MODULAR CONSTRUCTION FOR SUSTAINABILITY USING BUILDING INFORMATION MODELLING

FINAL YEAR PROJECT UG-2018

By

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This is to certify that the Final Year Project titled

Modular Construction for Sustainability Using Building Information Modelling

Submitted by

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Has been accepted towards the requirements
for the award of undergraduate degree

Bachelor of Engineering in Civil Engineering

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ABSTRACT

Construction, as any expert in the construction business knows, can be a costly and time-consuming job. Delays are almost more frequent than on-time construction and can be caused by a variety of factors including excessive bureaucratic procedures, weather, and other unforeseen conditions, insufficient planning, a lack of people, and a variety of other factors. Long construction projects can have a negative influence on public opinion even before they are completed, especially if they cause delays or annoyance to individuals who live or work near the construction site. **Modular construction** is a method of constructing a building off-site, in a controlled environment, using the same materials and adhering to the same rules and standards as traditional structures.

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CHAPTER-1

1. INTRODUCTION

1.1. Study Background

The world is developing at a quick pace and thus we are seeing new construction projects and ventures springing up all around us. Construction projects may seem straightforward from an outer perspective, but a construction project is a complex system with multiple operations being carried out, interactions of materials and supply chains being integrated with each other, diverse labor force and several stakeholders working together to make sure that the project is delivered as per the scope of work and in the given time (Osuizugbo et al., 2020).

The use of fossil fuels such as gas and diesel has the most detrimental impact on the environment for construction companies. The building process necessitates the combustion of fossil fuels, which emits greenhouse gases and has a negative impact on the environment. Fossil burning is extremely harmful to our ecosystem. Every building project releases carbon dioxide, methane, and other pollutants into the atmosphere, polluting the air and perhaps contributing to global warming (El-Sayegh et al., 2021). Construction projects emit large amount of methane and carbon dioxide. Emission of these gases has the tendency to cause shortness of breath which itself induces other problems. As we have already developed that not only Pakistan but the whole world relies on construction sector, when the output of construction industry multiplies, so will its damaging effects (Kamali et al., 2019).

Let's assume a client who hires some contractor to build their project. During the project, some price hikes are observed and project cost goes up. In some cases, project costs are even known to double up. This sudden hike in project cost is most of the time not paid by the client and the contractor ends up getting a stay order on the built building before they can reimburse their costs incurred on the project. That could also happen to you traditionally followed project someday. However, in a Modular Project, the possibility of that happening is alleviated (Meszek et al., 2019). In this case, cost of the project is quickly estimated and after contract signing, assembled parts and panels are sent to your shipping address. In case of medium to large scale projects, the assembly can be carried to the site where parts can be built and it takes only a matter of hours to assemble stories. So, we could say that risk of cost overruns and time delays is high in traditionally made structures. Just like this one example, many could be stated that would highlight how Modular Construction is adding value to the construction sector by allowing for mini-improvements in any area it can.

1.2. Research Significance

Construction industry, being the driving force behind the world's economy, still lacks technological advancements as compared to other industries. Construction industry has been experiencing a lack of efficiency improvement. Constructors have only managed to reach approximately half of the efficiency improvements compared to other industries in the last half of the century. One of the major reasons for the construction industry to be lagging other industries in efficiency is lack of digitalization and automation as well as the amount of time that it takes for a building to stand. This lack of automation and digitization puts hindrances in the workflows of construction processes while, a fortnight of time waiting before builders can continue working on the same project is as good as wasted. The sub-optimal working process is caused by the slow setting and large waiting-periods of construction sites.

Pakistan is a growing country that is now seeing a rapid increase in building activity. Construction is now Pakistan's second-largest industry, behind agriculture. Construction employs over 30-35 percent of the workforce, either directly or indirectly. In Pakistan, the building industry has played a critical role in creating jobs and assisting the country's economic recovery. A sector working on such a large scale should be eco-friendly as well as sustainable. The reality is quite contrary to the imagination (Farooq & Yaqoob, 2019). The aim of this research would be to enable the drive of system to more sustainable methods and techniques. In order to create a more sustainable future for all, SDGs (Sustainable Development Goals) were made by United Nations in 2015. Expected outcome of these goals is supposed to be achieved by 2030. These 17 interlinked global goals are supposed to be a "blueprint to achieve a better and more sustainable future for all".

The primary goal of the sustainable construction method is to reduce its impact on our environment by minimizing energy consumption & controlling waste production. The waste produced itself can find its uses in construction (Won et al., 2009). For instance, brick waste is used as fine soil to fill the gaps between coarse aggregate. Moreover, brick ballast can be used for making underlying foundation pads, when mixed with the mixture of cement and sand as well as for a variety of landscaping uses, like path edgings etc. Optimization in the construction process would not only benefit the local construction industry but also provide a boost to the industry worldwide by helping us make the construction more sustainable (Xu et al., 2019).

1.3. Problem Statement

In Pakistan, the construction industry is one of the largest users of global resources and contributors of pollution. The construction methods adopted at present are highly consuming in terms of time and energy. These methods of construction play a major role in polluting the environment and causing damage to the areas near the construction site. One of the major issues of the traditional method of construction is the waste of material. Pakistan is a developing country and cannot afford to waste its mineral resources. Modular construction is a modern technique of offsite construction that reduces the problem of waste and is more time-efficient. Therefore, there is a need for practical integration of Modular construction in Pakistan that can aid in sustainability in terms of cost and time efficiency.

1.4. Research Objectives

- To study the benefits of Modular Construction that can be incorporated in the construction sector.
- To identify the contributing factors of BIM in Modular Construction.
- To develop Housing Modular Structure while highlighting the contributing factors of BIM.
- To conduct a comparative analysis between a sustainable modular structure developed using BIM & a traditional structure made with construction practices that are generally used in the construction sector.

1.5. Scope and Limitations

The research aims at development of housing Modular structure and analyzing the costs it incurred in terms of money, time, labor, etc. The complete analysis of a developed model that covers the same Floor to Area ratio and incorporates the best value that a traditional structural design could have offered, can truly offer a fact driven comparative study. The scope of research widens to study Modular Construction and learn how the technology method can drive changes and innovation in the current construction industry. There lies a bridge of information exchange between BIM and Modular Construction. The research also aims to discover and identify the contributing factors that Building Information Modeling can incorporate into the manufacturing process. Based on the outcome of the research, we can conclude whether modular structure technology is better than traditional methods and technologies that have always been used. Instead of waiting a fortnight before coupling another story at your site, Modular construction will allow faster construction. Panels are fabricated and assembled at factories and brought to the construction site for installation. The whole process does reduce having to deal with construction waste however, there are certain factors that increase the cost of modular construction in comparison to traditional. The aesthetic sand spaciousness of the project are only some of the features that might be compromised. The finishing and outlook of the building is not as appealing but certainly follow the Sustainability Development Goals.

1.6. Summary

Advancements are required in construction sector technology in order to overcome the gap between building demand and building construction. That gap could be due to a lot of reasons but overcoming these hurdles is the main essence of this research. Incorporation of Modular construction technology in the construction industry would fasten up the process and provide high time efficiencies. Before thinking ahead, we need to remind ourselves how Modular construction can provide value to our projects while considering the areas where compromises would have to be made in order to achieve the desired outcome. Presenting a comparison between traditional structure and modern BIM-developed structure's characteristics and drawbacks would be the aim of this research.

CHAPTER-2

2. LITERATURE REVIEW

2.1. Problematic Issues in Traditional Method of Construction

Pakistan is a developing country with construction sector growing rapidly. The construction industry is Pakistan's second-largest industry after agriculture. Construction employs over 30-35 percent of the workforce, either directly or indirectly. But yet the pace construction sector is advancing with is too slow. In such modern era where we can have any task done in minutes easily construction projects take years to complete.

With the world on a very fast track, construction industry is still stuck with the old construction methods developed years ago with very little advancement. Given the rapid growth of infrastructure spending (which is expected to quadruple in the next 15 years), it's astonishing that the techniques and processes used are still outdated. Work is still primarily done manually and on-site, and productivity has been declining since the 1990s. The majority of building projects are plagued by delays and expense.
Even though the construction business is naturally long-term, it no longer thinks that way. Labor productivity can no longer keep up with total economic productivity. There are tons of problems in traditional construction methods.

From design to closing most of the projects are met with delays, bad weather conditions, labor strikes, miss-communication and misuse of resources, etc.

