It is well ventilated. Proper ventilation can prevent breathing difficulties and problems of a mouldy nature. |
| Water-proofing | ✓ | Waterproof | Waterproof design will ensure to keep the rain off and bring comfort even in the rainy seasons. |
| Insulation | X | Not Insulated | Uninsulated, it makes you feel hot in summer and cold in winter. |
| Fireproofing | X | Combustible | Fire safety is vital for survivors, and agencies cannot afford more risks. |

Summary:

The Exo Shelter has been designed to be the easiest to transport and not have to be assembled. This strength, however, is also its biggest weakness, as it severely limits the adaptability and performance of the shelter in other areas. The units cannot be tailored to meet individual user needs or certain site conditions, which significantly affects their functionality and the duration they can remain inhabited. Being mainly constructed for the purpose of shelter and sleeping, this limited space hampers activities like food preparation and storage or bathing. Therefore, Exo Shelters are more appropriate for rapid intervention during a crisis than as components of a phased intervention to restore normalcy in an affected population.

3.3.3 Container Housing (Prefabricated + Modular)

On 6th February 2023, an earthquake of 7.8 magnitude struck southern and central Türkiye and northern and western Syria. The earthquake led to destructions over the area of approximately 350,000 km² that can be compared with the size of Germany. Over 14 million people in Turkey were affected by the disaster, which is 16 percent of the country's population. Approximately 1.5 million people, according to UN development specialists, lost their houses. (*1.5 Million Now Homeless in Türkiye after Quake Disaster, Warn UN Development Experts | The United Nations Office at Geneva, n.d.; United States Geological Survey, 2023*)

An aerial view of a container city that was established in earthquake-hit Nurdağı district of Gaziantep on 26 April 2023, southern Türkiye can be seen in Figure 46: Container city set up in Nurdağı district of Gaziantep, Türkiye.



Figure 46: Container city set up in Nurdağı district of Gaziantep, Türkiye

There were 162 container cities built in the impacted area. (*Death Toll Exceeds 45,000 in Türkiye's Major Earthquake Disaster - Türkiye News*, n.d.). An estimated 689,000 individuals of the 3 million displaced people are still residing in container houses a year after the earthquake. These typically 21 m² (230 sq. ft) containers come furnished with running water, a shower, and a toilet. (Keddie & Cogal, 2024)

At a location in Besni, a city in Adiyaman province, over 1,200 people lived in around 300 containers (Figure 47: Container City in Besni, Turkey). (Keddie & Cogal, 2024)



Figure 47: Container City in Besni, Turkey



Figure 48: Inside a container in a camp in Iskenderun

From September 2023, a two-meter by eight-meter container imported from China has been home to this family (Figure 48: Inside a container in a camp in Iskenderun). This camp which is in the Iskenderun city along the coast of Turkey has about 600 containers some of which can hold up to 15 Syrian refugees each. Some camps have individual toilet and kitchen facilities in the containers, but this camp does not offer the same. However, it only has 50 toilet and 50 shower areas for 3,000 to 4,000 residents of the island. (Blackall, 2024)

Several Modular container manufacturers from China and Türkiye itself have been providing temporary housing for those affected by the damage of this earthquake. The prominent manufacturers are follows:

DORCE Prefabricated Building and Construction (Prefabricated)

These prefabricated units are of 21 sq. m floor area comprising a sitting area, bedroom, kitchen, and toilet/ shower room that were sold to Türkiye. Its base and roof were waterproof and insulated. The roof sheet metal protects its interior from any climatic condition, and a firm base attaches it to the ground. This temporary accommodation could be easily dismantled and employed in other works elsewhere and is also resistant to fire. They are transported by either land, rail, or air and made for rapid connection to site utilities (Figure 49: DORCE Prefabricated Container transportation). Every unit features integrated electrical, telecommunications, plumbing, and heating/cooling systems and can be installed at the assembly site within 24 hours of arrival. (Dorce Prefabricated & Construction, n.d.)



Figure 49: DORCE Prefabricated Container transportation

CBOX Container Houses (Modular)

Almost a year ago, a large Chinese supplier of container houses, CBOX, sold 5,000 units to Turkey for post-earthquake housing. Those units formed several "container communities" in the southeastern Turkish city struck by a big quake in 2023—Kahramanmaras. These communities offer survivors safe, comfortable, and convenient living spaces completed with schools, banks, supermarkets, laundry rooms, and pharmacies. The biggest community shelters 7,000 people that cover more than 2,500 containers. They are modular and removable units responsive to the local needs in a 3x7 meter measurement but easy for transportation, placement, and reconfiguration. Made for a family of three, they are equipped with a living room, separate bathroom, bedroom, and open kitchen for comfort and convenience (Figure 50: CBOX Modular Container houses colony in Türkiye). The container houses are safe, secure, earthquake-proof, and deployed quickly with a comfortable high living level. (CBOXCONTAINERHOUSE.COM, 2024)



Figure 50: CBOX Modular Container houses colony in Türkiye

The specific features of Container Housing and its critical analysis is listed in Table 3: Container Housing Specific Features and Critical Analysis Table 1: IKEA - Better Shelter Specific Features below:

Table 3: Container Housing Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|-------------|---|--|
| Dwelling and Size | 2-4 people | 20 to 40 feet length containers (13.5m ² – 26m ²) | Provided crucial space for relocated families and services through limited use of land resources. |
| Cost | | \$2000 - \$3000 | Cost is too expensive for this type of living space. |
| Installation Manpower | | 2-4 people | Effective utilization of manpower sped up the provisioning of shelters, crucial in emergency situations. |
| Power source | ✓ | On Grid: Needs City Power | Ensuring reliable electrical power is essential for lighting, heating, and medical equipment, though it can be challenging. |
| Window & Sunlight | ✓ | 1-2 windows | Living spaces were enhanced with natural light, though design changes were needed to maximize benefits. |
| Water Source | ✓ | On Grid: Needs City Water | There was a critical need for improving water supply systems to assure hygiene and basic living standards. |
| Cooking Gas Source | ✓ | It varied, some units having gas stoves, while others used electric or community cooking areas. | Access to cooking facilities was essential but varied greatly, impacting daily living activities. |
| Kitchen | ✓ | Some used communal kitchen, some had own kitchen. | Limited kitchen setups sufficed for emergency needs but were not ideal for long-term living arrangements in case of long-term permanent house is not yet constructed. |
| Sanitary Facility | ✓ | Some containers had integrated bathrooms. | Shared bathroom facilities typically led to hygiene problems, requiring improved design and maintenance strategies, while some units had their own bathroom in the unit. |
| Ventilation | ✓ | Cross Ventilation & Roof Vent. | Adequate ventilation is essential to prevent overheating and ensure air quality, especially in warmer months. |
| Waterproofing | ✓ | Waterproof | Effective waterproofing is necessary to withstand weather conditions and maintain structural integrity. |

| | | | |
|---------------------|---|--|---|
| Insulation | ✓ | Basic insulation was included but varied in effectiveness. Additional insulation was occasionally installed. | Insulation quality directly impacted comfort levels, especially in extreme temperatures, highlighting the need for higher quality materials and construction methods. |
| Fireproofing | ✓ | Non combustible | With safety being a critical element, continuous monitoring and maintenance were necessary to assure effectiveness. |

Lastly, the Fabrication, supply, installation and specific features of these container houses have the highest impact on the cost of the temporary housing in post-disaster housing although they tend to be one of the fastest solutions.

3.3.4 FEMA Trailer (Mobile)

FEMA trailers are temporary manufactured homes available to natural disaster victims. They generally come complete with bathrooms, kitchens, and furniture. They were first used in response to hurricane Katrina in 2005 in USA (Figure 51: FEMA Trailer Park in New Orleans, USA). Being typically designed to work on the grid, they will need sites with available water and electricity. The excellent mobility is their best advantage, letting them be close to the properties of the affected families and leave when there is permanent housing again. (Smith, n.d.)

It was found by the Federal studies that the trailers had high levels of formaldehyde, a neurotoxin and carcinogen. The levels were often 10 times what the CDC considers safe. Formaldehyde is used as a bonding agent in engineered wood. It was in the trailers' walls, floors, and built-in furniture. The trailers (Figure 52: Some of the FEMA Trailers in New Orleans, USA) were small, poorly ventilated, and rapidly built with cheap materials-making their levels especially high. (Smith, n.d.)



Figure 51: FEMA Trailer Park in New Orleans, USA



Figure 52: Some of the FEMA Trailers in New Orleans, USA

The specific features of FEMA Trailers and its critical analysis is listed in Table 4: FEMA Trailers Specific Features and Critical Analysis Table 1: IKEA - Better Shelter Specific Features below:

Table 4: FEMA Trailers Specific Features and Critical Analysis

| Feature | | Description | Critical Analysis |
|------------------------------|----------|--------------------------------------|--|
| Dwelling and Size | 4 people | 9.75m(D) x 2.4m(W) | Supplies 3.5 m ² per person; ideal for a family of five. |
| Cost | | \$24000 manufacturing and site setup | It is expensive, currently available for \$24000, and can be made retrofit for future use. |
| Installation Manpower | | 6- 10 people | Several subcontractors are needed to install the trailer along with its utilities in several days. |

| | | | |
|------------------------------|---|----------------------------|---|
| Power source | ✓ | On Grid: City Power needed | FEMA also avoids putting trailers where no electrical services are available. |
| Window & Sunlight | ✓ | 4-6 Windows | 4-6 small windows for daylight and cross ventilation. |
| Water Source | ✓ | On Grid: City Water needed | FEMA avoids deploying trailers in sites without running water. |
| Cooking Gas Source | X | No Gas Pipes | Two propane tanks supply gas for hot water, heating, and cooking. |
| Kitchen | ✓ | Small Kitchen | That includes oven, cabinets, sink, a propane stove. |
| Sanitary Facility | ✓ | Bathroom With Shower | Bathroom with cold or hot water shower. |
| Ventilation | X | Poor Ventilation | 42% of the dwellings had harmful levels of formaldehyde due to low ventilation and poor building materials. |
| Waterproofing | ✓ | Waterproof | Waterproof designed can ensure protection from rain infiltration and enhance comfort during rains. |
| Insulation | X | Poor Insulation | Poor insulation means that, for a stable temperature, much energy is used, which makes the. |
| Fireproofing | X | Easily Combustible | - |

3.3.5 Super Adobe Eco-Dome (Vernacular)

Iranian architect Nader Khalili developed Super Adobe. It consists of long barbed-wire-reinforced sandbags filled with earthen materials and a minimum of tools. A vital advantage of this technology is that it conforms with California's strict earthquake codes. However, the fact that the structure is permanent means land rights and construction permits need to be obtained. (CalEarth, n.d.)

Moreover, because of its size and the fact that it is built as a permanent structure, it is less suited for post-disaster scenarios where families would prefer temporary homes near their damaged properties (Figure 53: Super Adobe Vernacular house construc-

tion). The Basic Materials needed for its construction are: Low UV (ultra-violet) resistant degradable Synthetic sandbags (polypropylene tubes), galvanized barbed-wire, Shovels, Tampers and Soil & Water. (CalEarth, n.d.)



Figure 53: Super Adobe Vernacular house construction

The specific features of Super Adobe and its critical analysis is listed in Table 5: Super Adobe Specific Features and Critical Analysis Table 1: IKEA - Better Shelter Specific Features below:

Table 5: Super Adobe Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|-------------|---|---|
| Dwelling and Size | 2-5 people | 37 sq. m | Varied sizes, ideal for a family of five. |
| Cost | | \$150 - \$300 per m ² or more | Cost depending on the proportions of the ingredients (cement, gravel, etc.). Cheap construction |
| Installation Manpower | | It takes 1 skilled or 4 unskilled workers | Various contractors install the trailer, stairs, ramps, furniture, appliances, and power connections. |

| | | | |
|------------------------------|---|-------------------------------|--|
| | | to build one in 5 days. | |
| Power source | X | No Electricity | Solar panels are necessary if there is no power from the city. |
| Window & Sunlight | ✓ | 8 Windows | 8 windows were available for daylight and ventilation. |
| Water Source | X | No Water Connection | Problems arise when there is an infliction of damage to the infrastructure, or there are no lines for the water. |
| Cooking Gas Source | X | No Gas Pipes | Suitable for town gas and propane tanks. |
| Kitchen | X | Space provided only | Families will have to buy kitchen cabinets and equipment. |
| Sanitary Facility | X | No Sanitary facility | The area is designed for bathroom, but no setup of any kind included. |
| Ventilation | ✓ | Cross Ventilation & Roof Vent | - |
| Waterproofing | ✓ | Waterproof | Possibility to make the structure waterproof |
| Insulation | ✓ | Insulated | The mass of the building is used as insulation through the earth. |
| Fireproofing | ✓ | Not Combustible | Various contractors install the trailer, stairs, ramps, furniture, appliances, and power connections. |

3.3.6 Shigeru Ban Architects – Paper Log Houses/ Paper Partition System (PPS) (Recycled Materials)

Paper log houses are creations of Shigeru Ban's imagination after Japan's earthquake in 1995: temporary shelters made from recyclable tubes, paper beer crates filled with sandbags, and tent material as roofing. They are meant to be disassembled and their materials recycled (Figure 54: Paper Log House prototype). Designed to be semi-permanent for use over an extended period, disasters, or refuge, they are also not sufficiently temporary as a shelter, with poor insulation and the lack of everyday facilities

such as bathrooms and kitchens. They are particularly immobile, again posing a problem for land rights and permits. (ArchDaily Team, 2020)



Figure 54: Paper Log House prototype

The Paper Partition System (PPS) uses wooden panel walls fixed between paper tube columns, beer crate and sandbag foundations, and paper tube and plywood roofs (Figure 55: Paper Partition System (PPS) house prototype). Insulation is added throughout, and these buildings have been used in Rwanda, Poland, Slovakia, France, and Ukraine for relief in times of disaster. (Florian, 2023)



Figure 55: Paper Partition System (PPS) house prototype

The specific features of Paper Log House/ Paper Partition House and its critical analysis is listed in Table 6:

Table 6: Paper Log House/ Paper Partition House Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|--------------------|----------------------|--|
| Dwelling and Size | 4 people | 16 sqm | Accommodates a small family or group sufficiently, multipurpose for any kind of emergency. |
| Cost | | \$2,000 | - |
| Installation Manpower | 6hrs | 10 - 20 people | Skilled and unskilled workers would be required; training and management could delay the operation. |
| Power source | X | No Electricity | Residents must manage their city power connections. |
| Window & Sunlight | ✓ | 3 Windows | Three daylight and ventilation windows are in place. |
| Water Source | X | No Water Connection | Infrastructural damage or the absence of water lines could lead to problems. |
| Cooking Gas Source | X | No Gas Pipes | Able to work with town gas or propane tanks. |
| Kitchen | X | No Kitchen | There are no private kitchens; families must share communal kitchens or have no cooking facilities. |
| Sanitary Facility | X | No Sanitary facility | No toilets: families either use shared bathrooms or don't have in-house facilities. |
| Ventilation | ✓ | Cross Ventilation | - |
| Waterproofing | ✓ | Waterproof | With specific coating it has been made waterproof |
| Insulation | X | Poor Insulation | It claimed to regulate temperature with the operable roof and sponge tapes, although there are reports that it is not insulated. |
| Fireproofing | ✓ | Not Combustible | With specific coating it has been made fireproof. |

3.3.7 Suricatta Systems – Suri

Suri, the product of a Spanish team with experience in building repairs, is an emergency shelter in transition – from rapid response to complete assimilation after disaster. In use today in the Middle East, sub-Saharan Africa, and the refugee crisis in Europe, Suri boasts a modular grid system that links units into far more significant space; this makes it suitable for a variety of uses, including emergency field hospitals. Manufactured in a flat-packed fashion, 12 units fill every shipping container and can be easily installed on-site. Its telescopic design unfolds to a rectangular shape, with fillable outer walls for soil or sand that provide stability and thermal insulation (Figure 56: Suricatta Systems Prototype Unit, Figure 57: Suri Shelter being sold Online (Source:). Added features such as water collection and filtration, solar panels, lighting, and mosquito repellent are part of the package. (Suricatta Systems, n.d.; Tucker, 2015)

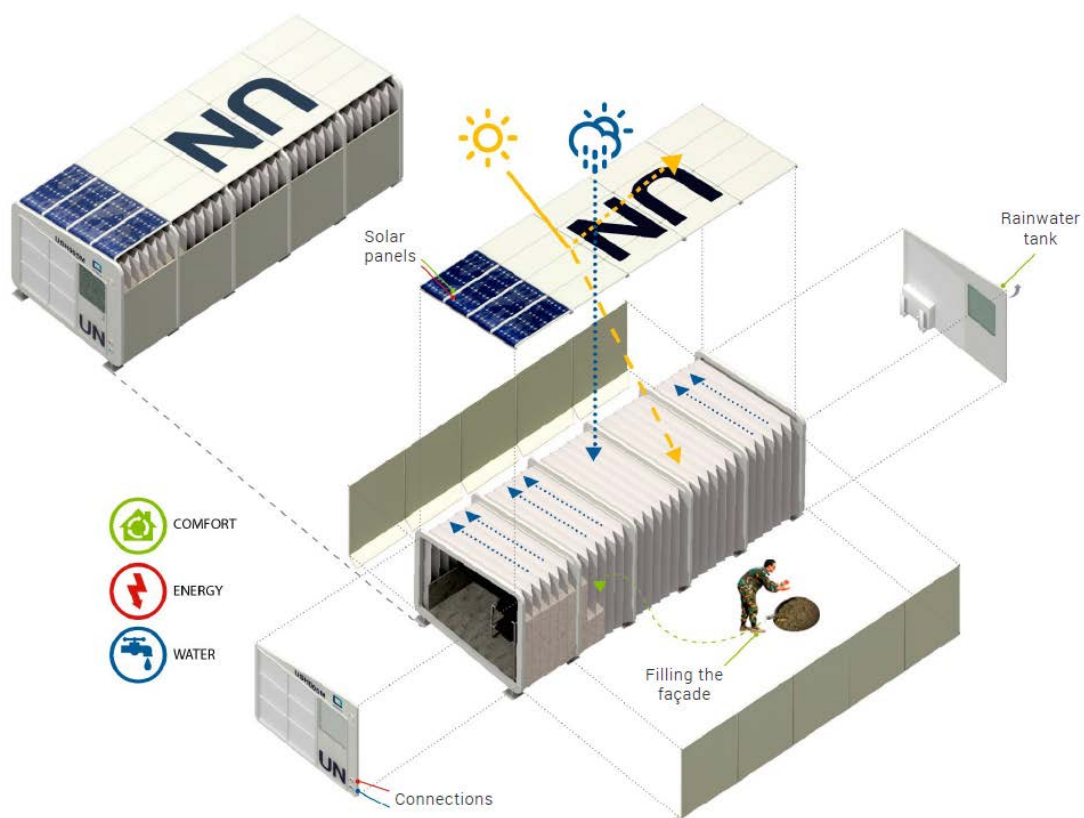


Figure 56: Suricatta Systems Prototype Unit (Source: (Suricatta Systems, n.d.))



