Modular Homes for Artsakh Refugees

A Major Qualifying Project
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Abstract

Housing has become an outstanding issue for refugees displaced by natural disasters and war across the globe. Refugee housing has often been created for temporary use, not taking into consideration that these individuals need proper and more permanent housing. This project presents a design framework and offers one solution for constructing semi-modular refugee housing in Armenia that integrates proper structural and mechanical systems. These systems ensure the complex is sustainable, economically feasible and more permanent to fit the needs of a range of family units.

MQP Design Statement

In this Major Qualifying project, the team designed modular homes for refugees in Armenia that included detailed structural and mechanical components along with financial analyses. The team also incorporated aspects of local design and culture to ensure the building would provide a familiar and comfortable atmosphere. The use of Autodesk Revit, AutoCAD, Sketchup, RISA 3D, Lumion and Climate Consultant aided in our analysis and overall design process.

To establish our design, the team utilized different case studies demonstrating humanitarian architecture and modular construction. We focused on five key components when creating initial models: accessibility, aesthetics and culture, green space, sunlight and wind direction, and community. Our team used a ranking system based on structural integrity and architectural knowledge to select an implementation strategy for each component. We also incorporated elements of sustainable design within these components.

For the structural system the team decided on using a modular system based on shipping containers. Building with containers enabled the creation of simple structural forms that were easily repeatable. The team gathered information about the structure and materials of shipping containers from various container manufacturers as well as official organizations like the International Organization for Standards (ISO) and the International Code Council (ICC). In conjunction with the design program RISA 3D and the review of previous shipping container analyses, the team was able to determine whether the shipping container systems would be sufficient to support the complex on their own, or if further reinforcement would be required.

The design and layout of our housing complex is based on site analysis for optimal passive systems. Natural Ventilation and Solar Strategies are implemented based on the positioning of the building to maximize passive ventilation and solar heat gain. The Revit software allowed us to break down our peak heating and cooling loads in order to optimize our energy usage.

Executive Summary

Shelter is among the most basic human needs. For as long as humans have existed, dwellings and shelters have been a cornerstone of society. However, a wide range of events could occur in which this most basic need is ripped away without notice. Whether the cause is from natural or man-made disasters, there has been a consistent need to house displaced individuals. These displaced individuals not only lose their houses; however, they lose their "homes" where they have felt comfortable and settled.

Over the past few years, the Artsakh War between Armenia and the neighboring country Azerbaijan has put many people in a dangerous predicament. The people of the Artsakh region have been scattered all across Europe, with most of them retreating to The Republic of Armenia. The need for housing refugees has increased worldwide and therefore the issue can no longer be treated with temporary solutions. Our team sought to create a more permanent solution to refugee housing in Armenia.

Our framework for design has aided in creating comfortable, desirable, and permanent housing for Artsakh refugees residing in Armenia. To accomplish this, the team focused on meeting this housing need while sustaining the sense of community and home. The complex was designed with the following elements in mind: green space, community, accessibility, and cultural aesthetics. The inner courtyard provides space for community gathering and recreation which are important components for displaced peoples. The shape of the complex is based on the white pattern of the Artsakh flag. This pattern represents the connection between the Republic of Armenia and the Artsakh region. The building is finished with a volcanic tuff exterior which is commonly found in Armenia. The complex is also arranged to take advantage of passive solar heat gain and passive ventilation. Within the complex there are two-person, single family and multigenerational units. There are a total fifteen units that can house between one and nine people. Since our complex has an underlying focus of cost effectiveness and sustainability, we utilized the shipping containers as a structurally sound, cost-effective base for our units. Shipping containers are commonly found in most parts of the world, making this design universal. Shipping containers are usually discarded after a few years of use. Most of these used containers are still suitable for use in housing and could be recycled.

In order to develop the mechanical systems within the complex, there was an emphasis on creating an efficient building envelope and conducting the building energy simulation in order to determine the peak cooling and heating loads and energy usage intensity. Provided that shipping containers serve as the basic structure of our homes, we created innovative solutions to integrate the corrugated steel within the building envelope. In order to develop a suitable building envelope, we integrated a system of wall, roof, ceiling and floor assemblies. The material properties of the layers within these assemblies determine the performance of the overall building envelope. The performance of the building's energy is mostly based on the efficiency of the building envelope and the square footage of each space.

To ensure using shipping containers as the main structural element of the complex would be a viable option, the team did research into the structural integrity of shipping containers. The necessary information was gathered for completing a structural analysis, such as possible loading scenarios, material properties of the shipping containers, and the allowable deflection limits of the steel members. The team also used RISA 3D to analyze different cases and scenarios in which the shipping containers would be stacked within the complex. Through these analyses and the provisions of the International Building Code (IBC) we proved the structure to be structurally feasible.