Table 1: Problematic Issues in Traditional Methods of Construction

Sr. No.	Problematic issues in traditional methods of Construction
1.	Delays
2.	Organizational Structure
3.	Communication Gap
4.	Time Consuming
5.	Connection Gap
6.	Safety Issues
7.	Weak Performance Management
8.	Limited Skills
9.	Environmental Hazard

2.2. Major Causes of Delays in Construction Processes

Most of the construction projects are met with delays one way or the other. There is always this sword of. Large projects take at least 20% longer to finish and are up to 80% over the budget (Abwunza et al., 2020). Delays can happen for various reasons such weather, equipment delay hanging above a construction project ready to fall at a time no one knows exactly failures, labor shortages, missing or incorrect data, project mistakes and conflicts. Whether we talk about the lack in information flow or poor planning, delays in construction projects costs.

Table 2: Major Causes of Delay in Construction Sector

Sr. No.	Major causes of delays in the construction sector
1.	Changings in initial specifications
2.	Lack of information
3.	Lack of resources
4.	Disputes
5.	Poor Planning
6.	Weather conditions
7.	Labor Challenges
8.	Approvals
9.	Non-compliance sub-contractors

2.3. Pre-Fabricated Panels

Prefabricated wall panels are prefabricated modules that are manufactured in a controlled environment. Builders send the home's construction specifics to the factory, where the drawings are entered into a computer program that creates wall panels according to the home's demands. In a quality-controlled setting, manufacturers may cut, nail, and screw the components together, resulting in a stronger, more lasting wall construction. Because they are constructed with higher-grade timber from a huge inventory of resources at the factory's disposal, premade wall panels are also more dimensionally correct.

The wall units are labelled for assembly and transported straight to the project site after they've been produced. When the builder is ready to install the wall panels, they simply follow the factory-defined installation and assembly processes.

Trade contractors assemble all of the elements on the work site while the house is being built in traditional wall frame construction(C. Zhang et al., 2021). However the builder may typically examine the process to ensure a high-quality home, it can be difficult and time-consuming to verify that each wall unit is built according to the blueprints and in a consistent manner. Work delays or costly rebuilds can be caused by bad weather, scheduling issues, construction faults, and keeping a competent working force.

The traditional wall framing process has a number of disadvantages in addition to quality difficulties. The builder is particularly vulnerable to theft since trade contractors require raw lumber on the project site to frame the house. Traditional wall framing also generates a lot of garbage on the project site, which raises the cost of construction by raising clean up and disposal fees.

Prefabricated wall panels, like roof trusses, can give builders a competitive advantage, larger profit margins, and shorter building cycle times. Whatever is beneficial to the roof is beneficial to the rest of the house as well.

2.4. Modular Construction and its Benefits

Modular construction is a revolution in the construction industry which is in its initial stages. This method of construction caters all the questions with a proper solution. Major issues involved in traditional construction methods automatically settle down in the case of modular construction (Karthik et al., 2020). Since Modular Construction is done in a closed environment so it reduces the risk of heavy and tragic accidents. It is an eco-friendly method. Following are some of the benefits of modular construction:

Table 3: Benefits of Modular Construction

Sr. No.	Benefits of Modular Construction
1.	Flexible
2.	Speed of building
3.	Minimal environmental impact
4.	Portable
5.	Attractive design
6.	Less complexity
7.	High quality construction
8.	Durable materials
9.	Less construction waste
10.	Low labor cost
11.	Mass production
12.	Low risk factor
13.	Energy Efficient
14.	Reliable Performance
15.	Future Benefits
16.	Less Work on Site
17.	Accurate Size
18.	Scheduled Construction

2.4.1. Concept of Modular Construction

Modular construction is the process in which a building (whether it be an apartment, business building, and even homes are now starting to be built with shipping containers) is constructed off-site, under controlled conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time. The process consists of buildings produced in modules to be later put together on site. 60-90% of the work is completed in a factory-controlled environment under the required conditions. This adds to the time efficiency, perfect designs and sustainability.

Single unit modules are designed according to the facility being catered, then these modules come together in different arrangements to make the required building or house or any sort of facility. Furthermore, by fabricating the modules inside a controlled environment, worries about weather delaying construction of the modular units is virtually eliminated. It also provides workers safer and more comfortable conditions to be more productive and produce a higher quality product. Also, the modules arrive on-site usually outfitted with flooring, cabinets, counters, plumbing and electrical fixtures, and appliances, thereby needing little effort and time to be ready for use.

2.4.2. Impact on Environment

Billions of tons of construction waste is generated annually. Buildings also account of CO2 emissions. As modules are designed in a controlled environment so construction waste is out of the equation (Jeong et al., 2022). With Eco-friendly materials being used in modular construction, lowering the environmental impact and reducing the waste generated. Eco-conscious manufacturing techniques have become more popular in recent decades as a result, with a modular construction approach, in particular, offering builders the chance to save both money and time while helping support the planet too. Modular buildings also consume less energy as the energy poured into the assembly process is only a fraction of that which would be used on-site.

Noise pollution is reduced to an appreciable level by opting for modular construction as activities are happening far away from the site in a controlled environment. With a recent surge of interest in building reusability and recyclability, modular builds can provide the flexible solution the buildings of the future need. It could be easily dissembled and relocated to a new location which eliminated the salvage waste.

2.4.3. Impact on Sustainability of Construction Sector

Around 40% of landfill waste comes from construction sector. The US Environmental Protection Agency (EPA) estimates that new commercial construction generates around 3.9 lb of waste per sq. ft. Modular buildings are more sustainable as off-site construction involves no landfill waste. With the use of recyclable material in modular construction this waste can totally be removed. Modular buildings can be relocated and reused.

The module units once designed can serve for any building purposes. Modular buildings are flexible, they have very little to no impact on the surrounding environmental. No problem of dust, debris or unwanted pollutants.

Modular building provides a number of environmental advantages (Waris & Hameed, 2020). For example, trash in landfills is reduced by streamlined design and efficient production. The quality of features such as insulation may be better ensured when buildings are built in a factory setting. In a factory, energy use is easier to manage than on a building site.

2.5. Special Sustainable Techniques of our house

A special reason to incorporate BIM techniques in our model was the efficiency in the life cycle analysis that could be made of our model. BIM can be used for measures like green building materials, energy efficient appliances, natural lighting, water conservation techniques, site assessment, indoor health and suggested indoor decorative measures, environmental impact reduction, sustainable operation, and as easy as possible maintenance (Calianno et al., 2020). Let us talk about how we were able to utilize BIM in order to bring about some of these sustainability lead ideas into our Module home (Sidik et al., 2021).

- Flat roof
- Double glazed windows
- Energy efficient appliances
- Water harvesting system
- Wind turbines
- Eco paints
- Low flow washroom

2.6. Traditional v/s Modular House

The presence of v/s suggests that following literature will be comparison based.

- **Portability:**
  The portability of the modular house is an advantage over the traditional construction method. Our developed module is specifically designed to be a complete home while being portable and a BIM designed accurately manufactured structure.

- **On-site safety:**
  On site, the module can be easily carried and opened with MEP components already installed. It is safer than traditional construction method as it does not involve the labor involved human hassle. Traditional construction method is known to have incurred some fatal accidents (Wiki, 2016).

- **Human hassle:**
  On-site accidents are known to cause project delays that can last up to months. In certain cases, litigation can cause project delays that could take years and even make one party lose possession. These unimaginable delays are mostly cause by human hassle related complications in the traditional construction method.

- **Energy Conservation:**
  Very little energy is lost when excellent construction, sufficient insulation, and appropriate windows are used. Furthermore, having openable windows provides for greater air circulation and prevents the accumulation of indoor air pollution (Karthik et al., 2020).

- **Construction Time:**
  According to PBC, a UK-based research organization, a modular structure may be

built 50 percent faster than traditional construction, resulting in a faster return on investment. Traditional construction method can take months of construction time and fatigue before any investment return can be made (Tong, 2021).