Figure 57: Suri Shelter being sold Online (Source: (satellite-telecom.shop, n.d.))

The specific features of SURI Shelter and its critical analysis is listed in Table 7:

Table 7: SURI Shelter Specific Features and Critical Analysis

| Feature | Description | | Critical Analysis |
|------------------------------|-------------|--------------------------------------|--|
| Dwelling and Size | 5 people | 5.2m(L) x 2.9m(W) x 2.6m (H) | 15.08m ² for a 4-unit combination model accommodates a small family or group sufficiently, multipurpose for any kind of emergency. |
| Cost | | \$20,500 for a 4-unit model | It is extremely costly for the disaster relief and temporary housing. |
| Installation Manpower | | 2 people | Quick and efficient to set up with minimal labour and time requirements to deploy. |
| Power source | ✓ | Off Grid: Solar powered | Ensures sustainable, off-grid power solutions suitable for remote or disaster-hit areas. |
| Window & Sunlight | ✓ | 2 Windows | It gets the maximum intake of natural light to ensure comfortable living conditions. |
| Water Source | ✓ | Rainwater collection and filtration. | A proper source and water availability are realized from the ability to get them from the rainfall, with a filtration system that ensures efficient use. Improves resource scarcity in areas with a reliable source. |

| | | | |
|---------------------------|---|---|--|
| Cooking Gas Source | X | No Gas Pipes | Able to work with town gas or propane tanks. |
| Kitchen | X | No Kitchen | There are no private kitchens; families must share communal kitchens or have no cooking facilities. |
| Sanitary Facility | X | No Sanitary facility | Very much needed features for health in temporary settlements. |
| Ventilation | ✓ | Ventilated façades can breathe, waterproof, and thermally and acoustically insulated. | Offers excellent thermal comfort and acoustic insulation, making it perfect for different climatic conditions. |
| Waterproofing | ✓ | Waterproof | Provides protection against water, enhancing durability and structural integrity. |
| Insulation | ✓ | High level of thermal and acoustic insulation. | Improves living conditions by maintaining comfortable indoor temperatures and reducing noise. |
| Fireproofing | X | Combustible | - |

Lastly, it is important to point out that Suri structures prioritize the space's comfort and present some specific elements that should not be linked solely to the Shelter idea. These structures can regulate thermal interchange and simplistically, it can be said that this is rather beneficial; however, the replacement of these walls with natural dirt or sand is rather complicated and can prove to be utterly impossible when used as the initial response right after the disaster. Similarly, the choice of a proper land on which these shelters are to be built may become a problem. The Suri shelters when tested for real do work in many ways in the kinds of environments like refugee camps which can be considered as a conflict-stricken areas, but they are not suitable for first response to disasters.

3.3.8 Comparison Chart of Case studies projects

Following is the comparison chart of all the researched case studies projects:

| Feature | Better Shelter | Exo Shelter | Container Housing | FEMA Trailer |
|------------------------------|--|--|--|---|
| Dwelling | 5 people | 4 people | 2-4 people | 4 people |
| Covered area | 18.5m ² | 7.5m ² | 13.5m ² – 26m ² | 23m ² |
| Cost | \$10,000 | \$5,000 | \$2,000-\$4,000 | \$14,000 |
| Installation Manpower | 4 people | 4 people | 2-4 people | 1-4 people |
| Power source | ✓ Offline | ✓ Online | ✓ Online | ✓ Online |
| Water source | X | ✓ Online | ✓ Online | ✓ Online |
| Cooking Gas source | X | X | ✓ | X |
| Window & Sunlight | X | ✓ | ✓ | ✓ |
| Ventilation | ✓ | ✓ | ✓ | X |
| Water Proofing | ✓ | ✓ | ✓ | ✓ |
| Insulation | X | X | ✓ | X |
| Fireproofing | X | X | ✓ | X |
| Kitchen | X | X | ✓ | ✓ |
| Sanitary Facility | X | X | ✓ | ✓ |
| Major Disadvantages | <ul style="list-style-type: none"> • Basic shelter • No sanitary facilities • No kitchen • Not insulated • No window • Needs flat sites • No storage space • Industrial cold look for “home” | <ul style="list-style-type: none"> • Basic shelter • No sanitary facilities • No storage space • No cooking • Not insulated • Needs infrastructure to operate • Needs flat sites • Industrial cold look for “home” | <ul style="list-style-type: none"> • High initial cost to build and install • Tight living area • Crane needed for installation and assembly on-site • More permanent than temporary • Needs building permission • Industrial cold look for “home” | <ul style="list-style-type: none"> • Very tight living area • Breathing problems because of toxic materials • No storage • No temperature comfort • Needs infrastructure to operate • Very expensive to build & install |

| Feature | Super Adobe | Paper Log | SURI Shelter |
|----------------------------|---|---|---|
| Dwelling | 4-5 | 4-5 | 4 |
| Covered area | 37m ² | 16m ² | 15.08m ² |
| Cost | \$150 to \$300 | \$2,000 | \$20,500 |
| Installation Manpower | 1-4 people | 10-20 people | 2 people |
| Power source | X | X | ✓ Off Grid |
| Water source | X | X | ✓ On Grid |
| Cooking Gas source | X | X | X |
| Window & Sunlight | ✓ | ✓ | ✓ |
| Ventilation | ✓ | ✓ | ✓ |
| Water Proofing | ✓ | ✓ | ✓ |
| Insulation | ✓ | X | ✓ |
| Fireproofing | ✓ | ✓ | X |
| Kitchen | X | X | X |
| Sanitary Facility | X | X | X |
| Major Disadvantages | <ul style="list-style-type: none"> • More permanent • Land right issues • Needs building permission • Too big to be located on the disaster survivors' property • No sanitary facilities • No cooking • Needs infrastructure to operate • Flat space required | <ul style="list-style-type: none"> • Basic shelter • Land approval • not insulated • No sanitary facilities • No cooking • Needs infrastructure to operate • Flat space required | <ul style="list-style-type: none"> • Very High initial cost • Tight living area • Complicated replacement of dirt walls • More permanent than temporary • Flat space required • No bathroom • No cooking • Not suitable for initial disaster response |

3.3.9 Summary of Findings:

In conclusion, Container House type of temporary housing was found to be of the most features for the given disadvantages as compared to other options.

Deployable structures, due to their rapid construction, are ideal for emergency needs, including post-disaster situations. However, these could result in operational challenges as it is transported as a single piece and requires a crane upon installation. Infrastructure should be readied beforehand, together with planned settlement costs during a given period. Moreover, the second life of these structures can contribute to the alleviation of economic issues related to having temporary housing. Thus, an excellent post-disaster management plan will consider all these points. (SÜALP & COŞGÜN, 2023)

The application of modular construction in post-disaster housing reconstruction can be enhanced if it is scaled up. The role of government in setting up plans, funding departments and policies, and providing equipment, training and other necessities to prepare and respond to different disasters could decrease the effects of disaster capitalism. In order to overcome storage problem, it may be advisable for contracting manufacturers to stock a certain number of basic material than stocking numbers of complete modular units to avoid repair and storage costs. Temporary housing arrangements require to have laid down objectives or goals as well as timelines especially to prevent them from assuming the meaning of permanency. Due to zoning regulations and limited space in Construction industry, modular construction has not been widely used. Transit and erection of modular systems involve movements within urban areas which can be more of a challenge and involving a lot of time and resources (Zhou, 2023)

3.4 Selection of Energy Efficient Materials

One of the main objectives was to identify locally available and cost-effective energy efficient materials with properties including durability, applicability, thermal conductivity, reflectivity and density etc.

Now, using the container house design from the lesson learned from the case study projects, cost effective and energy efficient materials with their properties from various sources were explored, some of the materials vendors were interviewed to discuss the advantages and disadvantages and the thermal properties of the materials.

Using the lessons learned from the case studies project researched above, following are the selected locally available and cost-effective energy efficient materials for the design of the proposed Modular House:

Structural Framing

Mild steel is selected for the frame structure of the Modular house. The steel is sufficient for the required strength and weighs less than other alternatives. Moreover, the material is easily available in Pakistan and economically viable. The steel is layered with red oxide paint to induce water resistance and with proper maintenance the life expectancy of the material can be approximated at 50 years. (AISC, 2016)

The Structural Modelling of the modular house, Hollow Structural Sections (HSS) Square 4x4x3/8 Columns section and HSS Square 2x2x3/16 framing sections are used as they are the standard size and readily available in Pakistan.

PVC (Poly Vinyl Chloride) sheets

PVC Sheets are used to make facade of Wall and Roof Sandwich Panels and for the External and Internal Doors. It is 100% waterproof and extremely durable. The material is also fire retarding and lightweight and cost effective also. Furthermore, it is aesthetically pleasing and provides a good, finished surface. In terms of sustainability and environmental impact, the material has no toxic gas releases. Additionally, the material is produced locally, thus having a lower carbon footprint. Moreover, the white colour of sheets combined with the insulation properties of the material helps to keep the inside of the shelter at moderate temperature. The technical properties are tested using German Institute for Standardization (DIN) tests, are shown in Table 8: Technical Properties of Rigid PVC Sheets. (Lectronic M Aterials et al., 2002; Mark, 1998; MatWEB, n.d.)

Table 8: Technical Properties of Rigid PVC Sheets

| Property | Standard | Rigid PVC |
|---------------------------------|------------|--|
| Physical Properties | | |
| Density | DIN 53479 | 1.38 - 1.42 g/cm ³ |
| Water Absorption | DIN 53495 | < 0.1% |
| Mechanical Properties | | |
| Tensile Strength | DIN 53455 | 45 - 60 MPa |
| Elongation at Break | DIN 53455 | 10% - 20% |
| Modulus of Elasticity | DIN 53457 | 2500 - 3000 MPa |
| Impact Strength | DIN 53453 | 2 - 10 kJ/m ² |
| Hardness (Shore D) | DIN 53505 | 70 - 85 |
| Electrical Properties | | |
| Volume Resistivity | DIN 53482 | 10 ¹⁴ - 10 ¹⁶ Ω·cm |
| Dielectric Strength | DIN 53481 | 20 - 40 kV/mm |
| Dielectric Constant | DIN 53483 | 3.0 - 3.4 |
| Thermal Properties | | |
| Melting Point | DIN 53765 | 160 - 210 °C |
| Coefficient of Linear Expansion | DIN 53752 | 5 - 7 x 10 ⁻⁵ /°C |
| Thermal Conductivity | DIN 52612 | 0.16 - 0.19 W/m·K |
| Flammability Properties | | |
| Flammability Classification | DIN 4102-1 | B1 (hardly inflammable) |

Polyurethane Insulation Board

Polyurethane Insulation Board is the best insulation product available in Pakistan. The use of polyurethane reduces the conduction of heat through roof, walls and considerably reduces the temperature within the house. Properties of rigid polyurethane foam (PUR/PIR) are as follows (European Association of Polyurethane Insulation Manufacturers, n.d.)

- Thermal Conductivity (λ -value or U-Value) ranges between 0.020 W/(m·K) and 0.050 W/(m·K).
- Density ranges between 30 kg/m³ and 45 kg/m³, but it can reach up to 100 kg/m³ for some applications.

For the development of the Modular house, Thermal Conductivity of 0.0159 W/(m·K) and density of 32 kg/m³ is used which is most used insulation in Pakistan.

Internal Wall Timber Studs

Timber is utilized for the construction of Internal Wall Studs, being the most economical and lightweight option. Timber studs prevent wall panels from bending and acts as a support. The timber used is well-seasoned, termite-proof and sealed within the sandwiched wall for protection, to greatly increase its life span. Timber has an overall negative embodied energy and is one of the most sustainable materials if the forests are managed well. The weight to strength ratio of timber is an additional benefit as it helps in the objective of making the structure as light as possible. (Abera, 2024)

Gypsum Board

Gypsum board is an energy-saving construction material that is used for its insulating capacity and facility of fixing with ease. It plays a vital role in regulating temperature in structures by insulating the physical flow of heat out of the building and keeping the building envelope thermally insulated. Another advantage of gypsum board is that its materials are natural and if it is recycled, then it is environmentally friendly. Due to its relatively light weight, it lowers the entire structural load, thus could signify potential savings with construction costs and materials. Also, gypsum board has properties of fire resistance which creates additional safety and longevity to buildings. The use of these materials is an excellent solution for modern energy-efficient designs and creates a beautiful relationship between heat and cold insulation, stability and eco-friendliness. The Table 9: Technical Properties of Gypsum Board below shows the technical properties of gypsum board. (Sharifi et al., 2017)

Table 9: Technical Properties of Gypsum Board

| Property | Gypsum Board |
|----------------------|------------------------|
| Thermal Conductivity | 0.25 W/m·K |
| Density | 1380 kg/m ³ |
| Specific Heat | 1.09 J/g·K |

Double Glazed UPVC Window with clear/Low-E coating

UPVC windows are very efficient in thermal resistance and eliminating noise intrusions into homes. They provide insulation during the chilly winters and keep the inside cool during the hot summertime due to their property that does not allow heat to pass through them easily. Further, they do not fade easily, and they are of high strength, tough, durable and rot resistant which makes them last for a long time. Properties of double glazed UPVC window with clear/Low-E coating used for the development of the modular house are as follows (Carmody & Northernstar, 2012):

- Thermal conductivity (U-value) of double glazing typically ranges from 1.1 to 3.0 W/(m²·K).
- Thermal conductivity (U-value) of UPVC frame ranges from 1.8 to 2.5 W/(m²·K).
- Density is typically around 1400 to 1600 kg/m³.
- Thermal conductivity (U-value) of Low-E (low emissivity) coatings can typically range from 1.0 to 1.2 W/(m²·K).

For the development of the Modular house, Thermal Conductivity (U-Value) of 1.9873 W/(m·K) is used which was automatically calculated by selecting the standard values from the Revit library for the specific window construction.

Plywood sheets for Flooring:

For flooring, Plywood sheets are selected as they are a strong and lightweight material capable of withstanding moist conditions. The material is manufactured locally and is easily available. Hence, the sheets are an effective decking material. Other substitutes include concrete slabs and fibre cement board but were rejected because of the increased cost and weight. Marine ply is also water retardant and has a life expectancy of over 25 years. An additional benefit is its smooth finished surface. The technical properties can be seen from Table 10: Technical Properties of Plywood (RigaWood Plywood Handbook, 2022).

Table 10: Technical Properties of Plywood by (RigaWood Plywood Handbook, 2022)

| Property | Value |
|--------------------------------|-----------|
| Density (kg/m ³) | 670 - 760 |
| Thermal Conductivity (W/(m·K)) | 0.17 |

| | |
|---|--------|
| Bending Strength Parallel to Grain (N/mm ² , 4 mm) | 77 |
| Bending Strength Perpendicular to Grain (N/mm ² , 4 mm) | 8.9 |
| Modulus of Elasticity Parallel to Grain (N/mm ² , 4 mm) | 13,808 |
| Modulus of Elasticity Perpendicular to Grain (N/mm ² , 4 mm) | 1,531 |
| Moisture Content (%) | 06-10 |

3.5 Development of 2D Architectural Plan of Proposed Modular House

2D Architectural plan for the proposed Modular House was developed using the lessons learned from the case studies discussed above. Architectural planning of house was done by using basic architectural rules of size and space planning for a standard shipping container of external dimensions 6100x2440x2590mm (Length x Width x Height). After developing some floor plans, they were reviewed by few architects and thus finalized a 2D architectural model for Modular House as shown in Figure 58: 2D Architectural Plan of Modular House and the front elevation is shown in Figure 59: Front Elevation of the Modular House.

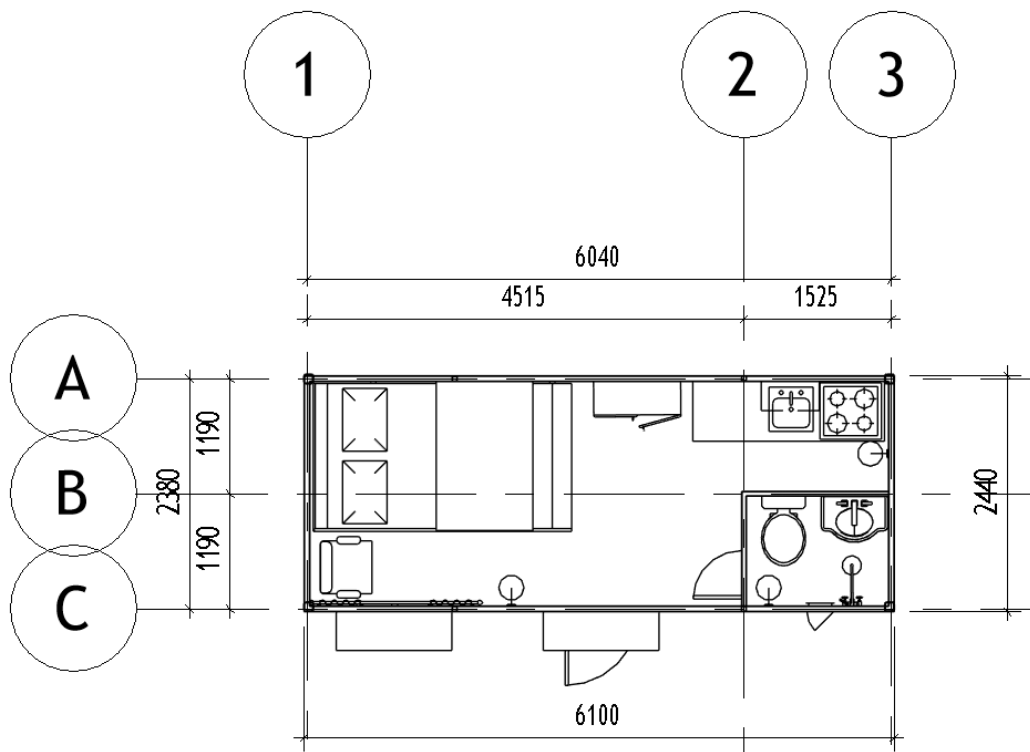


Figure 58: 2D Architectural Plan of Modular House

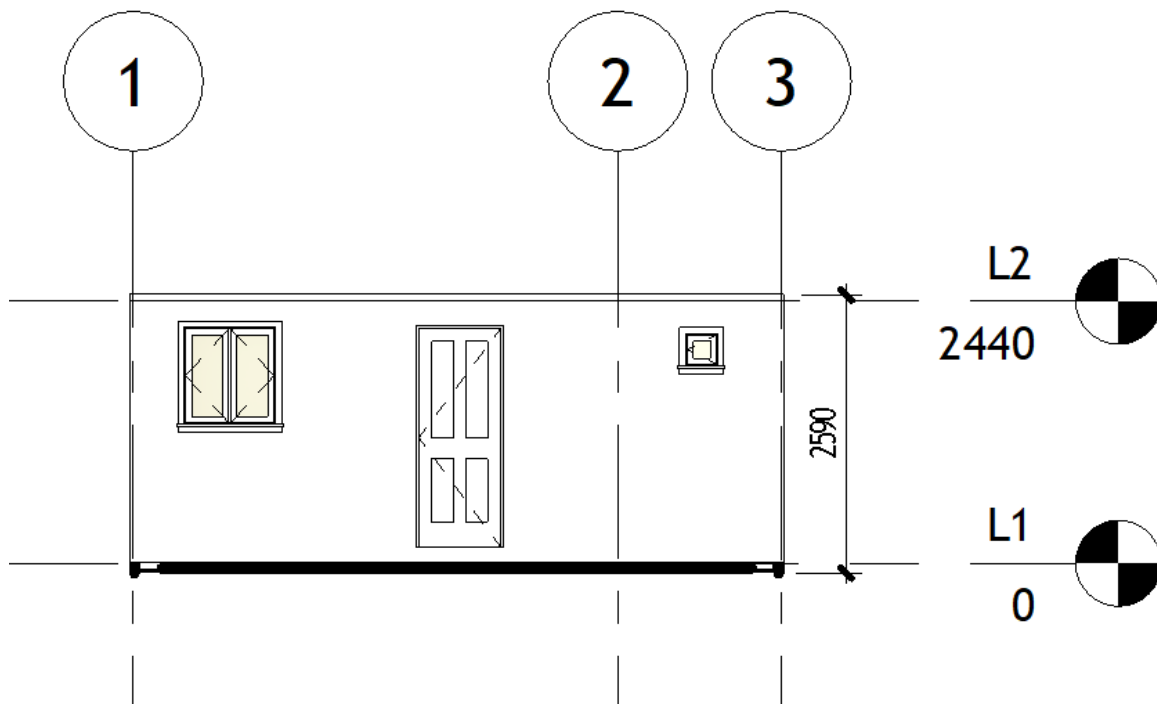


Figure 59: Front Elevation of the Modular House

This design incorporates all the specific features required for adequate use in case of post-disaster recovery and reconstruction as it has a covered area of 13.8sqm sufficient to accommodate 2 people at a time, use of lightweight but structurally adequate design, only 2 people are needed to assemble this modular house with common tools, on grid power source, on grid water source, fully equipped kitchen and bathroom facilities. It is thermally insulated and waterproof as it has energy efficient materials that will lower the lifecycle cost of this house.

3.6 3D BIM Modelling (Structural + Architectural)

The initial step of BIM modeling is to develop a 3D Model from 2D architectural plan. 3D BIM model was developed using Autodesk Revit 2025 (Student Version). Autodesk Revit provides extensive source of material library and families that helps in easily developing 3D BIM model. In Revit, the ease to construct any building is the main reason that Revit has become the landmark for developing architectural model and its

application is growing day by day in the local AEC industry. 3D BIM model contains detailed information of architectural, structural and MEP details of house.

The idea behind developing a 3D BIM model was to use energy efficient materials on building envelop (roof, walls, and windows) from the lessons learned from the case studies. Then developing its Construction Schedule using Primavera P6 and then Simulation using Autodesk Navisworks Manage. Then finally the Energy Analysis using Autodesk Insight 360.

Structural Model Development

Firstly, the Structural Model was made using HSS Square 4x4x3/8 Columns section on all four sides of the house along with its sectional properties are shown in Figure 60: HSS Square 4x4x3/8 section columns on all four sides.

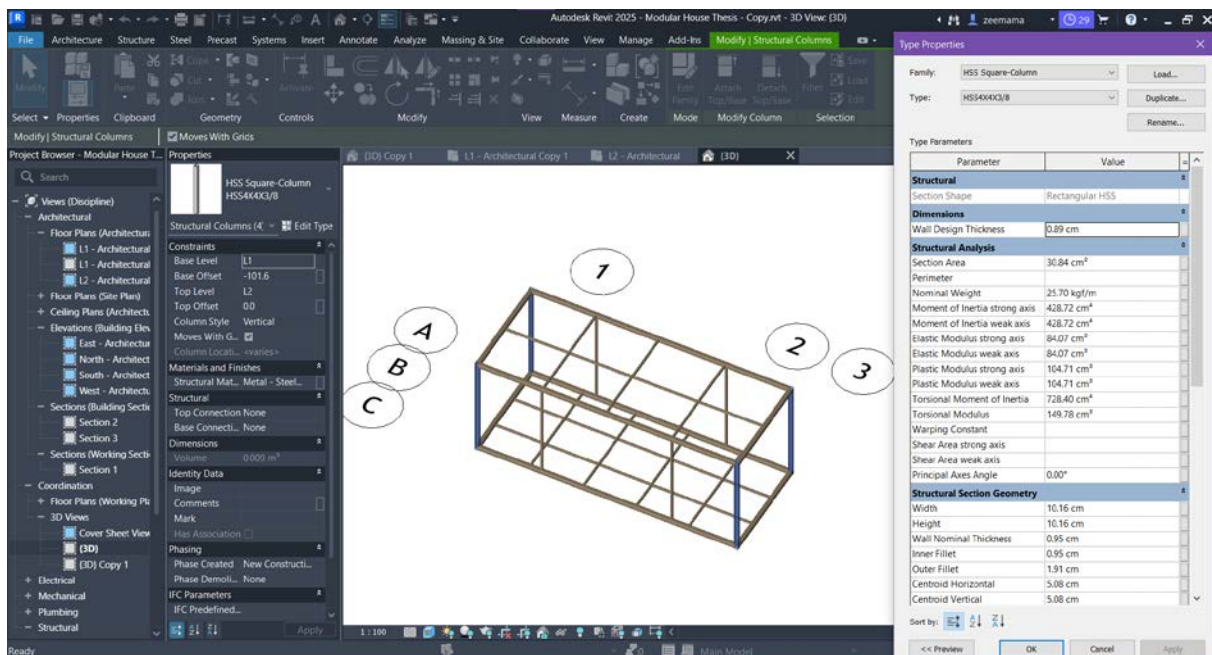


Figure 60: HSS Square 4x4x3/8 section columns on all four sides

Then again using HSS Square 4x4x3/8 Framing section, the top and bottom of these columns were connected on the perimeter to make a box frame as shown in Figure 61: HSS Square 4x4x3/8 section Framing on all four sides.

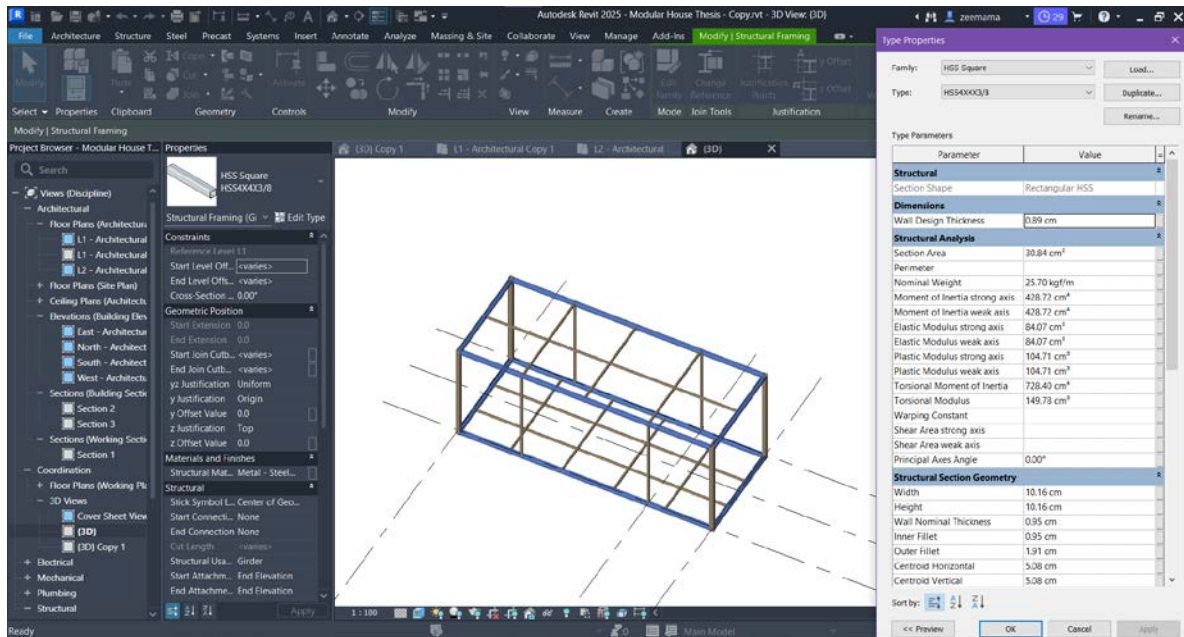


Figure 61: HSS Square 4x4x3/8 section Framing on all four sides

The floor has additional HSS Square 2x2x3/16 sections, four of them between the Grid 1 to 3 and two of them between the Grid A to C. Also, for the Roof Level-2 at 2440m, additional HSS Square 2x2x3/16 sections, three of them between the Grid 1 to 3 and one between the Grid A to C. The sectional properties and location of these strengthening sections can be seen in Figure 62: HSS Square 2x2x3/16 sections for floor and roof strengthening.

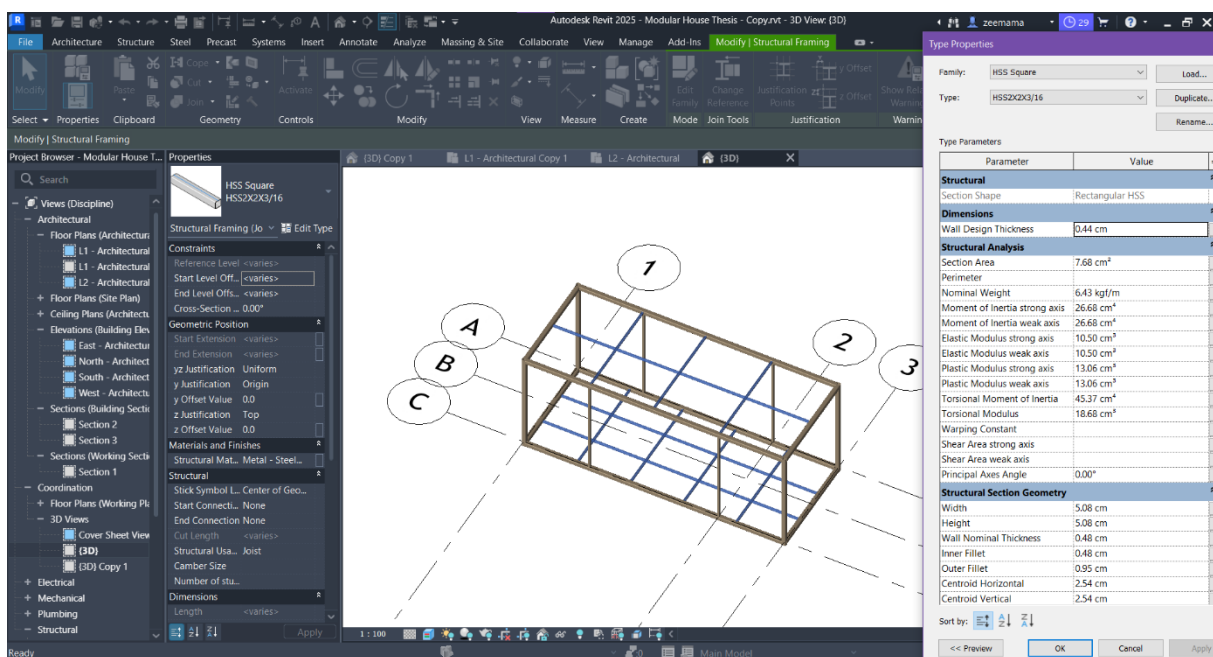


Figure 62: HSS Square 2x2x3/16 sections for floor and roof strengthening

Additional HSS Square 2x2x3/16 Column sections are provided on the longer sides of walls of the model for wall strengthening as shown in Figure 63: HSS Square 2x2x3/16 sections for strengthening of Walls.

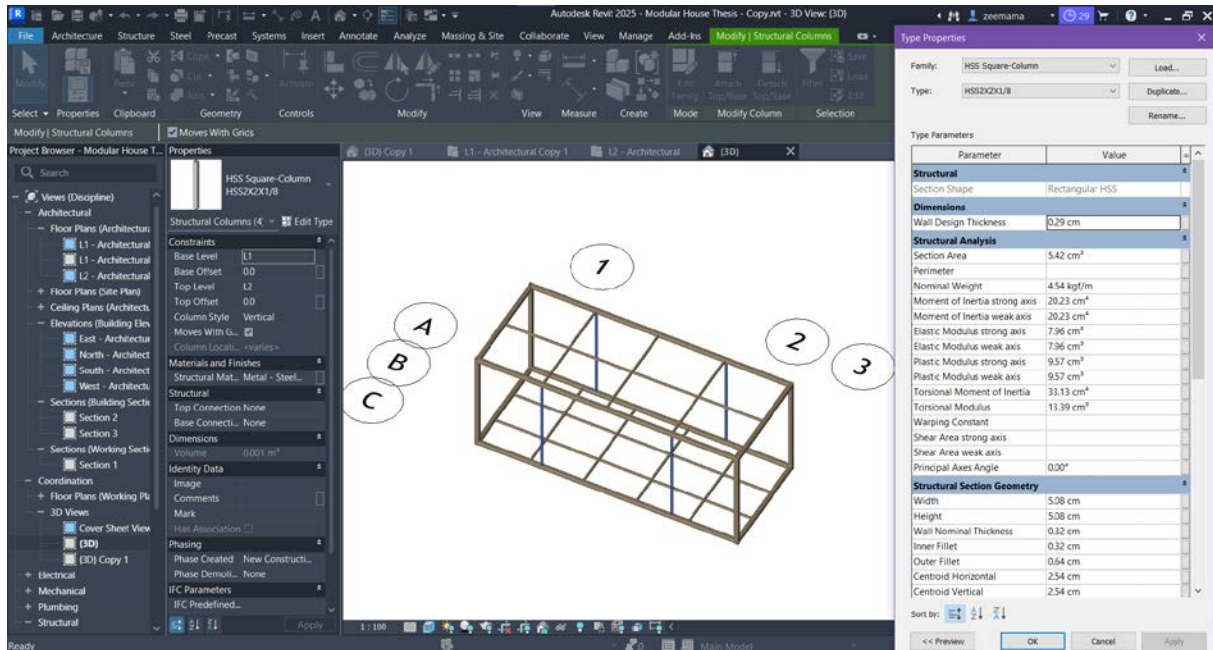


Figure 63: HSS Square 2x2x3/16 sections for strengthening of Walls

Architectural Model Development

The External Walls and the Roof of the model were made as a sandwich panel with an outer PVC sheet of 5mm, central Polyurethane Insulation Board of 50mm and a room inside facing of Gypsum Board of 5mm. The total thickness of this sandwich panel is 60mm to achieve a high Thermal Resistance (R-Value) of 3.1732 (m².K)/W as shown in the Figure 64: External Walls Sandwich Panel section for External Walls and Figure 65: Roof Sandwich Panel section for Roof sections. The Exterior walls and roof colour is set to white as it is used to set the exterior surface absorptivity which influences the rate of heat loss or gain as a function of solar frequency.