- **Waste Management:**
According to new statistics published by the construction site BIM how, the building industry is responsible for 23% of air pollution, 50% of climate change, 40% of drinking water contamination, and 50% of landfill trash (Freitas & Magrini, 2017). Slowly, construction industry has grown to be one of the biggest consumers in terms of energy and time-consuming industries. As a process, this is damaging our environment (Spišáková et al., 2021). But Modular Construction takes the advantage in this case as in this mode of construction, there are no wastages, each and every dimension and type is pre-determinate and you can choose to change any product and add alterations according to your need or taste (Prema, 2021).
- **Quality Production:**
Modular structures are developed in an encased plant that is temperature and weather conditions controlled. Dissimilar to traditional development, modular makers can keep supplies and the structure out of the components which has benefits. Weather conditions delays are disposed of while the structure is being built. The materials used to construct your modular structure are likewise kept in a temperature-controlled climate so they experience no adverse consequences from water or outrageous intensity. The structure site is ready while your structure is under development, which abbreviates the task course of events.
- **Productivity/Workmanship:**
One obvious feature is that modular construction allows a portion of the work to be done in a manufacturing plant while the rest of the work is done on the job site. This effective advantage maintains the project on schedule and speeds up construction time while being productive (Bon & Hutchinson, 2000).

- **Environmental performance:**
There are a few advantages to modular building in terms of sustainability. For example, a well-thought-out plan and efficient production reduce trash to landfill. The nature of components, for example, can be better assured by supplying structures in a processing plant context (Tavares et al., 2019).

  Shorter time for construction, requires less energy and does not contribute to pollution as much. Less daily traffic and machinery required. Modular Construction has lower level of noise pollution, traditional construction on the other hand can cause great noise disturbance in the area where construction is going on. A large increase in recycling materials often discarded as waste on-site.
- **Transportation Restrains**:
When your structure is finished and has passed assessment at the processing plant, it's transported to the site. On the spot, your structure will be set by nearby codes and producer's rules. While there is an assortment of ways of hindering a structure, most modular structures utilize an over the ground framework with substantial

wharfs.

Our model is specifically designed to be easy to transport. The folding mechanism is what allows the house to be hassle free and truck transportable.

2.7. BIM and its Application in Modular Construction

It might be subjected to question why our group worked so many days in and out on applying Building Information Model techniques to our developed module. Let us try to explain how important it was to integrate our model. BIM allows professionals working in the construction sector to plan and design precisely, and construct with tools and insights in a way to achieve maximum efficiency (Lee et al., 2020). Moreover, BIM enhances the communication flow among project members and as a result of that, engineers are able to come up with improved design and construction process. It has made coordination and fabrication of MEP components in Modular Construction be easy and operate smoothly. It has been made possible to virtually manage and design the functional properties like MEP all based on the model, while sitting in a distant room.

Prior to the use of BIM software, cost estimates would be generated from quantity take-off using 2D drawings. This technique is still used to this date observing from the experiences we have had on-site. BIM automates this process with 3D models, and the information is refreshed automatically whenever any changes are applied. Under the traditional approach, design changes usually require the repetition of long calculations. The process when done manually is an arduous task and leaves ways for corruption and dishonesty. BIM can visualize all the physical and functional properties in the module while providing exact and accurate estimates (Darko et al., 2020).

Making a life cycle analysis using BIM is also something that can be easily done. Modular buildings may be evaluated in an interactive way using BIM technologies and the model developed. Green building materials, energy efficiency, natural lighting, water conservation, site evaluation, indoor health, environmental impact reduction, sustainable operation, and maintenance are all examples of BIM applications. All of these properties are also addressed in the section 2.5 stating biased and factual data regarding our model.

More could be said on to how BIM tools are applicable and pertinent in Modular Construction, but a few bullet points should do justice by stating the gist of the point.

- It enables digital design flow to fabrication workflow easily for all the disciplines.
- With the use of BIM Modelling services in Modular Construction, use of prefabricated modules is increased along with resolving all the potential issues in the design stage itself, saving time and money on the project.
- BIM analyses the exact data of the site with collaboration and gives precise measurements of the prefabricated modules to sub-contractors.

CHAPTER-3

3. METHODOLOGY

Project completion has taken place in 3 stages.

1. **Literature Review**
   It was done for the problem identification and or all studies we needed to do for the existing techniques or facts.
2. **Development of Model**
   It included the whole process of coming up with the modular structure and making it feasible according to the environment of Pakistan
3. **Comparative Analysis**
   It was done to know if modular construction is actually better to use or suitability.

3.1. Problem Identification

In the first phase, an extensive literature review was done to identify key parameters that would affect the sustainability in the construction sector of Pakistan. Most of the research papers suggested that traditional method of construction in Pakistan is extra time consuming and prevails the resources consumption that is adding to the pollution of the world. All the issues that would cause the delays in construction process were short-listed as well. Our research also focused on finding the new alternatives of construction processes in the construction sector of Pakistan.

Next papers were studied to find if the other techniques are better for bringing the sustainability than the traditional. Certain processes and new innovations were suggested in the research papers catering to the need for introduction of suitability in housing system but there was still a lack of implementation of the sustainable construction methods and techniques in Pakistan. We came up with the solution of developing self-sustaining modular units for living.

3.2. Development of Model

In second phase, we went for developing a highly sustainable modular structure that can be implemented in Pakistan. For the modular house we knew we would keep it covering comparatively a smaller area. The family size we used as an assumption was a family of 2-3 people. We developed different plans as options to choose one from them.

A plan was chosen but there were some of the key parameters that were having the direct impact on the design of our plan that were not considered previously while making the plan. These factors include the limitations that were brought up due to the transportation that has to be one after making of house in the factory. Also, we did not cater the customizability of house as per client's requirement. So, there was a need to develop the plans again keeping in mind all the affecting actors.

Now, we were to prepare a plan and check the dimensions of the house if they are applicable or not. We knew that modular construction is a process in which houses are prepared in the factory and then transported on site so, the main task was the transportation of the house. We catered this problem by proposing a unique style of the house that is a T-shaped modular house. This housing plan was transportation friendly.

Firstly we used AutoCAD for making different house plans. Then, we stepped on Revit to cater the 3D requirements as well. We prepared a whole 3D single story house on it including the MEP model. For a better view understanding, we made a walkthrough video on Lumion. It made it easy to show how our design will transfer into real-world experiences and emotions. After developing one T unit. We checked some ways by which we can merge or use one or more single T units to cover larger areas or storeys. We combined T sections and produced housing structure on larger area.

After the preparation of the model, the material for construction was decided. It was very important part of our project because we wanted to find material that would make the house more durable and sustainable. We visited some of the prefabrication factories in Islamabad to see what material they are using and how they work. Different materials were seen that were being used. We did our research work and decided the best that we could use.

Next step was to bring some sustainable features in our house model. We did a thorough research on the features that can be incorporated. Through home sustainability we wanted to help the owner save money on utilities, water, and system and appliance maintenance. Plus, make a healthier atmosphere for them, their family, and the world. So, we chose 7 techniques to be implemented in our modular house that would make the model more sustainable.

3.3. Transportation of House

The most critical part of entire project was to determine an easy way of transportation of modular house to the site. For the actual application of portability of a house we contacted logistics companies in Pakistan. They told us some standards that must be followed in order to make the house transportable. In Pakistan maximum width of logistic vehicle allowed is 10´-12´. . We implemented a new folding mechanism to fold our house so that the area is compacted to 12´. The total width of the house is 36' and length is 36'. The fixed portion of the house is 12'x36. The rooms on the side that are making the width 36' are folded. We folded the rooms on sides in such a way that the total width of the house remains 12´. Since we induced the hinges and bolts in the walls so first the wall to wall connection is detached and then the walls of room are folded with the help of hinges.

3.4. Cost Analysis

Furthermore, the cost analysis for material of modular house and that of traditional house was performed. The foundation would same for both and there will be difference in cost of material only. Cost analysis was done by consulting the MES for rates and the quantities were taken from Revit for both modular and traditional houses.

3.5. Comparative Analysis

In third phase, we did a comparative analysis between the modular structure we made and a traditional structure of the same design and dimensions as ours. Comparative analysis was based on literature review. We checked different aspects of both the construction methods and concluded our results.

4. RESULTS AND DISCUSSION

4.1. Development of Model

The model is of a house that has dimensions of 36’x36’. Our house comprises of 2 bedrooms with attached bathrooms and open kitchen along with drawing room and dining. This is a single storey house. The rooms have dimensions of 12’x12’. Our ceiling height is 10’. This house is designed keeping in mind the family of 2-3 persons. This gives a vibe of studio apartment due to its open kitchen and dining. Since, we ha the limitations of the width of house, we did not want to make separate rooms for drawing room and kitchen. The open design is made to give less crowded look. Our house takes 8 days to get built in factory and the installation time on site is 1 day.