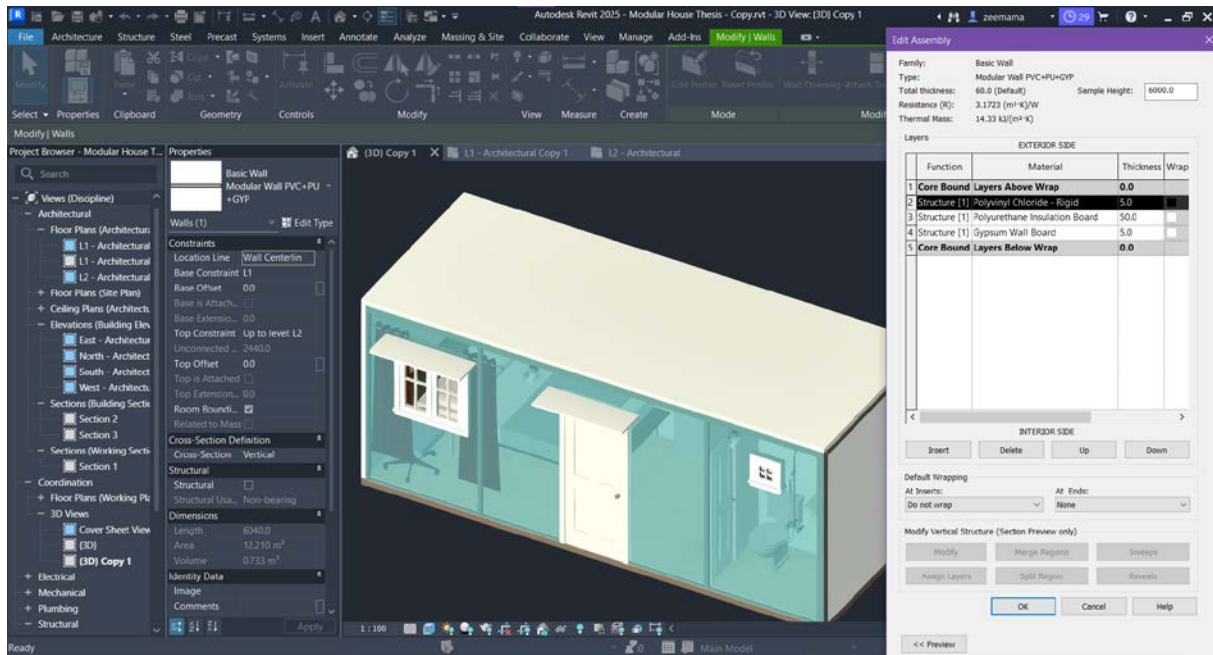


Figure 64: External Walls Sandwich Panel section

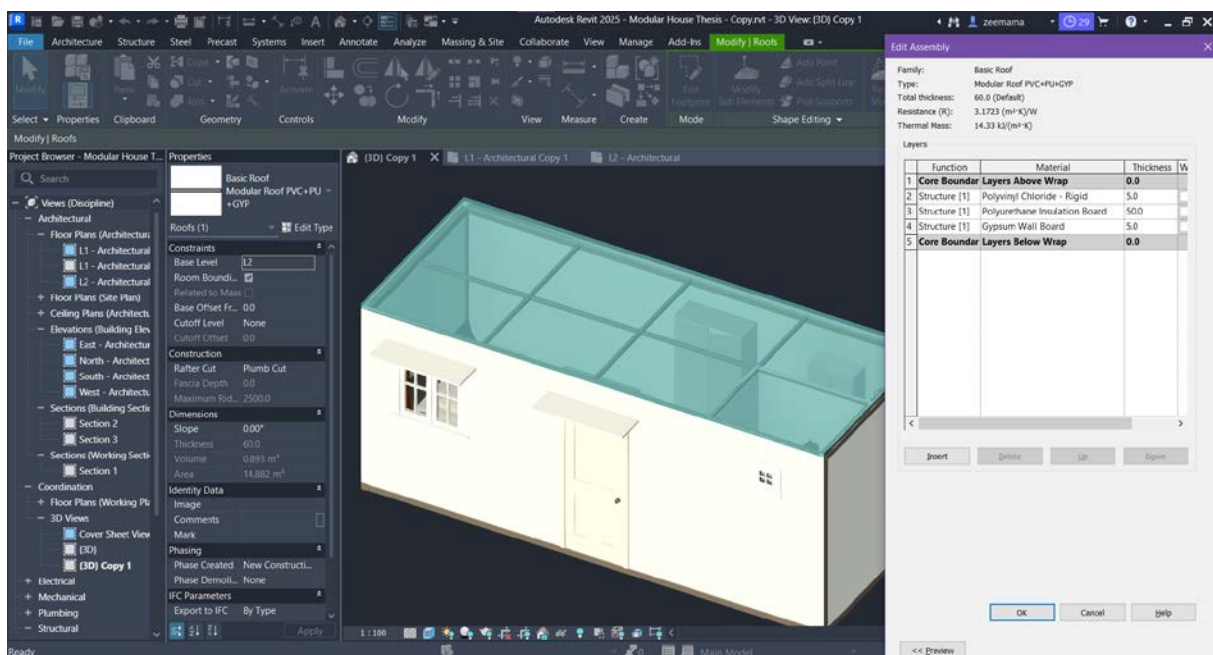


Figure 65: Roof Sandwich Panel section

The Internal Walls of the model were made with Gypsum Board of 5mm each on both sides supported by central Wooden Joists/ Studs of 40mm. The total thickness of this panel is 50mm with a Thermal Resistance (R-Value) of 2.1206 (m².K)/W as shown in Figure 66: Internal Wall Panel section.

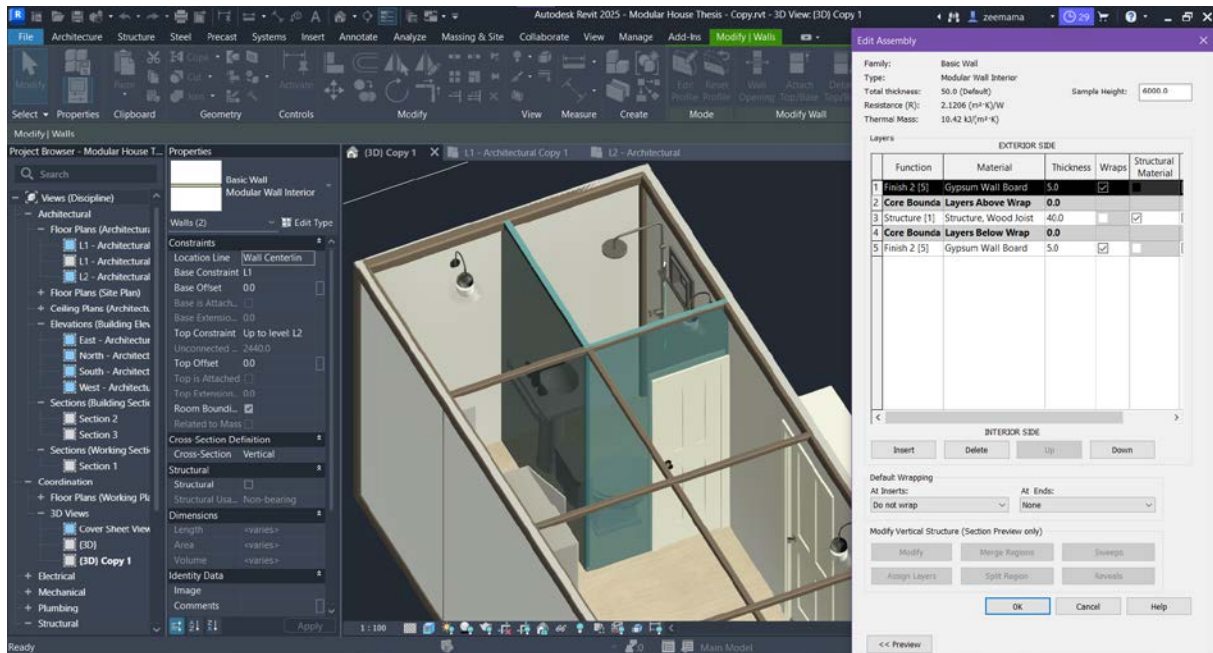


Figure 66: Internal Wall Panel section

The Floor was made from 16mm Plywood Sheathing resting above the HSS Square 2x2x3/16 sections mesh frame for additional support with a Thermal Resistance (R-Value) of 0.1509 (m².K)/W as shown in Figure 67: Flooring section.

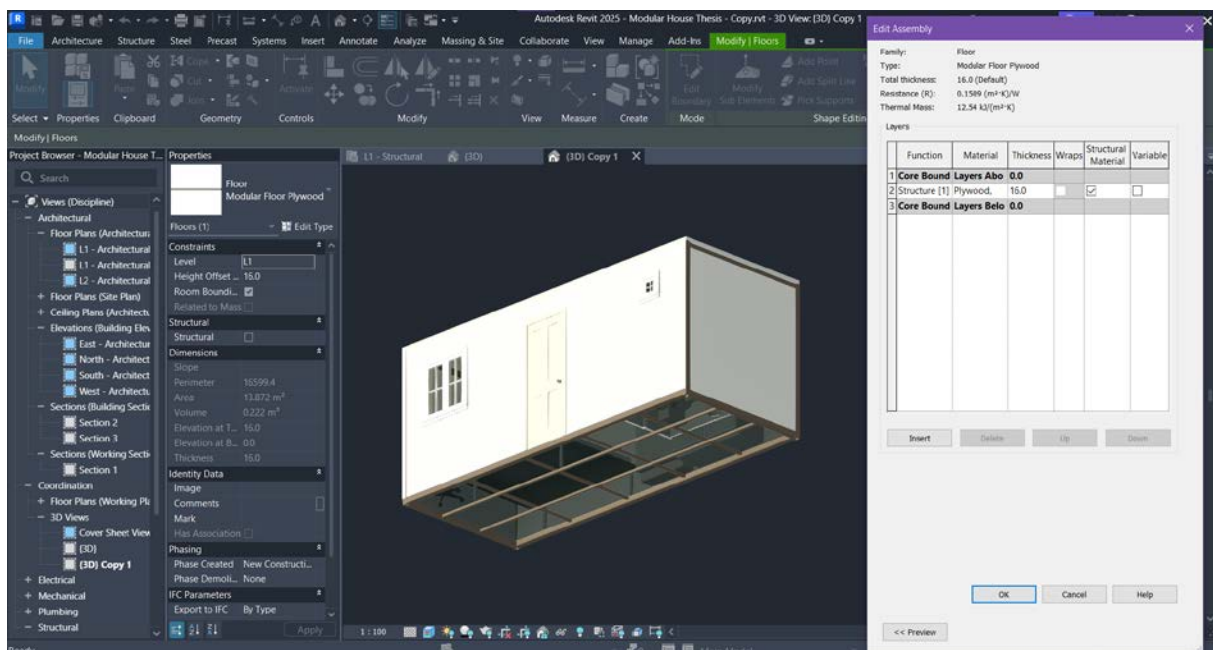


Figure 67: Flooring section

The Window on the front side is 850x900mm double sliding pane window with PVC frame and Double glazing ¼ inch thick with clear/ Low-E coated glass that has total

Thermal Resistance (R-Value) of 0.5032 (m².K)/W as shown in Figure 68: Window Properties:

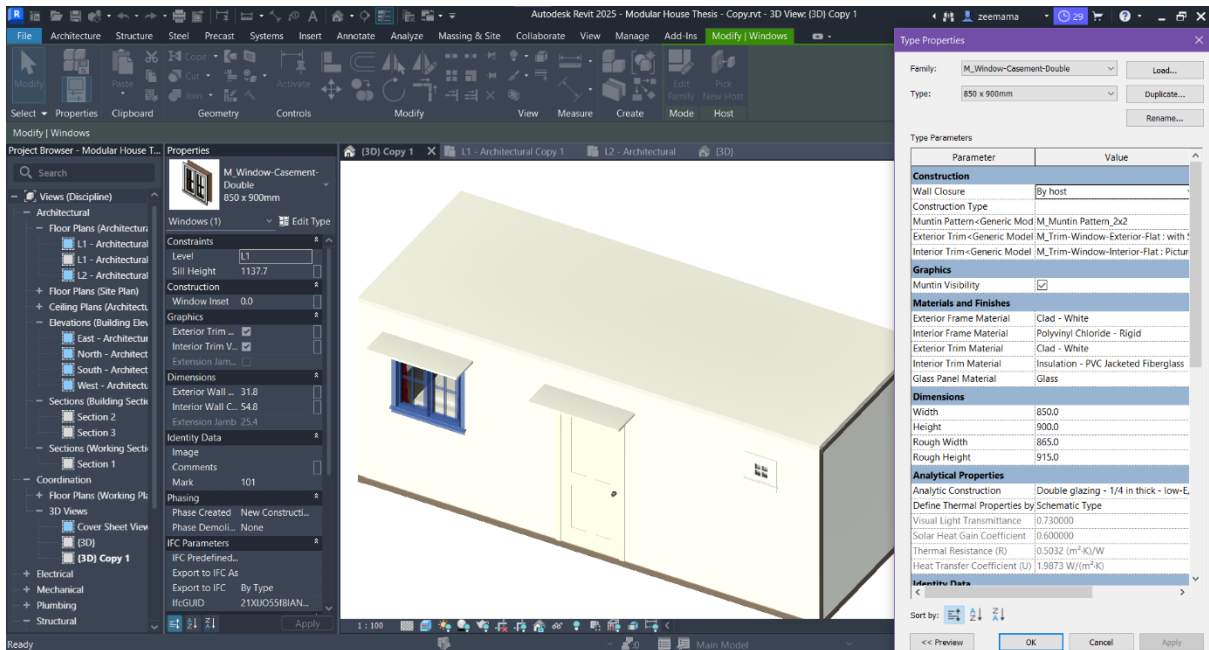


Figure 68: Window Properties

The External Door on the front side is a 762x2032mm Single Flush PVC door (Figure 69: External Door Properties) and the Internal door for the Washroom is a 762x2032mm Single Flush PVC door (Figure 70: Internal Door Properties). These doors have total Thermal Resistance (R-Value) of 0.4557 (m².K)/W.

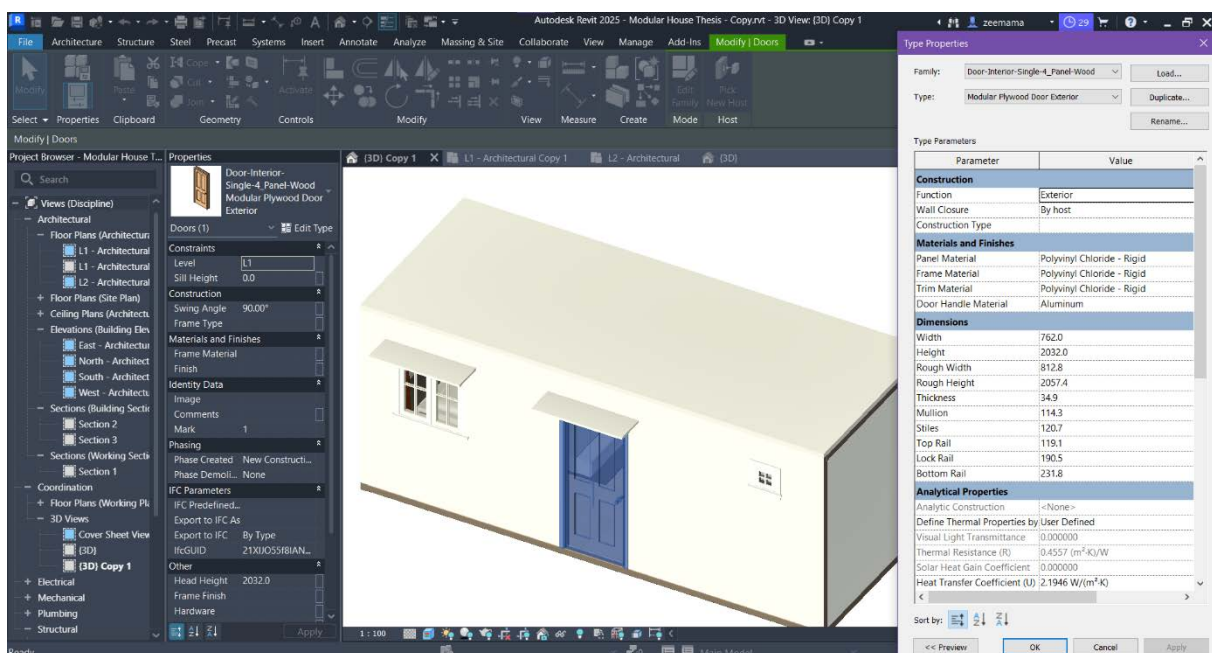


Figure 69: External Door Properties

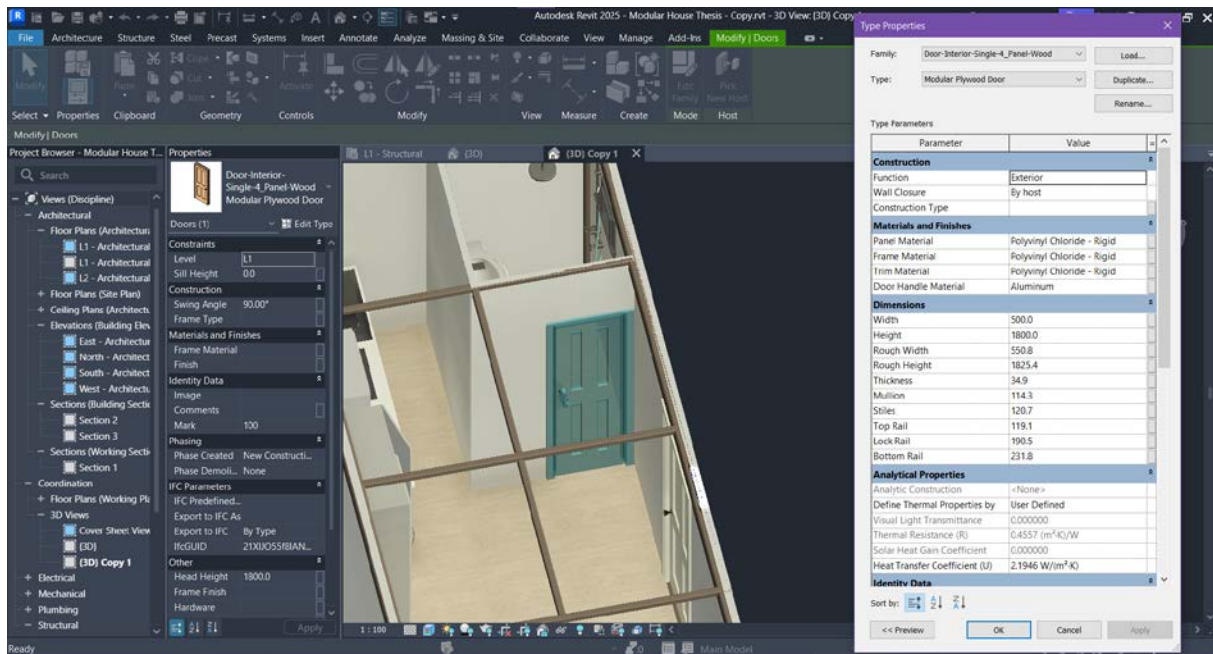


Figure 70: Internal Door Properties

Shading for the Window and the Door is also provided using a PVC sheet of 30cm, to reduce the thermal gain through the window and the door into the building envelope as shown in Figure 71: External Window and Door Shade:

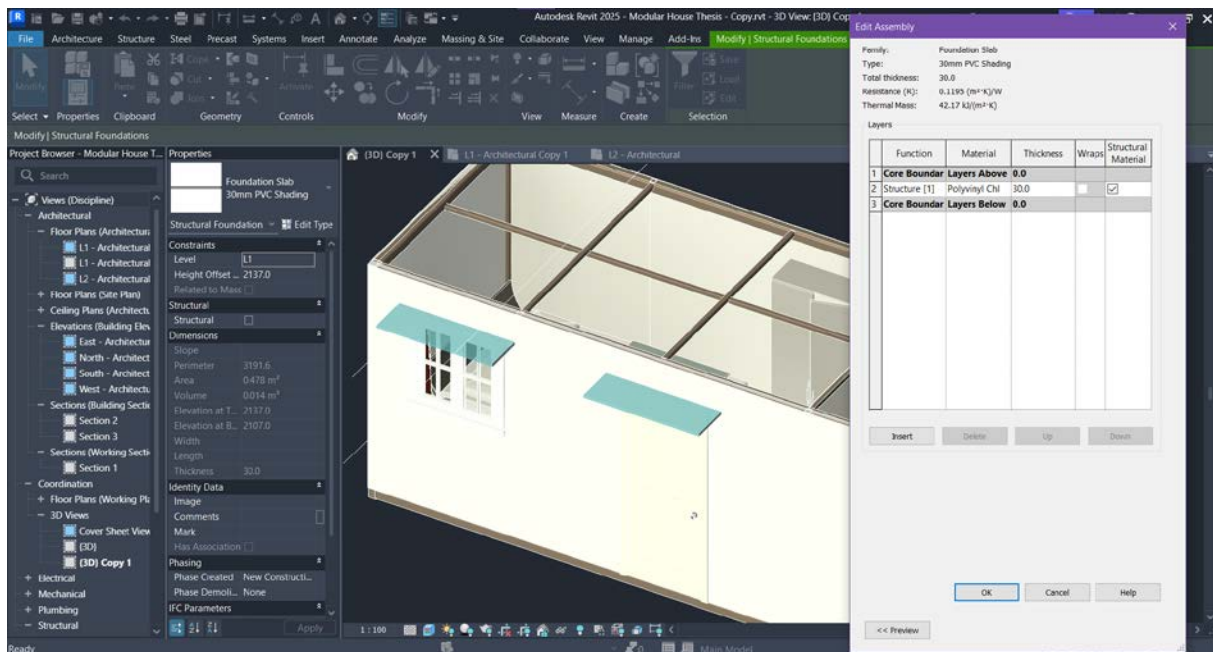


Figure 71: External Window and Door Shade

Then placing the Finishing and MEP fixtures in the house which include the Double Bed, Chair, Wardrobe, Kitchenette with Sink, Stove, Cupboard, fixing of light fixtures and then the installation of Plumbing fixtures like Shower, Water Closet and Sink for the Washroom as shown in the Rendered section in Figure 72: Finishing and MEP Fixtures.



Figure 72: Finishing and MEP Fixtures

3.7 Modularization, Assembly and Transportation of Modular Units

A Modular design is essential for the structure mainly for the reason of quick assembly and logistical requirements. Most trucks have a 2.44m (8 feet) wide base and 12.2m (40 feet) lengths standard for shipping containers. The design of this modular house is therefore conforming to already existing infrastructure of storage, transportation, hauling and stacking purpose. Hence, all components, when disassembled, are capable to fit and perform as per the exact dimensions of a shipping container. Standard size of a shipping container, along the length is another characteristic of the design, making it easily customizable and expandable. Joining multiple units can make one large hall, clinic, school or perhaps an office space for multipurpose use or transformed into a

multistorey building. Having standard dimension also adds to structural stability as stresses are not developed in narrow asymmetrical sections. Moreover, a standard design makes it easy to replace, repair or modify components of house, hence reducing maintenance costs. Figure 73: HSS Framing Plan for Floor Deck shows the HSS floor framing plan, forming a rectangular shape with joists in the middle forming the floor deck. For placing on flood prone area, the model can be placed on an elevated foundation or in case an overall elevated and sloped surface to allow proper drainage.

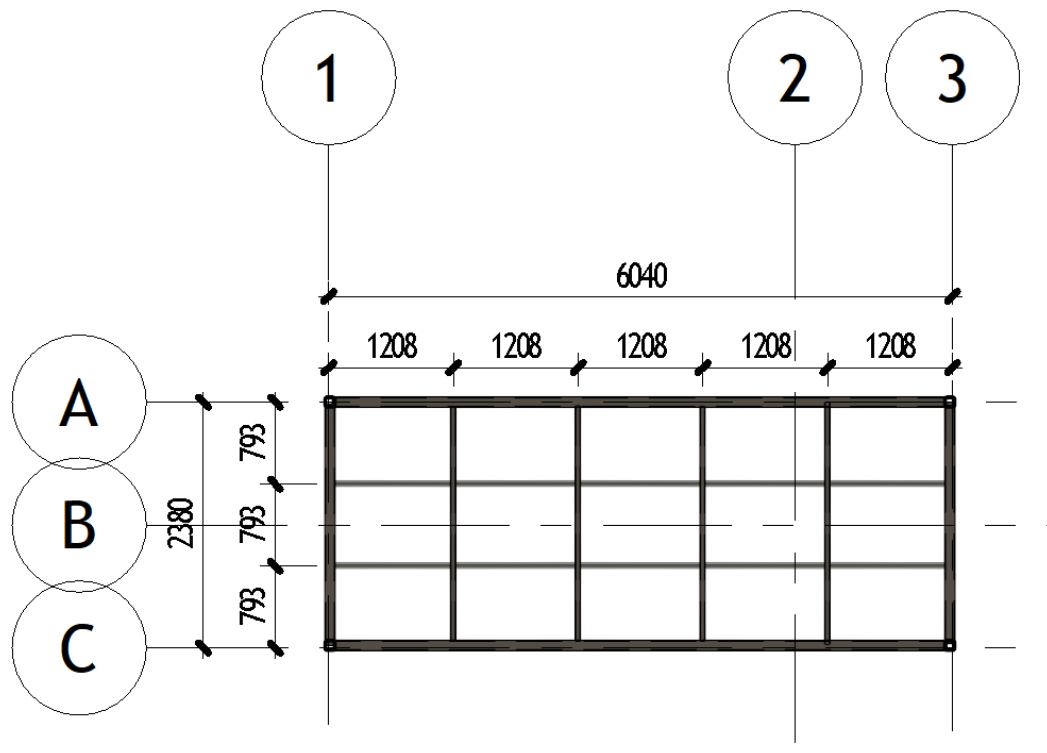


Figure 73: HSS Framing Plan for Floor Deck

Assembly of the structure can be done by two to three workers using simple hand tools, such as wrenches, screwdrivers, levelling instruments and a ladder. The same tools are required for disassembling the structure or for loading and unloading from trucks being a result of light weighted modules.

Transportation of Flat-Pack Design

The ability of this modular structure to be flat packed during transport makes it more economical as more houses can be fit into a single truck rather than one housing unit per truck, as seen with commonly used containerized homes since this modular design is supposed to be assembled and disassembled quickly making it a suitable solution.

One Modular Housing unit takes around 7.74m^3 of volume with dimension $6100 \times 2440 \times 520\text{mm}$ on disassembly into a flat pack.

Therefore, at least Eight Units (8 Nos. Modular Houses with four in front and four in the back loaded vertically) can be transported using a truck that is used for transporting 12.2m (40 feet) long containers as shown in Figure 74: Eight Flat Packed Modular Housing Units can be transported on a 12.2m (40 feet) Long Truck.

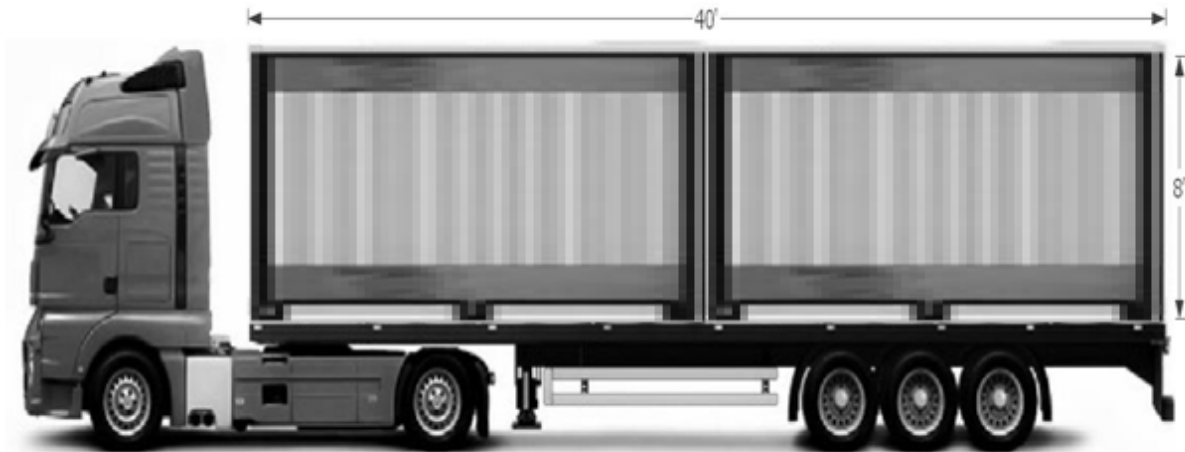


Figure 74: Eight Flat Packed Modular Housing Units can be transported on a 12.2m (40 feet) Long Truck loaded vertically 4 in a row

Furthermore, a maximum of Ten Units can be transported if the units are stacked horizontally in two rows on the same truck with five in front and five in the back on top of each other as shown in Figure 75: Ten Flat Packed Modular Housing Units can be transported on a 12.2m (40 feet) Long Truck stacked horizontally 5 in a row.

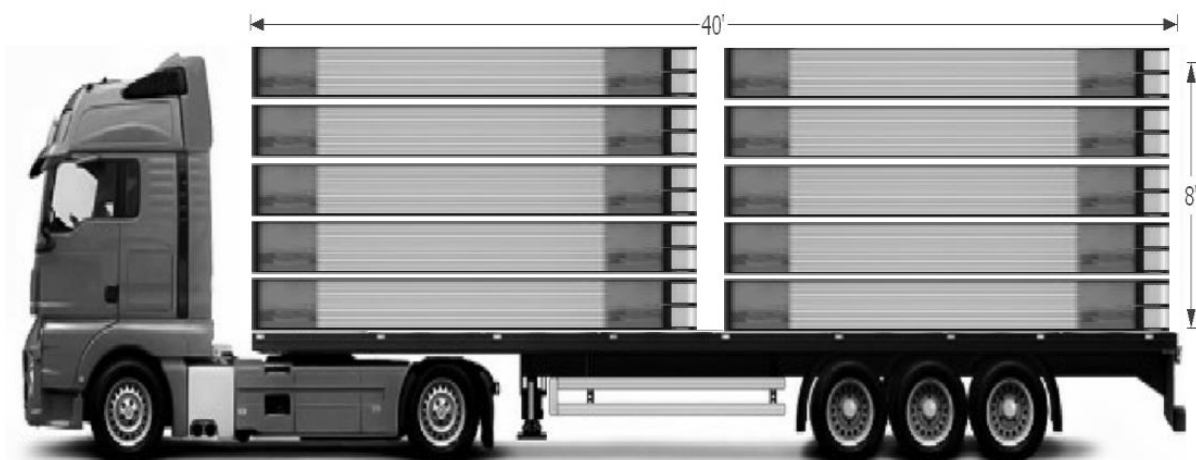


Figure 75: Ten Flat Packed Modular Housing Units can be transported on a 12.2m (40 feet) Long Truck stacked horizontally 5 in a row

With these loading configurations, several number of modular housing units can easily be transported to the flood affected region effectively.

3.8 Colony Planning

The colony is planned as shown in Figure 76. The application of a specific planning code is dependent on the location of a colony; hence the colony plan cannot follow a specific source without determination of the locality. Once a site is selected, the design may be modified based on local codes and requirements. For the purpose of this study, a hypothetical site is assumed which can be selected using Geographic Information System (GIS) software for implementation in actual conditions. GIS can be used to select the most suitable site for such a colony and can help shortlist sites based on factors such as, slope, access to site, availability of water, weather conditions, population density, employment opportunities, access to utilities, type of soil, etc.

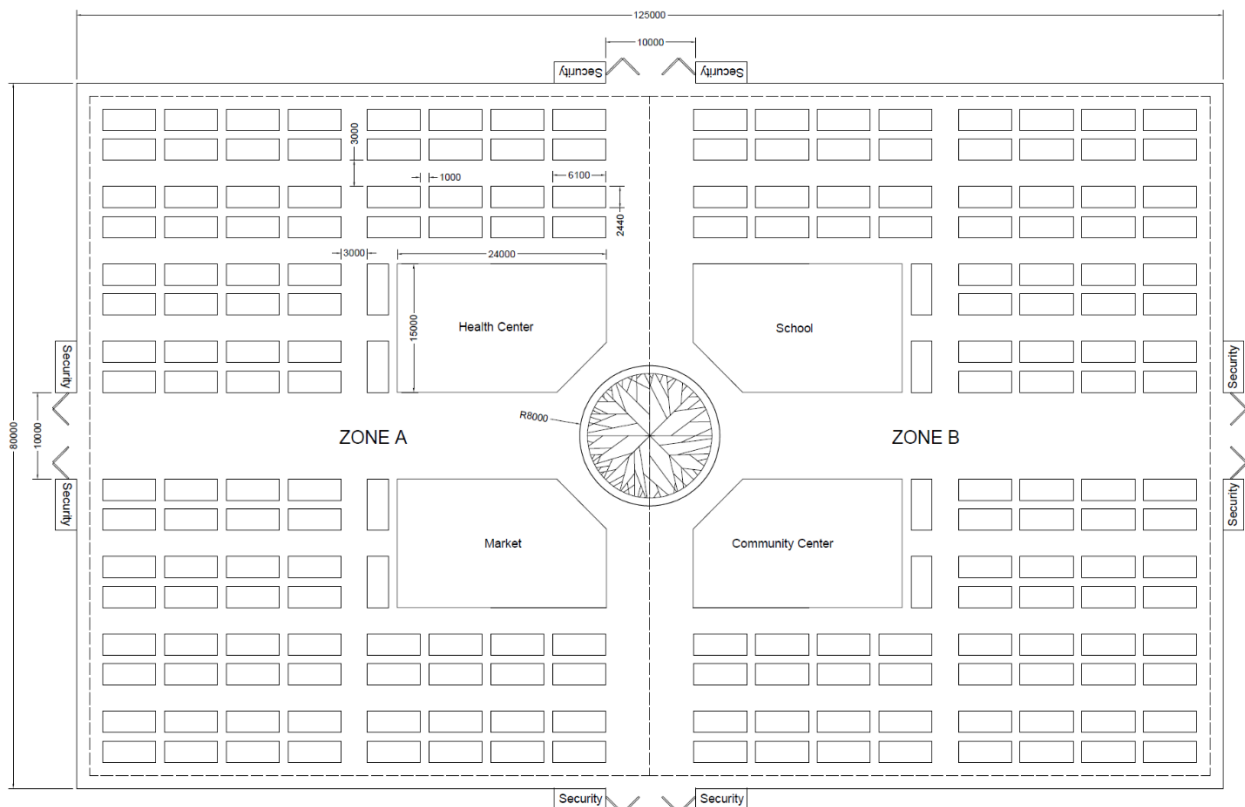


Figure 76: Zoning of Colony Planning

As shown in Table 11, the colony is planned for a population of 400 to 600 adults and children. The plan comprises of single bedroom Modular housing unit. Housing units

are selected to stay close to international standard of 3.1 people/ house. The population is calculated assuming a single bedroom housing unit can accommodate 2 adults, or 2 adults and 1 child per household. A large range of capacity makes the colony suitable for long term settlement where population growth is expected.

Table 11: Number of people per household in a Modular Unit

| Family Unit | Single Bedroom Modular Housing Units |
|--|---|
| 2 Adults per household | $200 \times 2 = 400$ Nos. |
| 2 Adults and 1 Child each per household | $(200 \times 2) +$ $(200 \times 1) = 600$ Nos. |

Public spaces and Amenities included in the Colony plan are as follows:

- Primary and secondary school
- Shopping area
- A health centre or clinic
- Religious space for 200 people
- Community centre
- Parks for recreational purpose.
- Security Check posts

The covered areas for different parts of the Modular Housing Colony are listed in Table 12 below:

Table 12: Covered areas of different parts of the Modular Housing Colony

| Part of the Colony | Covered Area |
|---------------------------|-----------------------|
| Total Colony Plan | 10,000 m ² |
| Zone-A | 5000 m ² |
| Zone-B | 5000 m ² |
| Modular Housing | 3000 m ² |
| All Amenities | 1200 m ² |
| Recreational Area | 200 m ² |

4. Analysis and Results

4.1 Introduction

This chapter analyses the detailed 6D BIM Analysis of the proposed Modular house for the development of a Modular Housing Colony for flood-relief. This is achieved by firstly performing the detailed analysis includes 4D Scheduling of the project timeline on Primavera P6, then by integrating the cost of the project, 5D Simulation model is realized using Autodesk Navisworks Manage. The last step is 6D Energy Analysis which is done by Autodesk Insight. This provides an in-depth understanding of the implementation of proposed Modular house as a flood relief solution and its viability.