4.1.1. Development of 2D Model

Following is the 2D ground floor plan of our modular house which was prepared initially on AutoCAD and then on Revit:

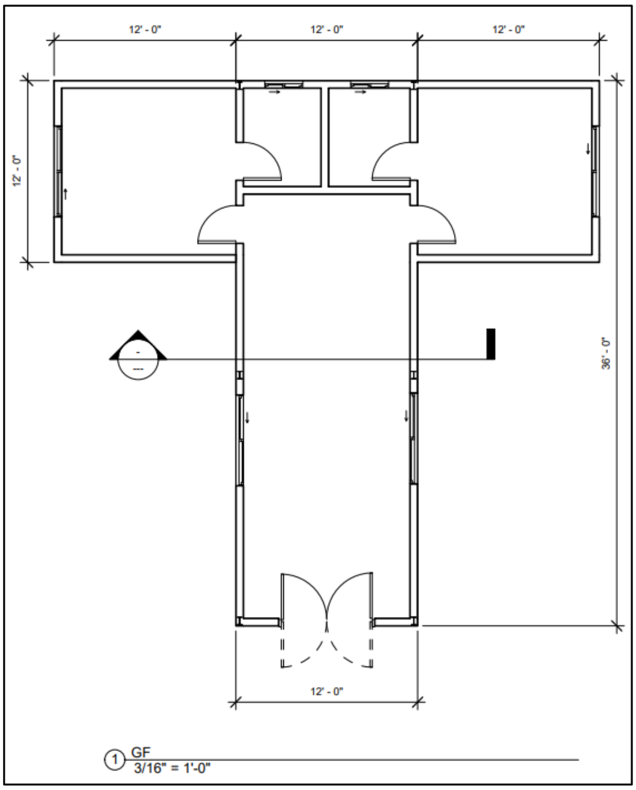

Figure 1: 2D Plan (GF) of Modular House

Next we prepared the 2D plans of our modular house on Revit which is shown as following:

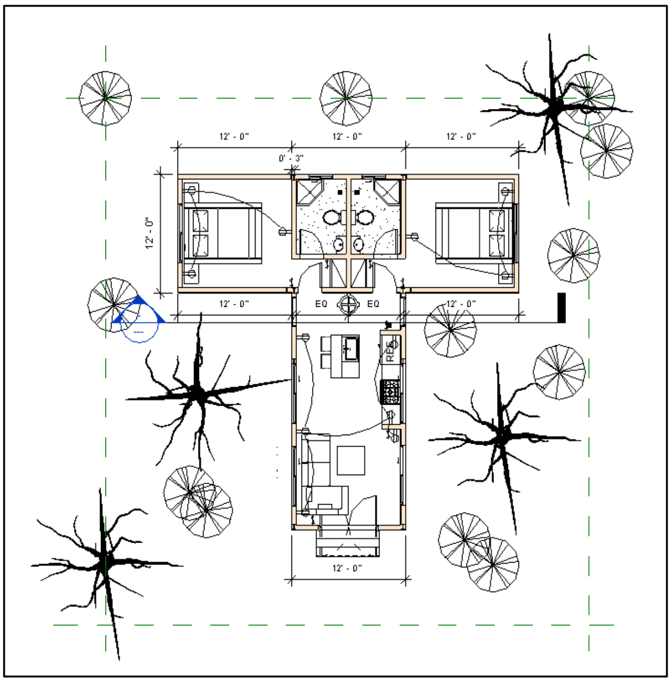

Figure 2: 2D Plan (GF) of Modular House in Revit

Following is the roof plan of our modular house prepared on Revit:

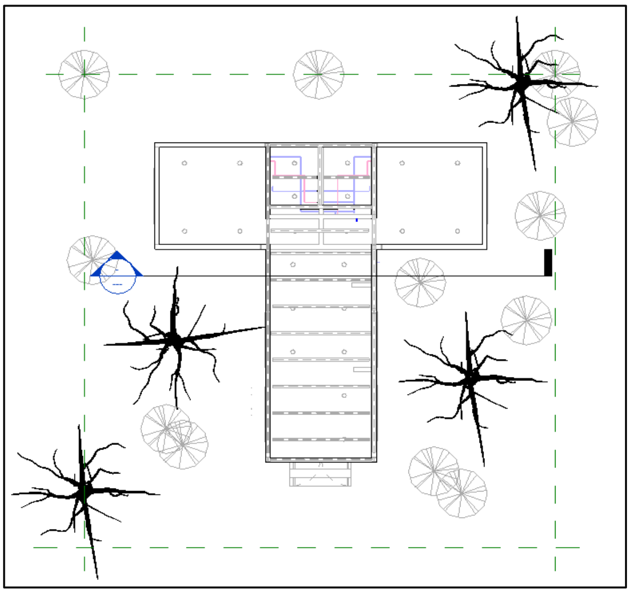
Figure 3: 2D Plan (Roof) of Modular House in Revit

4.1.2. Visualization of 3D model

In order to analyze the structure in a better way, a 3D plan of the modular structure was prepared. Following is the 3D plan of our designed modular structure:

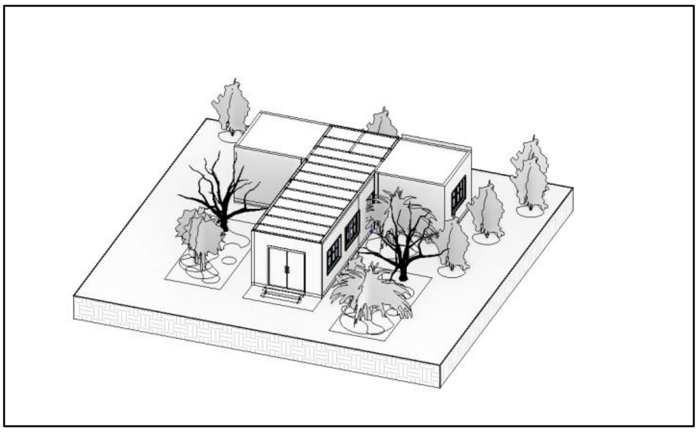

Figure 4: 3D Plan of Modular House in Revit

4.1.3. Development of 2D and 3D MEP Plan

After developing the model, work was done for plumbing, electrical and mechanical drawings. Our house will have all the fixtures installed when transported. Following are the 2D and 3D plans of MEP drawings:

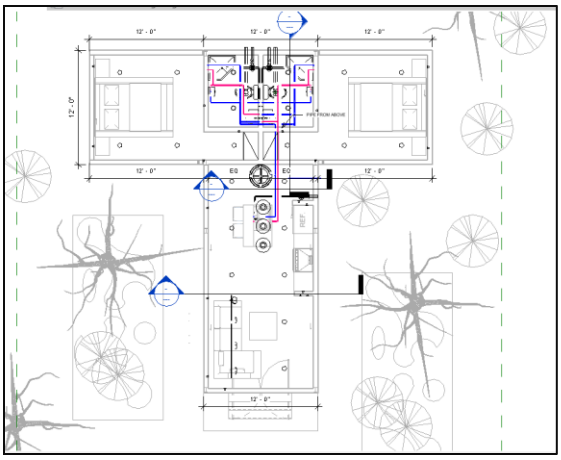

Figure 5:2D Plan Model of Plumbing

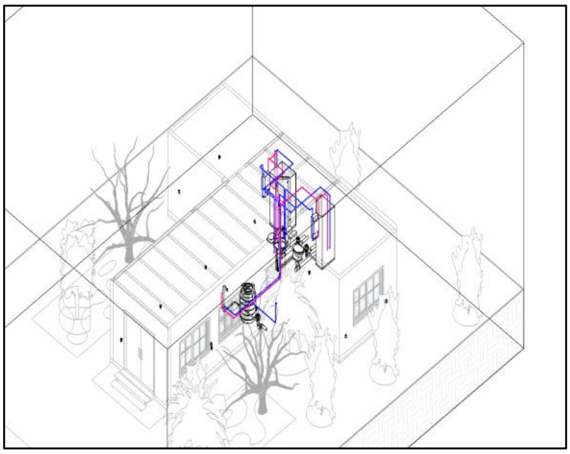

Figure 6: 3D Model of Plumbing

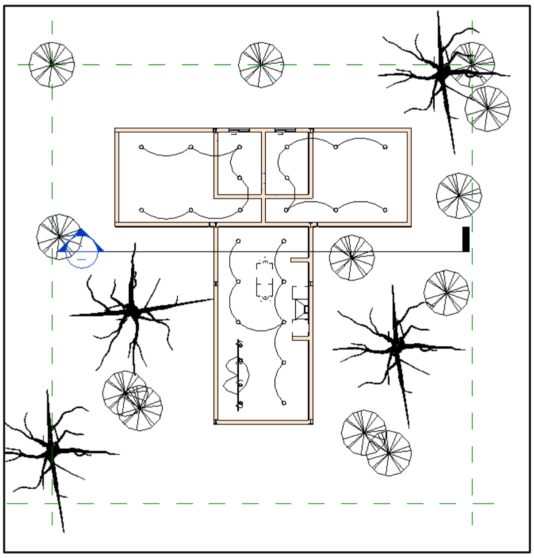

Figure 7: 2D Plan Model of Electrical

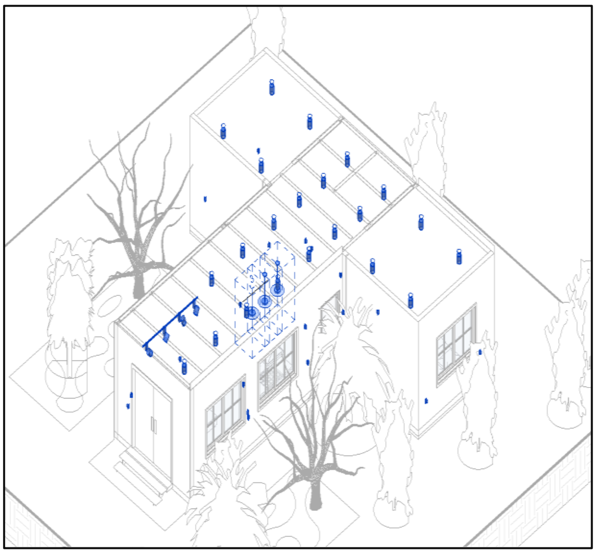

Figure 8: 3D Plan Model of Electrical

4.1.4. Visualization of 3D Realistic model.

Different views of our modular house were prepared on Revit and are shown below:

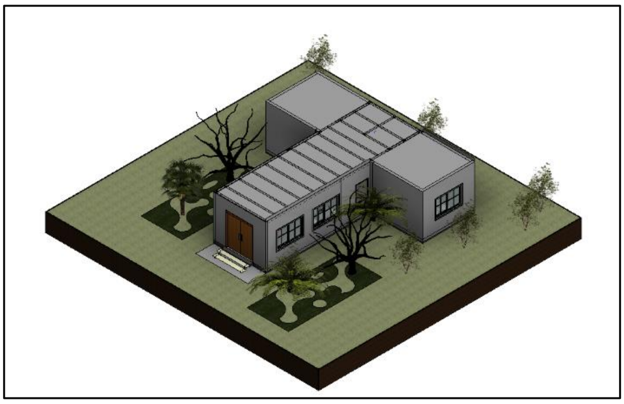

Figure 9: Realistic View of Modular House

4.1.5. Visualization of Lumion model.

Figure 10: 3D visual of modular house in Lumion

4.1.6. Visualization of Interior of House in 3D

Following are the insights of our house:

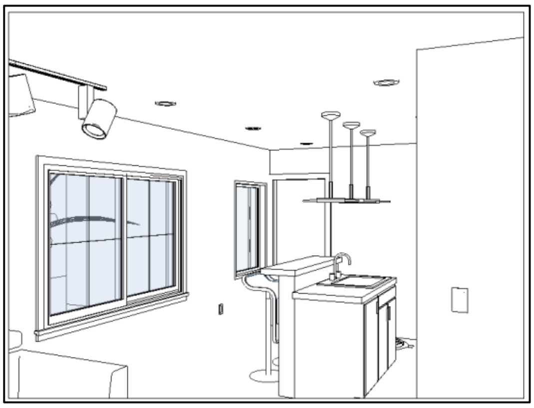

Figure 11: Walk through view 1 of Modular House

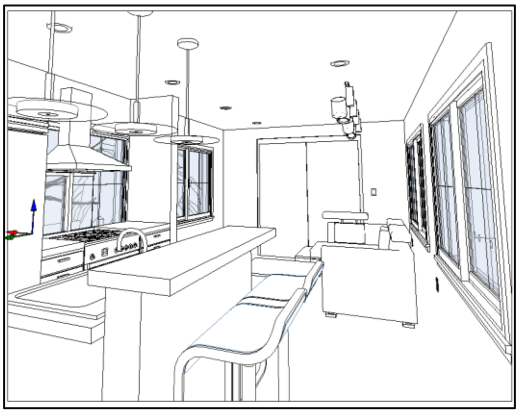

Figure 12: Walk through view 2 of Modular House

4.1.7. Different Alterations

After development of model, we tried to make some alterations in the plans an make it available for different requirements. This shows our model is flexible for different requirements of the clients. We made plans for more space coverage and more storeys.

Figure 13: 2 T units for more space coverage

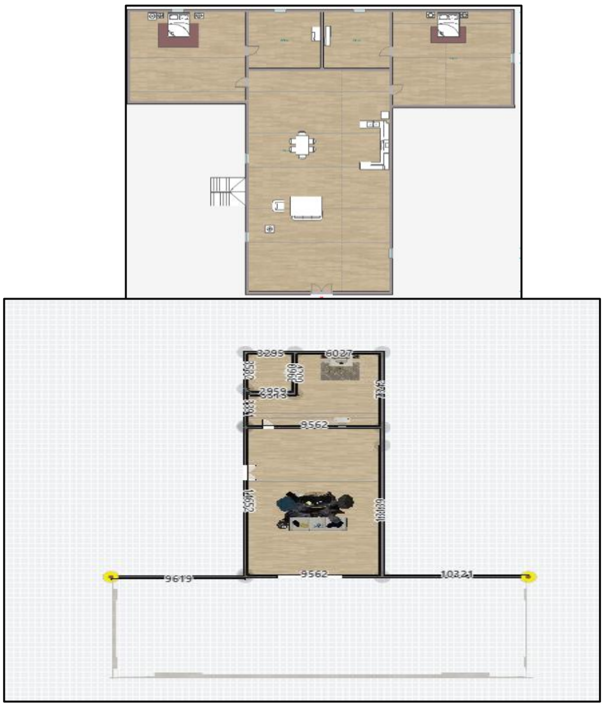

Figure 14: Double Storey House

4.2 Material for Modular House

After researching about the material the only the most sustainable and durable materials were chosen for our model.

4.2.1. Framework

For the framework of the structure, we used steel beams (W6x12) and columns (W6x12) between the sandwich panel walls in the fixed portion of the house. Steel purlins and bracings are use under the roof as we need load bearing characteristics as well.

4.2.2. Walls

We used sandwich paneled walls with Polyisocyanurate insulation as they are heat and water resistant, they are fire resistant, they refrain the external pressures and are the most secure insulation material available in Pakistan.

4.2.3. Windows and Doors

Wooden doors were used. Aluminum doubly glazed windows were used to reflect the light. These windows have a life of 40 to 50 years and they are safe against bad weather and are highly durable.

4.2.4. Roof

For roof, Glass fiber roof is used. We prepared the roof plan by considering the load bearing conditions of the house and provided steel bracing in the center part of the house. Fiberglass roofing systems are well-known for their durability, extended lifespan, and great performance. Fiberglass roofs are a newer addition to the roofing business, however they have a longer lifespan of durability 20-30 years.

4.2.5. Connections

Walls are attached to other with continuous hinges and bolted connections.

All the material used was sustainable in terms of energy and time management.

4.2.6. Flat-Roof

We have given a flat roof to our house. Flat roofs are long-lasting. It is less expensive to build and maintain. Flat roofs require less material since they take up less area than sloping roofs. A flat roof is also water resistant. During the winter, cold roofs offer a distinct benefit. They prevent ice jams and leaks caused by the accumulation of snow on the roof. We have painted it white so, it reflects almost 80% for sunlight and keeps the house cool.

4.2.7. Water Harvesting System

Water harvesting system was induced in our modular house in order to recycle the water and avoid water wastage. Sewage water is purified within the house by use of activated carbon filters. Underground water storage tank was used in order to store water. Pumps were installed in the house to pump water in the house.

4.2.8. Doubly Glazed Windows

We have given big doubly glazed windows to provide good ventilation. Double-glazed windows help you save money on your energy costs, as well as beautify, insulate, and reduce noise pollution in your house. They also keep you safe from intruders and provide total seclusion.

4.2.9. Energy Efficient Appliances

Using energy efficient technology, little amounts of energy may be turned into the quantity of energy necessary to complete a task. Many of these appliances can operate at lower temperatures and consume less energy, allowing them to continue functioning until the task is completed. We have given, Power strips, LED bulbs and Tower fans in our house.

4.2.10. Energy Production Techniques

We suggested and modeled our home such that there can be applied electrical energy techniques like installation of wind turbines or solar panels.

4.2.11. Low Flow Washrooms

Low-flow toilets are both economical and environmentally beneficial.

By using gravity or pressure-assisted technology, a low-flow toilet uses 1.6 gallons or less of water every flush. As a result, your home's power and water bills will be reduced, and you'll be conserving water more effectively.

4.2.12. Eco-Paints

In order to reduce indoor air pollution and improve air quality in houses, low-VOC or zero-VOC paint were used. In addition to improving indoor air quality, earth-friendly paints can assist to enhance human health by decreasing the usage of dangerous chemicals.

We made our house sustainable in terms of time and energy.

4.3. Transportation of House

As a solution to the most critical part, which is transportation, we introduced a folding mechanism.

The truck we are using for the transportation purposes of our house is of the dimensions 12’x40’x11’.

4.3.1. Folding Technique

Total area of house we developed was 720 ft^2. We folded it into 288 ft^2. This was done by giving continuous hinges in the mid of wall and roof along the full length. This helped the walls bend well to fold. First of all the floor-wall bolts are opened then wall-roof bolts are opened from one side. This is done for both the rooms. The roof folds into half and then is folded on the roof from both the sides. Then the wall is pushed inside and all the walls are folded along the longer length of the house. We have provides 180 degree hinges on one wall-wall connection. By this connection one folded room is folded at the back of the house. This is done to keep the width not more than 13’. The floor is transported separately on the same truck and then attached again while installation of the house. All of the folding and unfolding is done manually.

This compacted area can easily be transported on trolleys from one place to another as modular houses are portable. We have contacted to Wahyd Logistic Company and they are ready to transport our house. The installation time would be one day for our house.

4.3.2. 2D Plan of Compacted House

Plan after compaction is as follows:

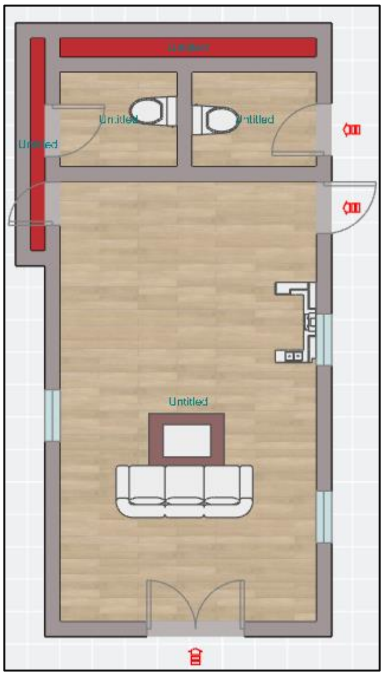

Figure 15: Plan of Modular House after Compaction

We also prepared a video on Blender 3.0 of our folding mechanism. Here, are some pictures save from the video of it.

4.3.3. Visualization of Folding Mechanism

The image below shoes the roof being folded in half with the help of continuous hinges provided in the mid length of the roof.

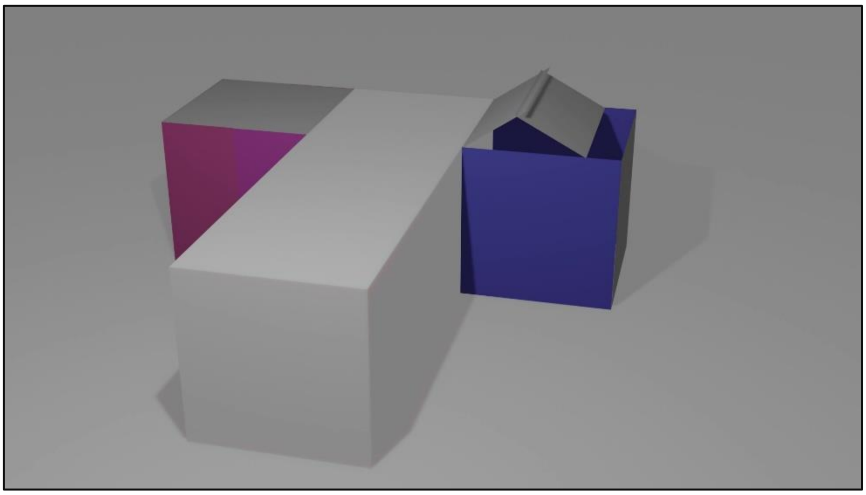

Figure 16: Roof Folding Room 1

The image below shows the folded roof on the fixed roof of the structure. The next step is wall folding which is also being showed in it.

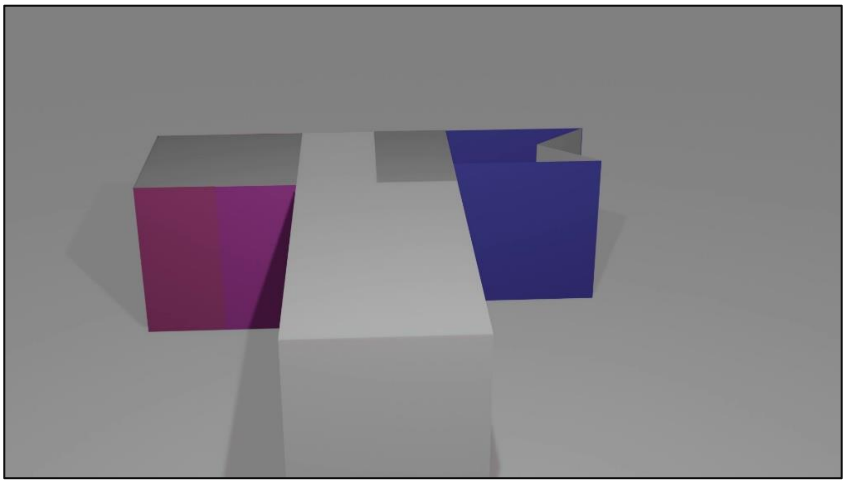

Figure 17: Wall of Room 1 Folding

The picture below shows all the folded walls along the length of the house rotating at 180 degree and aligning with the back of the house along the width.

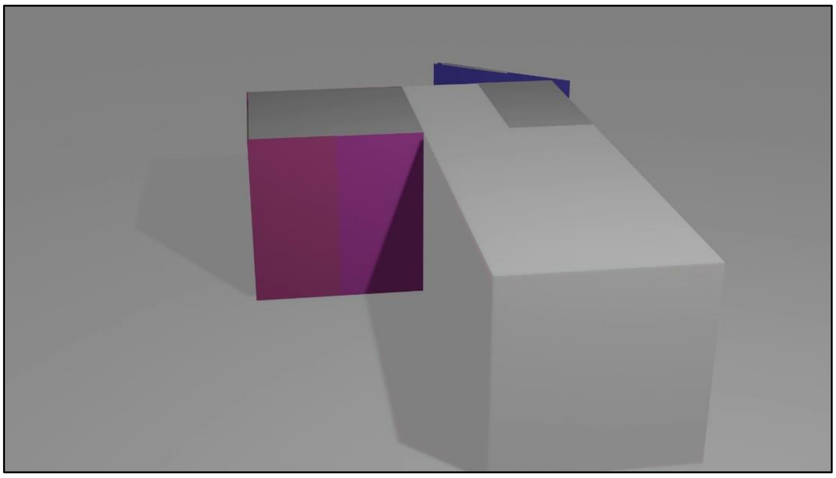

Figure 18:Room 1Folding

This is how the house looks after one room is folded.