4.2 4D Scheduling

Scheduling of this Modular House was done in Primavera P6 using conventional normal track scheduling techniques. After taken off quantities from 3D BIM model, it is integrated with project schedule. The schedule loaded quantities are then linked with cost information which includes material, labour, machinery and other related costs to find the total cost and time of project. By integrating project schedule with 3D BIM model, 4D BIM model was achieved.

Project scheduling was performed in Primavera P6 because it is prevailing Project management tool, and it is used widely in the world. It is very wide-ranging and several project planning software. This module support work breakdown structures (WBS) hierarchy. Activities duration and relationships were set according to conventional construction practices.

The Colony Planning Project for Zone-A: 100 houses and Zone-B: 100 houses, total of 200 Modular houses along with Amenities structures, the planned start was 1st January 2024 after scheduling duration of project was found to be 28 days which ends on 28th January 2024 using a 7 day a week work calendar with 11 hours of work each day. It is assumed that all housing structures have been prefabricated and stored at a location off site, hence transportation time is included in the schedule.

The time period can be further reduced and based according to the requirements. The total cost of the colony equals Pakistani Rs.32,708,900 (117,419 USD) for the work mentioned above for the development for the whole colony. (Figure 77)

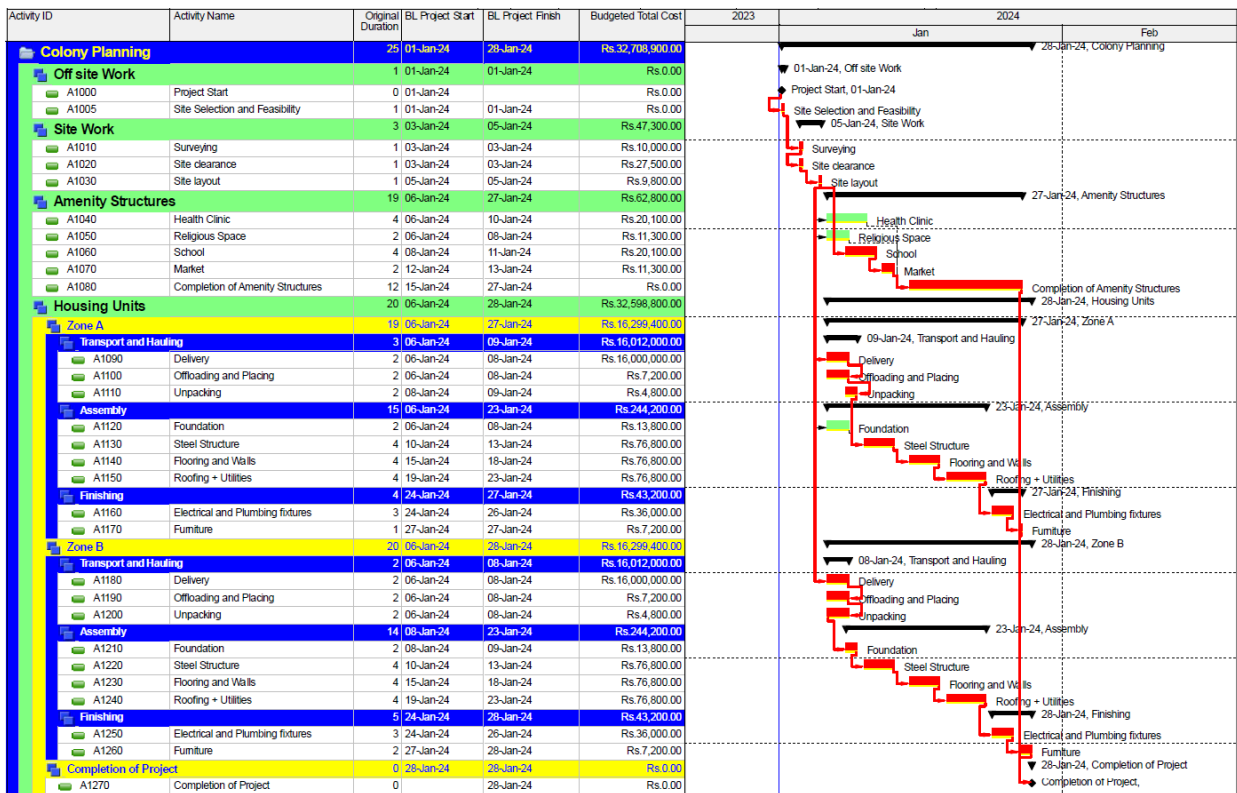


Figure 77: Primavera P6 Schedule

Resource rates are taken from average industry pay for workers and services. Details of resources are shown in Table 13 below. There is not over or under allocation found.

Table 13: Resource Sheet

| Resource Name | Type | Group | Max. Units | Std. Rate (Rs.) | Ovt. Rate (Rs.) | Cost/Use (Rs.) | Accrue At | Base Calendar |
|-----------------|------|-------|------------|-----------------|-----------------|----------------|-----------|---------------|
| Engineer | Work | GC | 4 | 0/hr | 0/hr | 0 | End | 7 days a week |
| Quality Control | Work | GC | 2 | 0/hr | 0/hr | 0 | End | 7 days a week |
| Surveyor | Work | GC | 5 | 0/hr | 0/hr | 5,000 | End | 7 days |

| | | | | | | | | |
|----------------------|----------|-----------|----|-----------|----------|---|-----------|---------------|
| | | | | | | | | a week |
| Construction Manager | Work | GC | 1 | 0/hr | 0/hr | 0 | End | 7 days a week |
| Skilled Labor | Work | Labor | 30 | 1,500/day | 200/hr | 0 | Pro-rated | 7 days a week |
| Unskilled Labor | Work | Labor | 50 | 900/day | 100/hr | 0 | Pro-rated | 7 days a week |
| Trollers | Work | Transport | 10 | 0/hr | 0/hr | 0 | End | 7 days a week |
| Truck | Work | GW | 1 | 1,500/day | 1,200/hr | 0 | Pro-rated | 5 days a week |
| Loader | Work | GW | 1 | 2,000/hr | 2,000/hr | 0 | Pro-rated | 5 days a week |
| Modular Unit | Material | U | | 160,000 | 0 | | Start | |

Autodesk Navisworks Manage supports Primavera P6, MS Project and CSV schedules which provides simulation of project.

4.3 5D Simulation

5D BIM is the investment realization simulation process with the investment cost information concerning the labour, material and equipment costs and real time visualization of the material and equipment use with respect to the project time. With the connection between the elements of the 3D Model from Autodesk Revit and the schedule from Primavera P6 as the 4D Schedule exported into Autodesk Navisworks Manage 2025 (Jankowski et al., 2015).

4.3.1 Fabrication and Assembly Cost:

The structural elements are to be fabricated, and the materials sourced from Karachi, Pakistan. The total expenditure includes local labour wages and the materials' transportation cost. The quantities have been taken off from Revit. The cost of fabrication can be further reduced through mass production, whereby repetitive work increases labour efficiency. In addition, the labour force is paid through hourly wage, which are employed for mass production to reduce costs. The bill of quantities is described in Table 14.

Table 14: Bill of Quantities of Modular House

| No. | Item | Rate (PKR) | Unit | Quantity | Total Cost (PKR) |
|--|--|------------|----------|----------|--------------------|
| 1 | Mild Steel HSS4X4X3/8 and HSS2X2X1/8 (including pipes, nuts, bolts, red oxide & wastage) | 110 | Kg | 1340 | 147,400 |
| 2 | Plywood Floorboards | 3,000 | sqm | 13.8 | 41,400 |
| 3 | Wall Sandwich Panel | 1,200 | sqm | 41.6 | 49,920 |
| 4 | Internal Gypsum wall | 500 | sqm | 20 | 10,000 |
| 6 | Timber Studs | 3,500 | bundles | 6 | 21,000 |
| 7 | Roof Sandwich Panel | 1,200 | sqm | 13.8 | 16,560 |
| 8 | Electrical (wiring and fixtures) | 7,000 | lump sum | 1 | 7,000 |
| 9 | Window | 16,000 | lump sum | 1 | 16,000 |
| 10 | Ventilator | 5,000 | lump sum | 1 | 5,000 |
| 11 | Door | 7,000 | nos. | 1 | 27,000 |
| 12 | Plumbing fixtures | 24,000 | lump sum | 1 | 4,000 |
| 13 | Fabrication (Steel and Carpenter) | 30,000 | lump sum | 1 | 30,000 |
| 14 | Finishing Material | 5,000 | lump sum | 1 | 5,000 |
| TOTAL Cost of Modular House (PKR) = | | | | | PKR 380,000 |
| | | | | | (USD 1,300) |

The steel fabrication process is fast, although this may be improved for precision to help make the structure more accessible to assemble. Members may not be labelled correctly if similar members are to be incorporated into the structure in four different possible orientations. The steel frame fabricated had a maximum error margin of $\pm 1.0\%$ from the desired dimensions. L-shaped members were bolted at one face and welded on the other face; this implies that the structure may be unbolted using a spanner.

4.3.2 Autodesk Navisworks Manage Workflow for 5D BIM

Autodesk Navisworks Manage enables users to link 3D BIM Model with 4D scheduling with cost data to perform simulation. The integrated cost-loaded project schedule can then be uploaded to Autodesk Navisworks Manage and then linked each scheduled activity with the BIM Model components to produce the 5D BIM Model as shown in Figure 78. 5D Model showed simulation with respect to time on Autodesk Navisworks Manage, how the work has been done. Navisworks Manage can open files initiated from a different CAD application and combine these files to create a single Navisworks Manage file. It does not have a template file format.

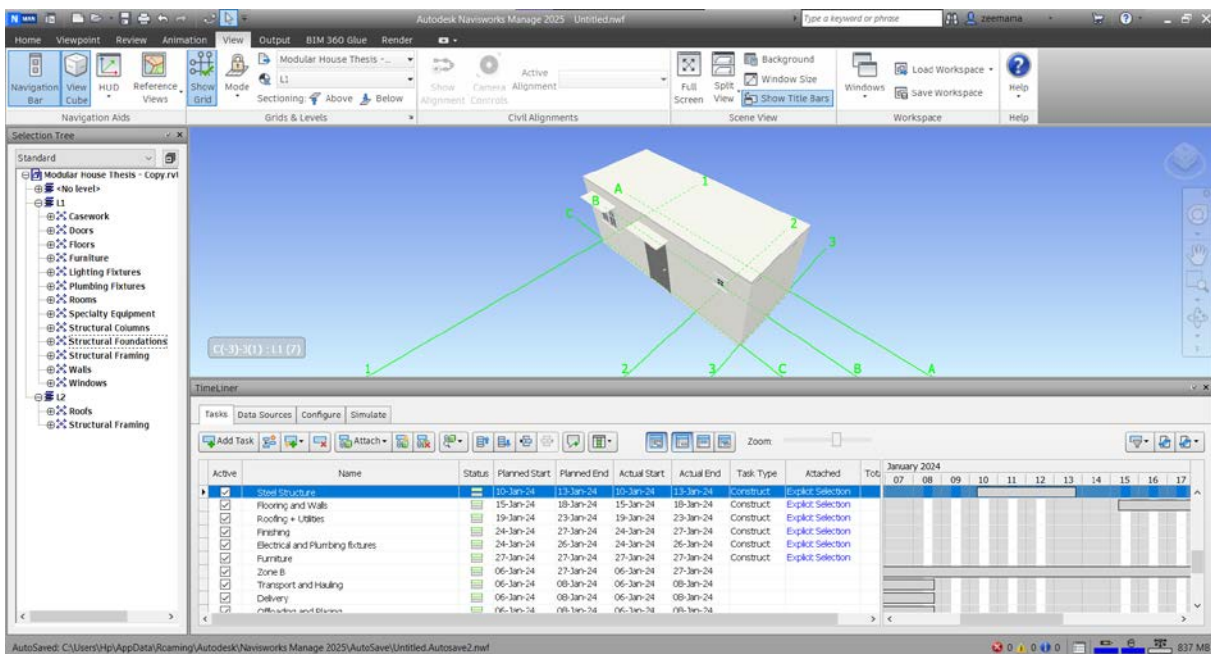


Figure 78: 5D simulation on Autodesk Navisworks Manage 2025

The Timeliner tool in Autodesk Navisworks Manage integrates 3D Model with 4D project schedule and perform 5D simulation. Figure 79 shows the simulation in progress

based on the schedule and the total cost incurred till 18th January 2024 along with the current activities in progress and percentage of completion.

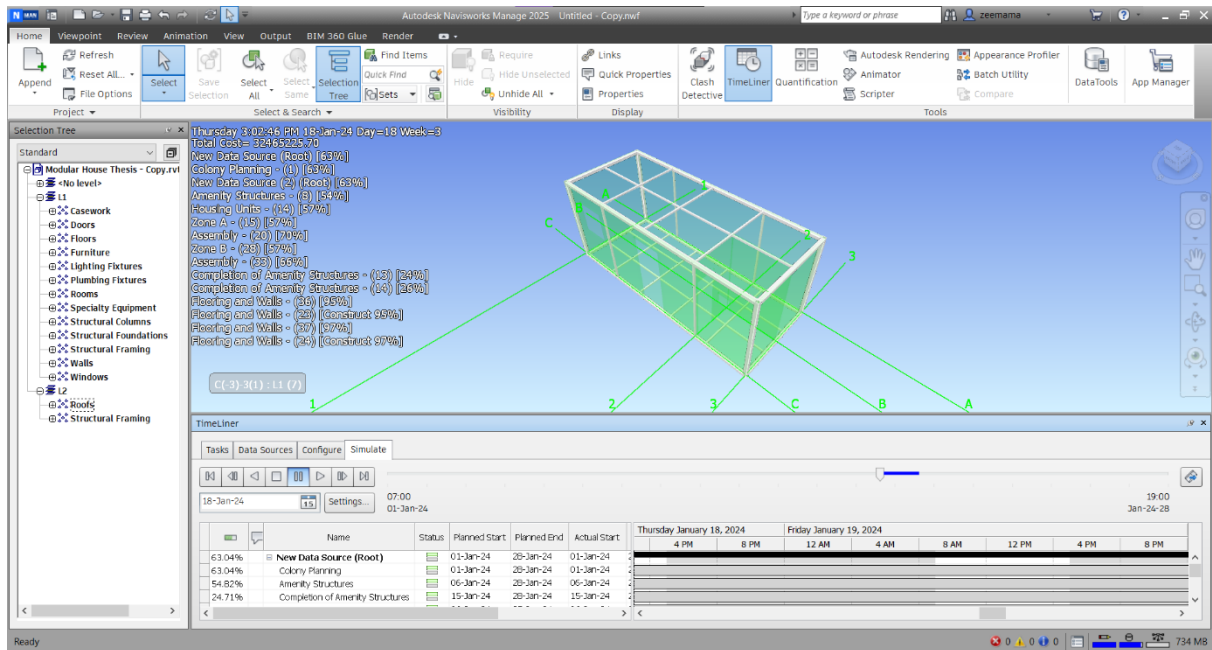


Figure 79: 5D Simulation in progress

The Timeliner takes schedules from several sources like P6 or Microsoft Project etc. Tasks in project schedule then linked with 3D Model. 5D simulation allowed us to visualise the results of the schedule after the model is simulated. It also allowed us to export the images and visual animation of simulation results. With the modification of project schedule, it automatically updates the 5D simulation.

Then after simulation, the video in AVI format can then be exported externally.

4.4 6D Energy Analysis

6D BIM is the measure of Sustainability. With help of distinct energy analysis programs, the analysis of building energy consumption is conceivable. The Software that has been used is Autodesk INSIGHT 360. It is an online tool that can provide the Energy consumption of the Revit 3D Model. The Energy Analysis is done by these steps:

- Defining of Rooms and Spaces in the Revit 3D Model. (Figure 80: Defining the Room and Spaces in the Revit Model)

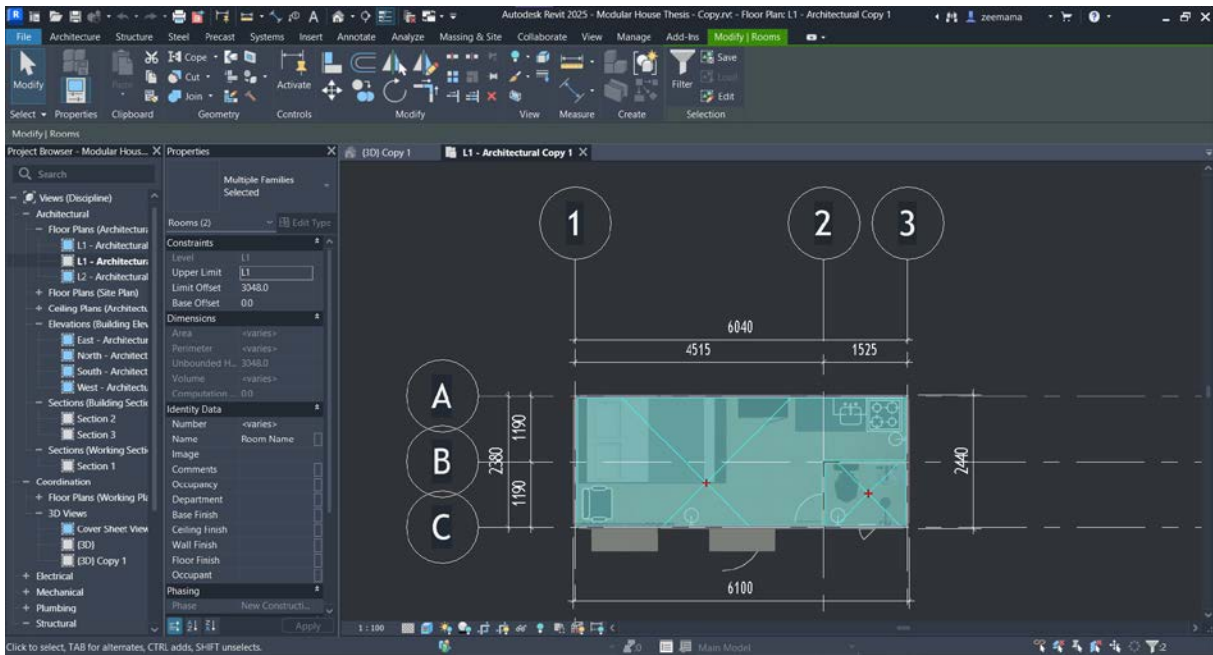


Figure 80: Defining the Room and Spaces in the Revit Model

- Configuring the energy setting and defining the Project Location of the model in Revit. (Figure 81: Configuring the energy settings in Revit)