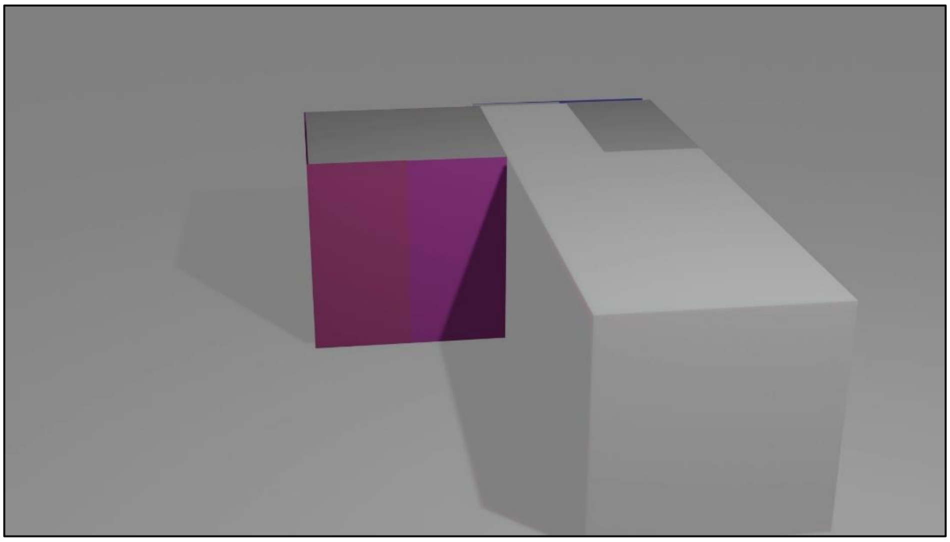

Figure 19: Completely Folded Room 1

The picture below shows the folding of second room. The roof is being folded with the same mechanism how roof of room 1 was folded.

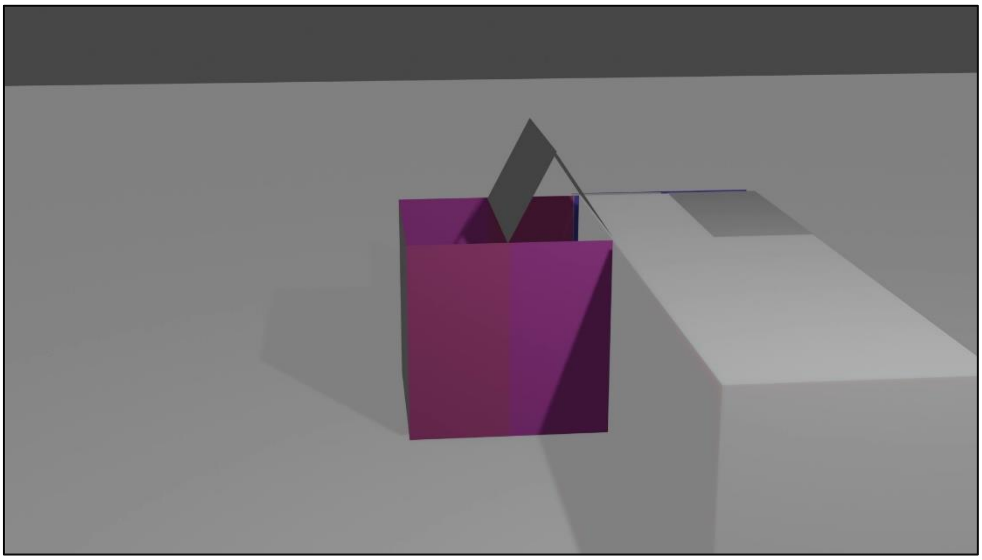

Figure 20: Roof Folding of Room 2

In the case of room 2 the continuous hinges are provided in two walls and they are pushed inwards to get completely fold. The image shows the process.

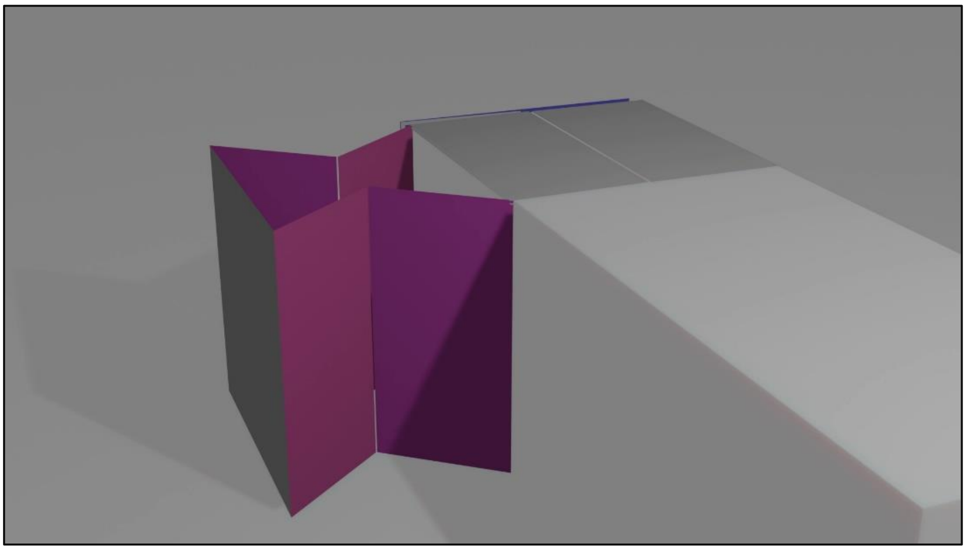

Figure 21: Figure 21: Folding walls of Room 2

After the two rooms are completely folded the compacted housing structure is easily transportable.
The image below shows how the compacted house would look like.

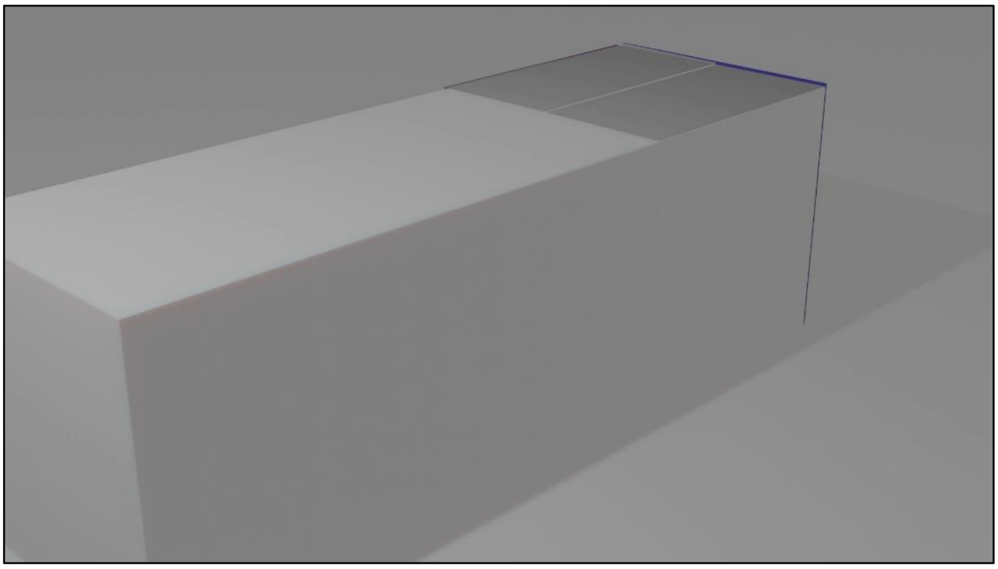

Figure 22: Compacted House

4.4. Traditional Housing Structure

The traditional house of same area and plan was prepared on Revit for comparative analysis purpose. This structure just has the difference of material and construction process. It is made up of R.C.C structure and Brick walls. The traditional house is given as follows:

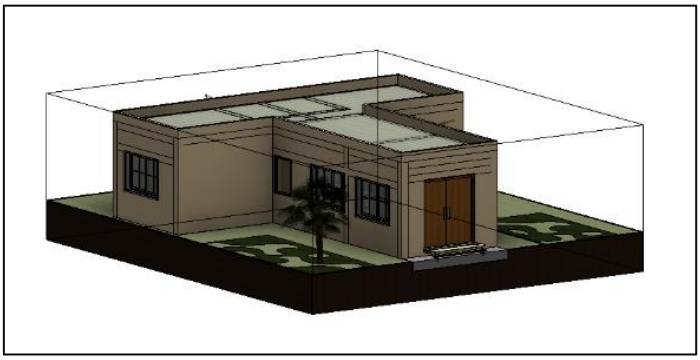

Figure 23: 3D model of traditional house

4.5. Comparative Analysis

After developing the conventional house in Revit, we analyzed both structures. We catered to almost all of the important parameters for the results.