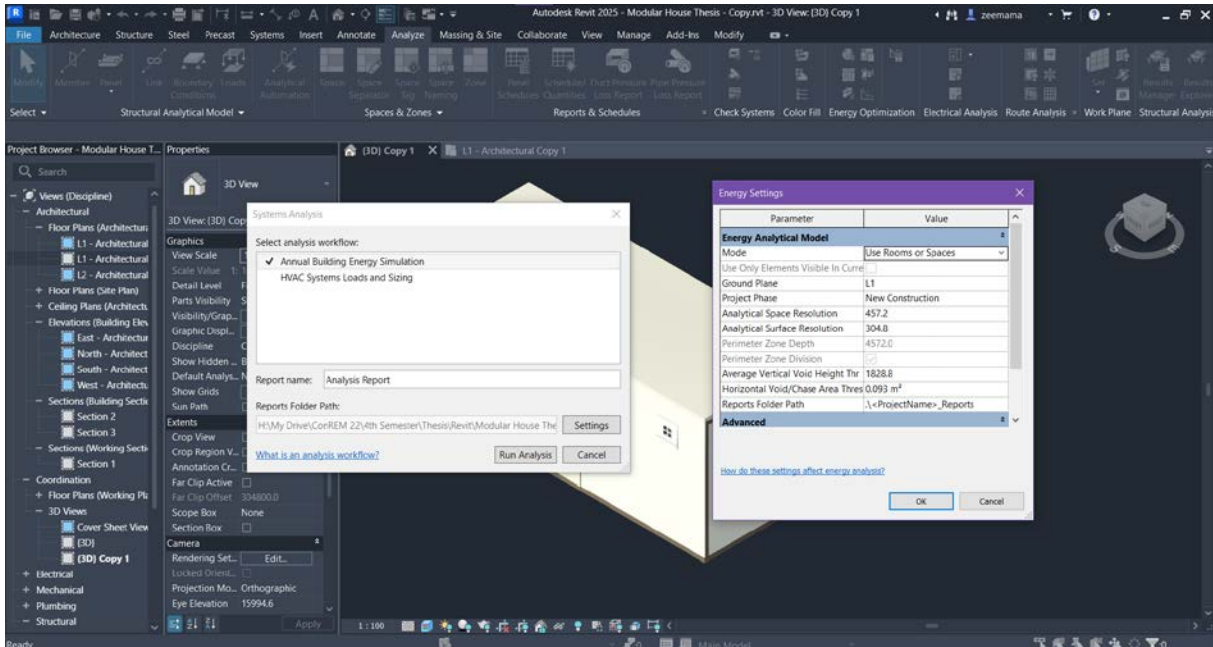


Figure 81: Configuring the energy settings in Revit

- Generating the Analytical Energy Model in Revit using generate button. (Figure 82: Generate the Analytical Energy Model)

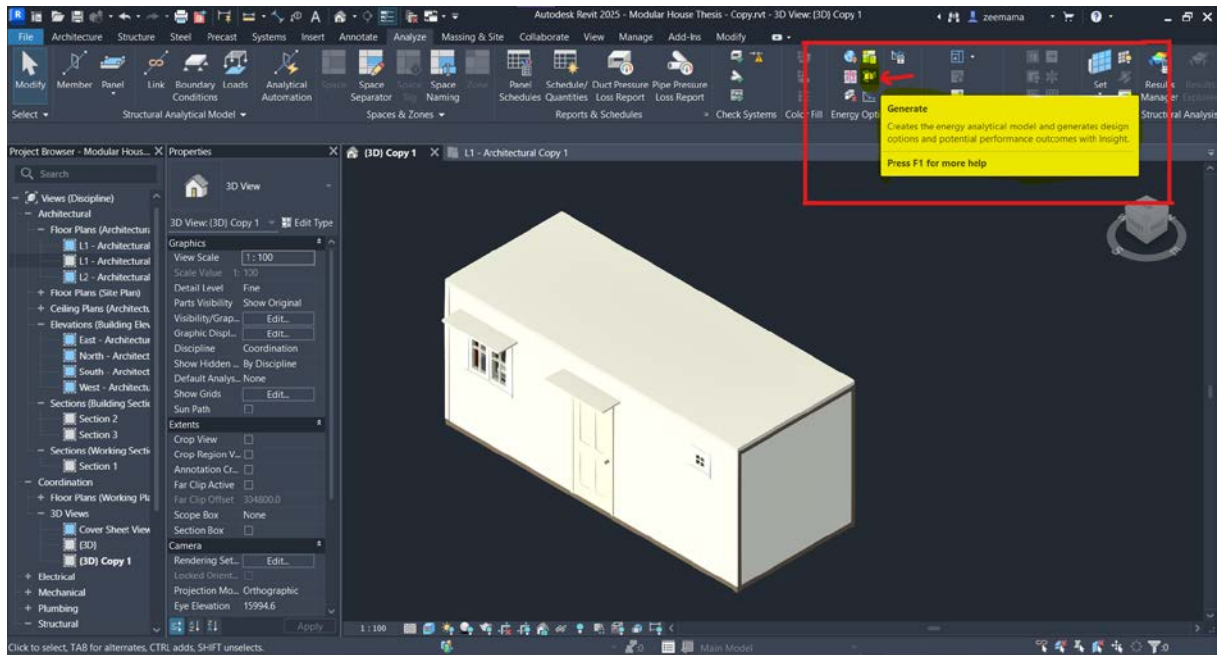


Figure 82: Generate the Analytical Energy Model

- Exporting the Analytical Energy Model to 'Autodesk Insight 360' through Revit built-in Energy Analysis Tab using the Optimize button. (Figure 83: Export to Autodesk Insight using Optimize button)

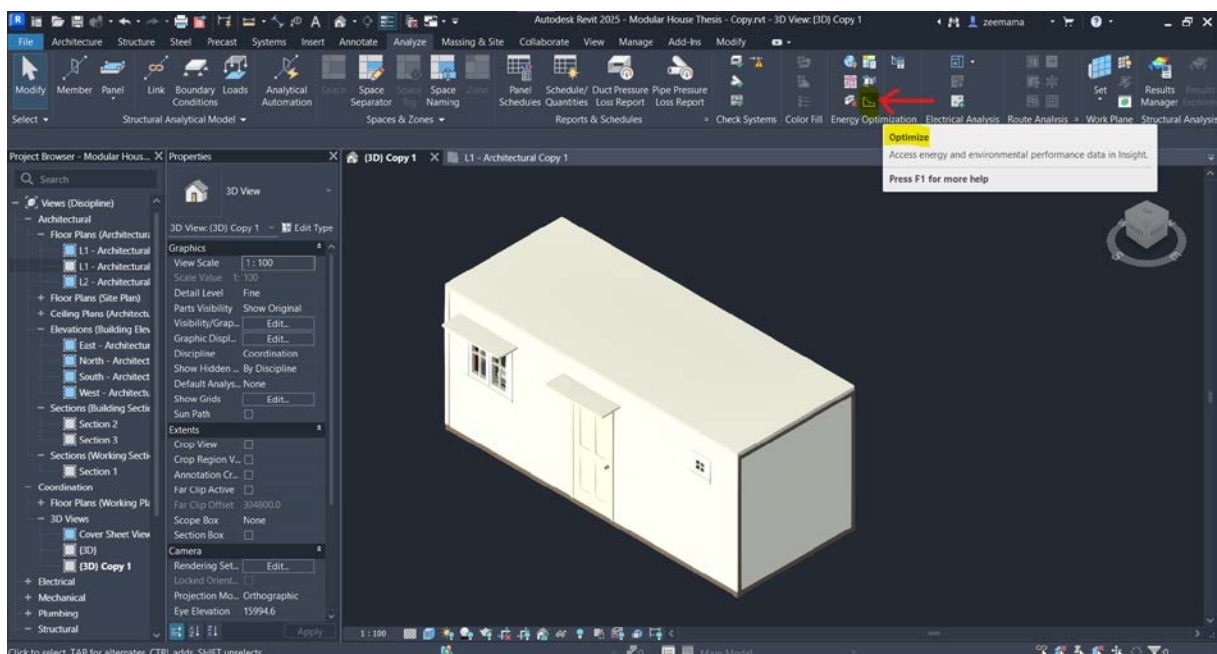


Figure 83: Export to Autodesk Insight using Optimize button

- The Energy Analysis is performed by Autodesk Insight 360 which gives the Annual energy consumption of 418 KWh/m²/yr which is the most optimum for the given plan being highly insulated and waterproof. (Figure 84: Autodesk Insight webpage for uploaded energy model)

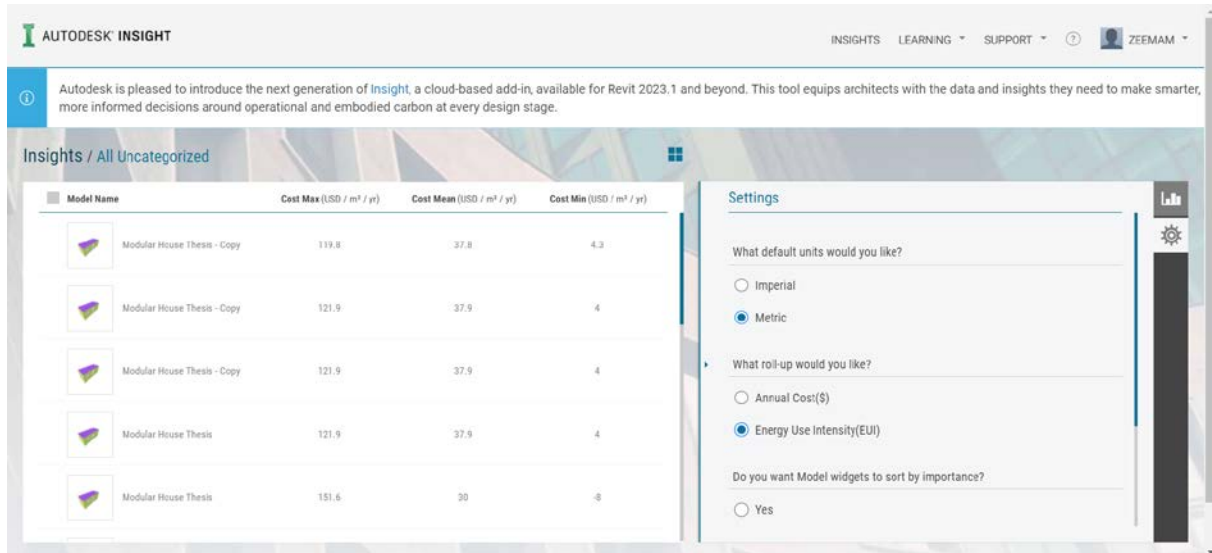


Figure 84: Autodesk Insight webpage for uploaded energy model

Autodesk Insight also offers the suggestions for the building orientation, Window-to-Wall Ratio, window tinting and glazing, the wall and roof insulation, ventilation, artificial lighting, daylight and occupancy, operating schedule, and PV panel suggestion.

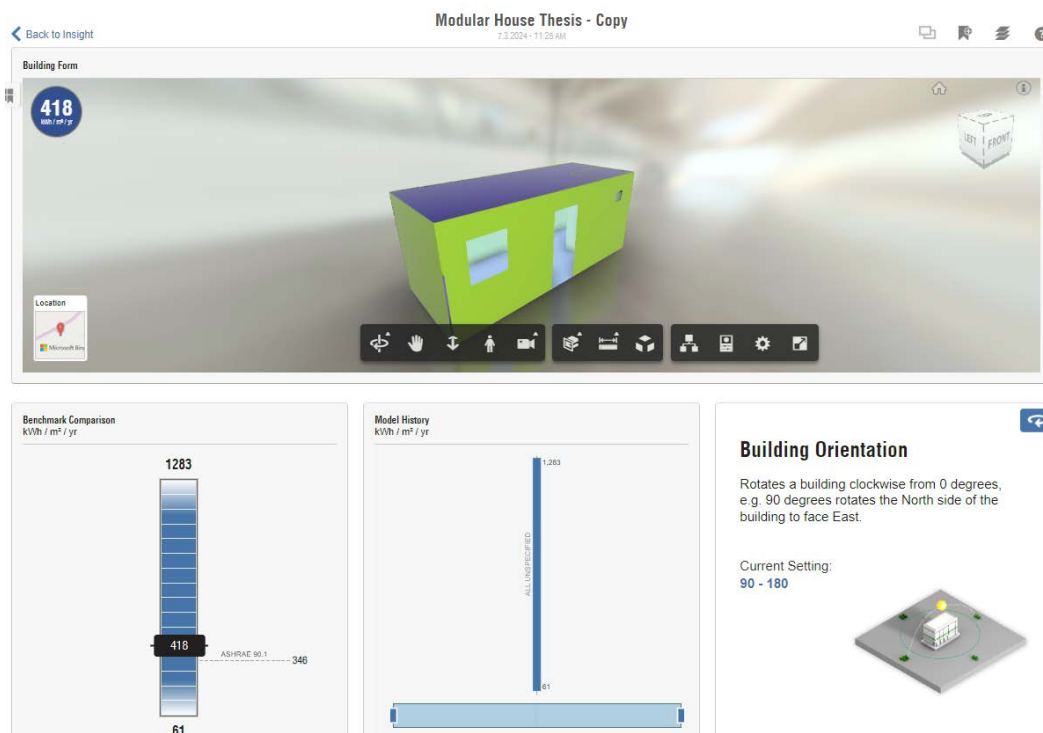


Figure 85: Autodesk Insight Model Energy Analysis and recommendations

5. Conclusion and Recommendations

Following can be concluded from this research:

1. For Research Question-1, based on the literature review and comprehensive analysis of the case study projects, historical data and future forecast, the implementation of Modular houses as a temporary housing solution for the victims of the flood-affected region in Pakistan is found to be feasible and a viable solution. as explored in Chapter 1, 2 and 3.
2. For Research Question-2, based on the literature review and comprehensive comparative analysis of the case study projects in Chapter 2 and 3, several best practices for design, energy efficient materials, specific features, transportation and deployment were identified along with the lessons learned from them. These were then used to propose a design for a Modular House based on locally available, cost-effective and energy efficient ideology. The proposed design serves as proof of concept for the design to be a viable option for use in circumstances where a large number of people need to be rehabilitated in a short span of time. Hence, providing a faster and cheaper solution in case of disasters or emergency crises on a large scale.
3. For Research Question-3, based on the proposed 6D Modular house design, Modularity and Assembly, Transportation methodology of the Colony plan layout, in Chapter 3, 4 and 5, it is concluded that the adoption of this plan, is found to be feasible for future events of floods in Pakistan as its timely deployment is found to be fast, energy efficient design, cost effective and capable to provide a safe sheltering solution for the flood victims as compared to conventional emergency housing practices. It was found that the Colony of 200 Modular houses with Amenity structures can be established in 28 days that could accommodate a population of 400 to 600 adults and children.

Because of an airtight waterproof insulated structure, and ground clearance in design of foundation, the houses are also feasible for use in flood-prone areas. Hence, the structure designed can help achieve great social benefit at a governmental level, as well as, prove to be appealing at a non-governmental level for use in labour colonies and other temporary settlements. Although, the design of colony is for a hypothetical

location, with advanced planning the same design can be implemented in multiple scenarios with slight modifications. Moreover, the colony size can be increased by repetition of the same design.

About the design, special care needs to be taken during fabrication of steel structure, as it could cause disbalancing while assembling without tolerance. Therefore, it is recommended that higher quality of work should be imposed for future use by the help of mechanized processes. The design of steel connectors should also be reviewed and improved. The objectives of the study were satisfyingly achieved; however, the design can be further improved with the help of experts and more research in the area.

Three of the UNSDGs were also identified and provided a viable solution for Goal-9: Industry Innovation and Infrastructure, Goal-11: Sustainable cities & communities, and Goal-13: Climate Action.

As recommendation, this research proposal is the first step towards the adoption of modular construction practice for disaster relief in Pakistan, thus has high potential for future researchers to do further research and analysis on this topic. It will also help them to take steps towards implementation of BIM in the industry. Government of Pakistan can provide the proposed Modular house for the same cost as of the cash assistance already being provided to the victims resulting in a better housing solution for the same cost, temporarily.

According to (Grand View Research, 2022), the modular construction industry is expected to expand at a compound annual growth rate (CAGR) of 6.4% until 2028, from its 2020 valuation of USD 84.4 billion. There is already has a massive potential for growth and it's about survival. In Sweden, Prefabricated modular buildings account to 70% of construction industry. It is recommended that new building techniques be used, such as the use of recyclable materials, prefabricated buildings, and Cross-Laminated Timber (CLT). According to (Ferdous et al., 2019), prefabricated components have demonstrated good performance in a variety of scenarios, including static, dynamic, seismic, fire, and long-term loads.

For Future implementation of modular construction practice, energy efficient material, and to replace conventional materials like steel, concrete, and wood in prefabricated

construction applications (such as GFRP multicellular slabs), research is required on new materials and technologies. One such technology is Fibre Reinforced Polymer (FRP) composites. The creation of design standards, enhanced mobility, and dependable interlocking connections between modules are among the other topics of interest, as is the use of 3D printing technology for sustainability, life cycle cost modeling, and building.