4.5.1. Construction process

The following is the image of the comparison of the processes of both the construction method:

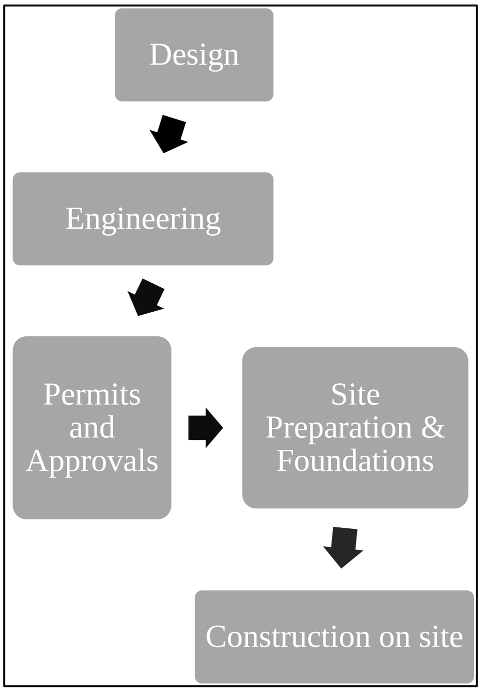

Figure 24: Conventional Construction Process

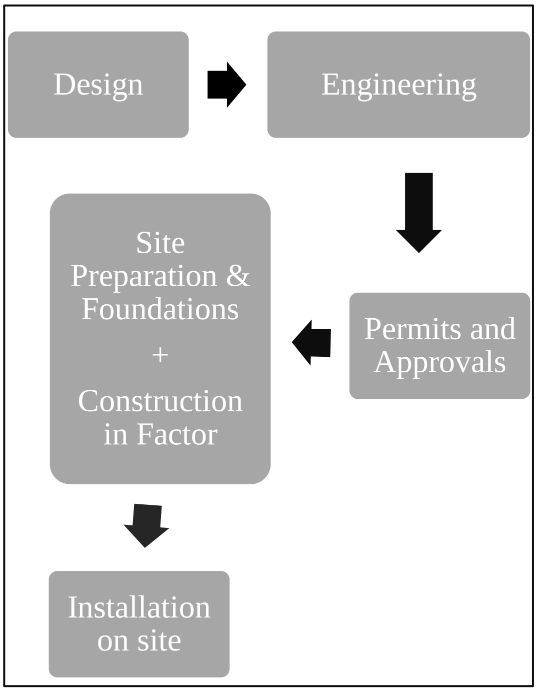

Figure 25: Modular Construction Process

- **Energy Conservation**

After research, it was found that modular construction is the best option if you want energy conservation. Modular construction not only saves 67 % on energy during the construction process, but it also saves money for the building's tenants. We can now recycle practically anything thanks to modern technology. The majority of recycled (and recyclable) materials are used in the construction of modular structures. The factory's regulated atmosphere enables for more precise construction while also allowing for in-house recycling of excess materials.

- **Construction Time**

  Traditional method of construction takes very long time to complete. Modular building enables for a portion of the work to be completed in a factory while site work and foundations are completed on the job site. This time-saving feature keeps the project on track and reduces construction time while maintaining efficiency. Modular Construction also leads to less delays due to more certain and systematic environment. There is no possibility of weather delays. According to a McKinsey analysis published in 2019, modular construction can be 20-50 percent faster than traditional construction. So, Modular Construction speeds up the work.

- **Waste Management**

  One of the most significant advantages of modular homes is waste management. There is no need for surplus material because modular homes are produced to exact specifications in factories, resulting in considerable waste reduction. Streamlined design and efficient manufacturing limit the amount of waste. It was estimated that the on-site construction process generates solid waste up to 2.5 times more than the modular construction process.

- **Quality Production**

  When compared to traditional building, modular construction has substantially greater quality and cheaper rework costs due to tighter control of the manufacturing process in industrial settings and precise engineering.

- **Environmental Impacts**

  Because of how Reinforced Concrete is extensively used and relied upon, it has an average of 635kg embodied carbon per m^3 during its manufacturing and usage, making it one of the most environmentally destructive materials. The global warming potential for the stick-built home was calculated to be 5% higher than the modular home. Modular homes are typically more eco-friendly than traditional site-built structures. This is due to the fact that factory-built homes are more efficient than conventional residences in terms of production.

4.6. Cost Analysis

According to a research by the Building Industry Institute (CII), which has been mentioned in certain publications, modular construction projects can save up to 10% on total costs and up to 25% on on-site labor costs. Other cost-cutting measures might include reducing on-site overhead, avoiding weather extremes, standardizing design, increasing energy efficiency, and improving installation efficiency.

We did a comparative analysis on cost of the material of both modular and conventional housing strcuture.

The total initial investment of modular house is more than the traditional house but in the longer run modular house is efficient and reduces the cost. It is also because we have installed energy efficient appliances in our house.

		Modular House		
	Item	Area (ft^2)	Cost per item (Rs.)	Total Cost (Rs.)
Framework	Steel Columns			160000
	Steel Beams			160000
	Eco Paints (Internal and External)	1900		200000
	Kitchen Cabinets and shelves			20000
Appliances	Tower Fan	1	9000	9000
	LED Bulbs	15	500	7500
	Ceiling Fans	4	5000	20000
	Bedroom Cupboards			40000
	Plumbing (pipes i.e water Harvesting System)			20000
	Electrical Wiring (Sockets, Switch Boards)			30000
	Sandwich Paneled Walls	1900	350/ft^2	650000
	Kitchen and bath accessories			250000
	Hardwood Floor	864	400/ft^2	375000
	Fibre Glass Roof	576	300/fr^2	172800
	Stairwork	2		40000
	Windows	6		180000
	Wind Turbine	1	40000	40000
	Mechanical (Bolts, Hinges)		600	20000
	Total Cost			**2394300**

	Traditional House
Item	**Cost (Rs.)**
Brick, Crush, Rori and Sand	437000
Cement, Kassu and Steel	407500
Others	18000
Plumbing and Wiring	80000
Tile Flooring	210000
Bath Tiles	78750
Electrical	161000
Kitchen and Bath Accessorie	253000
Paint and Ceiling	255000
Woodwork	60000
Windows and Mirrors	165000
Total Cost	**2125250**

Figure 26: Cost Analysis

4.6.1. Transportation Cost Analysis

We did a cost analysis for transportation as well. For conventional method of construction, cost is for the material transportation and that is not one time. It needs multiple trucks and trips to completely transport the housing materials. Whereas, in modular house there is just one time transportation cost for the transport of house only to the site.

We took the transportation cost for Islamabad to Lahore that makes 342 km. We asked logistic and cargo companies how much cost it would be for this distance and the dimensions our house has. They agreed to transport our house for Rs.1, 20,000 and for the conventional material transport onetime cost is Rs. 80,000. As for material transport cost is multiple of Rs. 80,000 conventional construction cost is more costly than the modular construction cost.

CHAPTER-5

5. CONCLUSION AND RECOMMENDATIONS

Literature Previous research was analyzed and found that in Pakistan, the construction industry is one of the largest users of global resources and contributors of pollution. The construction methods adopted at present are time and energy consuming. We provided a solution to it by implementing modular construction using BIM in Pakistan that can aid to sustainability. All the drawings including 2D and 3D plans were made in Revit and Lumion.

- The project was carried out in stages i.e. literature review, development of model, and comparative analysis to see characteristics of our house as compared to the traditional houses. Thorough research was done knowing about: Construction methods in Pakistan, Sustainable construction techniques around the globe, Benefits of modular construction, Contributing factors of BIM in modular construction, Research for sustainable construction material, Modular v/s traditional construction.
- All the study and analysis performed shows that the Modular House developed is suitable for Pakistan and aids to sustainability in terms of time and energy conservation. It can be folded in the dimensions that are easily transportable. The house structure prepared is typically more eco-friendly than traditional site-built structures. The majority of recycled materials are used in the construction of our modular structure. The walls used in the house are specially made of polyisocyanurate to withstand the extreme weather conditions of Pakistan. Pakistan's highest recorded temperature is 54° while it melts at 200° that is safe. All the other material used is also highly sustainable.
- The modular structure we prepare has several benefits, including its **quality, price, speed, safety, and less time and energy consumption**. It solves most of the issues we get from conventional structures. It has just the limitation of flexibility with the plans on bigger areas with folding mechanisms.

Further recommendations include the following:

- It is suggested that work on the structural designs and plans should be done. Drawings of proper hinges and bolts connections should be made.
- Structural Analysis of the house should be done, for knowing its load-bearing specifications.
- Proper work on the strength of structure for multiple story house is needed to be done.
- Hydraulic Mechanism for Folding should be induced in housing system for the less human need.
- Work on more compacted folding can be done for easy transportation.
- Strategies should be made that can work for cost reduction and sustainability.
- A detailed cost estimation/scheduling of house should be done to get a clear idea of how modular house is cheaper.
- Working on life cycle cost is required to be done.

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