Declaration of Authorship

I, Zeemam Abdur Rehman, hereby declare that the attached master's thesis was completed independently and without the prohibited assistance of third parties and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, DE, 5th July 2024

Location, Date



Signature of the student

References

- 1.5 million now homeless in Türkiye after quake disaster, warn UN development experts | The United Nations Office at Geneva. (n.d.). Retrieved June 25, 2024, from <https://www.ungeneva.org/en/news-media/news/2023/02/78128/15-million-now-homeless-turkiye-after-quake-disaster-warn-un>
- Abera, Y. A. (2024). Sustainable building materials: A comprehensive study on eco-friendly alternatives for construction. *Composites and Advanced Materials*, 33. <https://doi.org/10.1177/26349833241255957>
- Ahmed, I., & O'Brien, D. (2009). *Sustainable organic building materials for housing: the case of post-disaster reconstruction in Indonesia*.
- AISC. (2016). *Specification for Structural Steel Buildings*.
- ArchDaily Team. (2020). *The Humanitarian Works of Shigeru Ban*. <https://www.archdaily.com/489255/the-humanitarian-works-of-shigeru-ban>
- Arif, M., Chenghu, Z., Olah, J., Shehzad, K., & Ahmad, M. (2022). Specifying the Domineering Role of Governance in the Long Term Environmental Excellence: A Case Study of Pakistan. *SAGE Open*, 12(3). https://doi.org/10.1177/21582440221121731/ASSET/IMAGES/LARGE/10.1177_21582440221121731-FIG2.JPEG
- Baghchesaraei, A., & Reza Baghchesaraei, O. (2015). Using Prefabrication Systems in Building Construction. In *Article in International Journal of Applied Engineering Research*. www.baghchesaraei.com,
- Bangash, Z. (2022). *Consequences of Pakistan's devastating floods | Crescent International | Monthly News Magazine from ICIT*. <https://crescent.icit-digital.org/articles/consequences-of-pakistan-s-devastating-floods>
- Barney, C. (2014). *EXO HOUSING UNITS: DISASTER HOUSING OF THE FUTURE*. <https://borgenproject.org/exo-housing-units-disaster-housing-future/>
- Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., & Woetzel, J. (2019). *Modular construction: From projects to products*.
- Better Shelter. (2023). *Delivering emergency shelters from EU to Türkiye*. https://bettershelter.org/projects_/delivering-emergency-shelters-from-eu-to-turkiye/

- Better Shelter - About.* (n.d.). Retrieved June 22, 2024, from <https://bettershelter.org/about-us/>
- Bin Javed, O. (2022). *How Pakistani entrepreneurs stepped in after flood disaster.* <https://www.aljazeera.com/news/2022/9/18/how-pakistanis-young-and-old-stepped-in-after-flood-disaster>
- Blackall, M. (2024). *Inside Turkey's container city where 80 earthquake survivors share a toilet.* <https://inews.co.uk/news/turkey-shipping-container-earthquake-2893878>
- Boxabl. (n.d.). *Boxabl.* Retrieved June 19, 2024, from <https://www.boxabl.com/casita>
- CalEarth. (n.d.). *SuperAdobe: Powerful Simplicity.* Retrieved July 4, 2024, from <https://calearth.org/pages/what-is-superadobe>
- Carmody, J., & Northernstar, K. H. (2012). *Measure Guideline: Energy-Efficient Window Performance and Selection.* www.ntis.gov/ordering.htm
- CBOXCONTAINERHOUSE.COM. (2024). *CBOX Container Houses Help Turkey Rebuild After Earthquake.* <https://cboxcontainerhouse.com/cbox-container-houses-help-turkey-rebuild-after-earthquake/>
- Charef, R., Alaka, H., & Emmitt, S. (2018). Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. *Journal of Building Engineering*, 19, 242–257. <https://doi.org/10.1016/J.JOBE.2018.04.028>
- Clarke, B., Otto, F., & Harrington, L. (2022). *Pakistan floods: what role did climate change play?* <https://theconversation.com/pakistan-floods-what-role-did-climate-change-play-189833>
- Death toll exceeds 45,000 in Türkiye's major earthquake disaster - Türkiye News.* (n.d.). Retrieved June 25, 2024, from <https://www.hurriyetaidailynews.com/death-toll-exceeds-45-000-in-turkiyes-major-earthquake-disaster-181273>
- Dialameh, M. (2017). *PORTABLE POST-DISASTER HOME.*
- Dobias, P. D. (2022, December 9). *Is emergency shelter fit for purpose?*
- Dorce Prefabricated & Construction. (n.d.). *Emergency Accommodation and Refugees Camp Projects.* Retrieved July 4, 2024, from <https://www.dorce.com/residential-housing/refugee-emergency-earthquake-camps/>

- European Association of Polyurethane Insulation Manufacturers. (n.d.). *Thermal insulation materials made of rigid polyurethane foam (PUR/PIR) Properties-Manufacture*.
- Federal Flood Commission. (2021). *Federal Flood Commission, Government of Pakistan, Annual Report*. www.ffc.gov.pk
- Ferdous, W., Bai, Y., Ngo, T. D., Manalo, A., & Mendis, P. (2019). New advancements, challenges and opportunities of multi-storey modular buildings – A state-of-the-art review. In *Engineering Structures* (Vol. 183, pp. 883–893). Elsevier Ltd. <https://doi.org/10.1016/j.engstruct.2019.01.061>
- FIFA. (2021). *Stadium 974*. <https://www.fifa.com/en/articles/stadium-974>
- Finch Buildings B.V. (2021, November 18). *WOODEN RESIDENTIAL BUILDING IN MONNICKENDAM COMPLETED IN SEVEN MONTHS*. <https://finchbuildings.com/en/houten-woongebouw-in-monnickendam/>
- Florian, M.-C. (2023). *Shigeru Ban Unveils Updated Prototype for Temporary Housing in Response to the Turkey-Syria Earthquake (ArchDaily)*. <https://www.archdaily.com/998888/shigeru-ban-unveils-updated-prototype-for-temporary-housing-in-response-to-the-turkey-syria-earthquake>
- Gerrard, N. (2023). *Four challenges facing modular housing construction - Construction Briefing*. <https://www.constructionbriefing.com/news/four-challenges-facing-modular-housing-construction/8029785.article>
- Ghannad, P., Lee, Y.-C., & Choi, J. O. (2020). Feasibility and Implications of the Modular Construction Approach for Rapid Post-Disaster Recovery. *International Journal of Industrialized Construction*, 1(1), 64–75. <https://doi.org/10.29173/ijic220>
- Gollapudi, N. (2024a, January 17). *ICC confirms New York's Eisenhower Park will not host international games before T20 WC*. <https://www.espn.com/story/new-york-s-eisenhower-park-unlikely-to-host-any-international-games-before-t20-world-cup-1417076>
- Gollapudi, N. (2024b, May 31). *New York's beautiful monster: how a cricket venue was created from scratch*. <https://www.thecricketmonthly.com/story/1435720/new-york-s-beautiful-monster--how-a-cricket-venue-was-created-from-scratch>

- GoP. (2021). *PAKISTAN: UPDATED NATIONALLY DETERMINED CONTRIBUTIONS 2021*.
- GoP Pakistan Meteorological Department. (2022). *Pakistan's Monthly Climate Summary August, 2022*.
- Grand View Research. (2022). *Modular Construction Market Size & Share Report, 2030*. <https://www.grandviewresearch.com/industry-analysis/modular-construction-market>
- Hafeez, S. (2023, November). *After successive floods, Pakistan is forced to consider resilient housing*. <https://dialogue.earth/en/climate/after-floods-pakistan-resilient-housing/>
- Hickory Group. (n.d.). *LA TROBE TOWER - Record setting project becomes Australia's tallest prefabricated building by using innovative Hickory delivery model*. Retrieved July 4, 2024, from <https://www.hickory.com.au/project/la-trobe-tower/>
- ICC-ES. (2023). *ICC-ES Evaluation Report ESR-4725*. www.icc-es.org
- International Monetary Fund (IMF). (2024). *PAKISTAN FIRST REVIEW UNDER THE STAND-BY ARRANGEMENT, REQUESTS FOR WAIVERS OF APPLICABILITY OF PERFORMANCE CRITERIA, MODIFICATION OF PERFORMANCE CRITERIA, AND FOR REPHASING OF ACCESS-PRESS RELEASE; STAFF REPORT; AND STATEMENT BY THE EXECUTIVE DIRECTOR FOR PAKISTAN International Monetary Fund*.
- Jamal, S. (2023, November). *Pakistani architect's bamboo homes rebuilding lives and livelihoods for flood survivors | Pakistan – Gulf News*. <https://gulfnews.com/world/asia/pakistan/pakistani-architects-bamboo-homes-rebuilding-lives-and-livelihoods-for-flood-survivors-1.91270855>
- Jankowski, B., Prokocki, J., & Krzemiński, M. (2015). Functional Assessment of BIM Methodology Based on Implementation in Design and Construction Company. *Procedia Engineering*, 111, 351–355. <https://doi.org/10.1016/J.PRO-ENG.2015.07.100>
- Johnson, C. (2002). *WHAT'S THE BIG DEAL ABOUT TEMPORARY HOUSING? PLANNING CONSIDERATIONS FOR TEMPORARY ACCOMODATION AFTER*

DISASTERS: EXAMPLE OF THE 1999 TURKISH EARTHQUAKES 1.
www.grif.umontreal.ca

Kara Fox CNN. (2022). *Pakistan's melting glaciers are 'erupting' and worsening floods.*
<https://edition.cnn.com/2022/09/01/asia/pakistan-flooding-glacier-outbursts-climate-intl/index.html>

Keddie, P., & Cogal, A. (2024). *Photos: Turks left homeless by earthquake stuck in container cities | Turkey-Syria Earthquake | Al Jazeera.*
<https://www.aljazeera.com/gallery/2024/2/6/photos-turks-left-homeless-by-earthquake-stuck-in-container-cities>

Keeth, M. V. (2022). *Prefabrication and Modular Construction: CM 214 Residential Construction Learning Module.*

Kessler, S. (2015). *If Reaction Housing Wants to Provide Disaster Relief, It'll Have to Shelter Festival-Goers First.* <https://www.fastcompany.com/3042416/hotel-30>

Lawson, R. M., & Ogden, R. G. (2008). 'Hybrid' light steel panel and modular systems. *Thin-Walled Structures*, 46(7–9), 720–730.
<https://doi.org/10.1016/j.tws.2008.01.042>

Lectronic M Aterials, H. E., Rocesses Andbook, P. H., ODERN P LASTICS H AND-BOOK Harper H, H. M., & Lastic M Aterials, P. P. (2002). *Handbook of Plastics, Elastomers, and Composites.* In *Plastics Materials and Processes*. McGraw-Hill Education. <https://www.accessengineeringlibrary.com/content/book/9780071384766>

Lu, N., & Korman, T. (2010). *Implementation of Building Information Modeling (BIM) in Modular Construction: Benefits and Challenges.*

Mallapaty, S. (2022). *Why are Pakistan's floods so extreme this year?* *Nature.*
<https://doi.org/10.1038/D41586-022-02813-6>

Mark, J. E. (1998). *Polymer Data Handbook.*

MatWEB. (n.d.). *Overview of materials for PVC, Molded.* Retrieved July 2, 2024, from <https://www.matweb.com/search/DataSheet.aspx?MatGUID=29340c5df4bf4de0a511419ce86db27b&ckck=1>

- MoneyBox Modular Housing. (n.d.). *Expandable Container House*. Retrieved June 24, 2024, from https://www.moneyboxhouse.com/modern-modular-expanding-container-homes-luxury-expandable-shipping-container-homes_p406.html
- National Disaster Management Authority. (2022). *NDMA Floods (2022) SITREP - 2022 (Daily SITREP No 158 Dated 18th November, 2022)*. <http://cms.ndma.gov.pk/>
- NYC Emergency Management, De Blasio, B., & Esposito, J. J. (n.d.). *CLOSE TO HOME: An Urban Model for Post-Disaster Housing*.
- Our Relief Units*. (2021). <https://bettershelter.org/our-shelters/>
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., Dubash, N. K., Edenhofer, O., Elgizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestvedt, J., Gomez-Echeverri, L., Hallegatte, S., ... van Ypersele, J.-P. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. EPIC3Geneva, Switzerland, IPCC, 151 p., Pp. 151, ISBN: 978-92-9169-143-2*. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf
- Panjehpour, M., Abdullah, A., Ali, A., & Voo, Y. L. (2012). Structural Insulated Panels: Past, Present, and Future. In *Journal of Engineering, Project, and Production Management* (Vol. 2013, Issue 1).
- Podder, A., Pless, S., Klammer, N., & Louis, J. (2020). *Integrating Energy Efficiency Strategies with Industrialized Construction for our Clean Energy Future: Preprint*. <https://www.researchgate.net/publication/345753308>
- RigaWood Plywood Handbook*. (2022). www.finieris.lv
- Riztria Adinda, N., Dwipriyoko, E., Amor Kusuma, D., -, al, Wang, Y., Xia, J., Xu, B., & Hořínková, D. (2021). Advantages and Disadvantages of Modular Construction, including Environmental Impacts. *IOP Conference Series: Materials Science and Engineering*, 1203(3), 032002. <https://doi.org/10.1088/1757-899X/1203/3/032002>
- Russell, A., & Potangaroa, R. (2008). *Houses of Homes? The Patterns of Design*.
- Saifi, S., Magramo, K., Maruyama, M., & Dewan Angela. (2022, August 30). *Pakistan floods caused by 'monsoon on steroids,' says UN chief in urgent appeal*. CNN.

<https://edition.cnn.com/2022/08/29/asia/pakistan-flood-damage-imf-bailout-intl-hnk/index.html>

satellite-telecom.shop. (n.d.). *SURI mobile modular Shelter 2,9mx5,2mx2,6m*. Retrieved July 4, 2024, from <https://www.satellite-telecom.shop/en/satellite-telecom-shop-home/182-suri-mobile-modular-shelter-29mx52mx26m.html>

Shahzad, W. M., Rajakannu, G., & Kordestani Ghalenoei, N. (2022). Potential of Modular Offsite Construction for Emergency Situations: A New Zealand Study. *Buildings*, 12(11), 1970. <https://doi.org/10.3390/buildings12111970>

Sharifi, N. P., Shaikh, A. A. N., & Sakulich, A. R. (2017). Application of phase change materials in gypsum boards to meet building energy conservation goals. *Energy and Buildings*, 138, 455–467. <https://doi.org/10.1016/J.ENBUILD.2016.12.046>

Shehzad, K., Xiaoxing, L., & Sarfraz, M. (2021). Envisaging the asymmetrical association among FDI, ICT, and climate change: a case from developing country. *Carbon Management*, 12(2), 123–137. <https://doi.org/10.1080/17583004.2021.1890449>

SI-MODULAR. (n.d.). *component system — [SI-MODULAR]*. Retrieved July 5, 2024, from <https://www.si-modular.net/modular-component-system>

Smith, H. (n.d.). *People are still living in FEMA’s toxic Katrina trailers — and they likely have no idea*. 2015. Retrieved July 4, 2024, from <https://grist.org/politics/people-are-still-living-in-femas-toxic-katrina-trailers-and-they-likely-have-no-idea/>

Solf, B., Guerrero, L., & Sherzad, S. (2024). *Article: Global Affordable Housing Shortages Can H.. | migrationpolicy.org*. <https://www.migrationpolicy.org/article/housing-crisis-immigrants-integration>

Spangler, N. (2024). *Creating the perfect stadium, playing surface critical to June’s T20 World Cup cricket matches on Long Island*. <https://archive.ph/20240401031806/https://www.newsday.com/long-island/nassau/cricket-matches-nassau-county-t20-world-cup-stadium-ak4ammvf>

SÜALP, Ç., & COŞGUN, N. (2023). Examination of Post-Disaster Temporary Housing Units in the Scope of Deployment Directions. *Mimarlık Bilimleri ve Uygulamaları Dergisi (MBUD)*, 492–506. <https://doi.org/10.30785/mbud.1322772>

Suricatta Systems. (n.d.). *SURI SHELTER UNIT for RAPID INSTALLATIONS*.

- The 2030 Agenda for Sustainable Development's 17 Sustainable Development Goals (SDGs)*. (n.d.).
- The Index Project. (2015). *EXO HOUSING SYSTEM by Reaction Housing*. <https://the-indexproject.org/award/nominees/139>
- The World Bank. (2022, October 28). *Pakistan: Flood Damages and Economic Losses Over USD 30 billion and Reconstruction Needs Over USD 16 billion - New Assessment*. <https://www.worldbank.org/en/news/press-release/2022/10/28/pakistan-flood-damages-and-economic-losses-over-usd-30-billion-and-reconstruction-needs-over-usd-16-billion-new-assessment>
- Thurairajah, N., Rathnasinghe, A., Ali, M., & Shashwat, S. (2023). Unexpected Challenges in the Modular Construction Implementation: Are UK Contractors Ready? *Sustainability (Switzerland)*, 15(10). <https://doi.org/10.3390/su15108105>
- Tucker, E. (2015). *SURI modular housing system provides emergency shelter for refugees*. <https://www.dezeen.com/2015/09/15/suri-modular-refugee-housing-system-emergency-shelter-suricatta-systems-urbana-de-exterores/>
- UNHCR Emergency Handbook. (2022). *Shelter Cluster*. <https://emergency.unhcr.org/coordination-and-communication/cluster-system/shelter-cluster>
- UNHCR RHU 1.2. (2022). *The Refugee Housing Unit (RHU) 1.2 Emergency Handbook*.
- United States Geological Survey. (2023). *M 7.8 - Pazarcik earthquake, Kahramanmaraş earthquake sequence*. <https://earthquake.usgs.gov/earthquakes/eventpage/us6000jllz/executive>
- UNOCHA. (2022). *Revised Pakistan 2022 Floods Response Plan: 01 Sep 2022 - 31 May 2023 (04 Oct 2022)*. <https://reliefweb.int/report/pakistan/revised-pakistan-2022-floods-response-plan-01-sep-2022-31-may-2023-04-oct-2022>
- VisitQatar. (2021). *Explore the innovative Stadium 974*. <https://visitqatar.com/intl-en/things-to-do/adventures/other-sports-and-activities/stadium-974>
- Xinhua. (2022). *China donates tents to Pakistan in flood relief aid - Global Times*. <https://www.globaltimes.cn/page/202210/1276508.shtml>
- Zhou, V. S. (2023). *Modular Units in Post-Disaster Housing Reconstruction*.