Sadly, there is an ever-increasing refugee crisis not only in Armenia, but across the globe. The modularity of the design and the easily connectable features of the shipping container units makes the project adaptable to accommodate any situation. The overall goal of our shipping container model is that it provides a structurally sound and affordable dwelling which ultimately creates a permanent solution for refugee housing in Armenia and around the world.

Please refer to Figure 1 on the next page for our overall design.

Figure 1: Site and Housing Complex

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Table of Contents

List of Figures

List of Tables

1. Introduction

Shelter is among the most basic of all human needs. For as long as humans have existed as settlers, dwellings and shelters have been a cornerstone of society. However, there is a wide range of events that can occur in which this most basic need can be ripped from people with little notice. Whether it be from natural disasters or man-made disasters, all around the world there has always existed a need to house displaced individuals. These displaced individuals not only lose one of the most important human needs but losing a place you call home is similar to losing a part of yourself.

Over the last 40 years, the country of Armenia has been through many hardships which has caused various housing crises. In late 1988, two earthquakes ravaged the northern region of Armenia. Due to poor construction methods and an abundance of old buildings nearly half a million buildings were destroyed leaving nearly 500,000 people homeless, more than 25,000 people killed, and another 140,000 injured (KPI, 2013). Global relief efforts after the earthquakes were swift, and although billions of dollars went to the reconstruction of the affected region, the effects of the earthquakes on homelessness are still felt in Armenia today. Additionally, a conflict between Armenia and the neighboring country of Azerbaijan began in early 1988 and continues to this day. This has left thousands of Artsakh people homeless, seeking shelter all across Armenia.

This project works to house refugees from the region of Artsakh. We wanted to provide permanent housing solutions where refugees would feel comfortable and have a sense of community. We also worked to make sure that the displaced people could be easily integrated into life in Armenia. These values of community and culture for displaced peoples, however, can be taken wherever the framework of this project is used. The modularity of the design is meant so that the project and the idea behind it, to house displaced people, can be adaptable to any situation.

2. Background

This chapter provides the necessary background information required to illustrate the need for affordable, sustainable and permanent refugee housing in Armenia. The chapter will review the historical context behind the current refugee housing dilemma in Armenia and why the permanent solutions are necessary. Next, the core principles of Humanitarian Architecture will be outlined. Lastly, the need for a sustainable and affordable design of refugee housing that will provide insight into the team's architectural design proposals.

2.1 Armenia, Azerbaijan and the Karabakh Region

The modern countries of Armenia and Azerbaijan have a long and complicated relationship dating back to their foundation in the early 1900's. Both countries are located in the Caucasus region, a mountainous area spanning Europe and Asia. The region got its name from the Caucasus Mountains, which has acted as a natural barrier between Eastern Europe and Western Asia throughout history. It is situated between the Black Sea and the Caspian Sea and is mainly occupied by the countries of Armenia, Azerbaijan, Georgia, and Southern Russia (Britanica).

In the year 1918, during the breakup of the Russian Empire, Armenia and Azerbaijan divided from the Empire to form the Republic of Armenia and the Azerbaijan Democratic Republic. During this time, a small area between the two Republics known today as the Nagorno-Karabakh or Artsakh region, was claimed by both Armenia and Azerbaijan. This caused mild tension between the two countries but did not result in war or fighting. Within two years of both countries declaring their independence, the Union of Soviet Socialist Republics (USSR) had formed in the wake of the fallen Russian Empire and with the help of Turkey, swiftly reclaimed Azerbaijan and Armenia in 1920.

When deciding on how to split the Soviet states up, a USSR council in charge of the Caucasus region gave the Karabakh (Artsakh) region to Azerbaijan, despite the region being home to around 89% Ethnic Armenians (Demoscope, n.d.). The two regions existed under the USSR as the Armenian Soviet Socialist Republic and the Azerbaijan Soviet Socialist Republic.

2.2 The Nagorno-Karabakh Conflict

During the breakdown of the USSR in 1988, Armenia and Azerbaijan began fighting over the Nagorno-Karabakh region in a conflict known today as the Nagorno-Karabakh Conflict. The heavily populated Nagorno-Karabakh region, which had been established during Soviet rule as the Nagorno-Karabakh Autonomous Oblast (NKAO), voted to unify with Armenia in February of 1988. The First Nagorno-Karabakh War began when Azerbaijan stripped the NKAO of its powers. By the end of 1992, Armenia and Azerbaijan were involved in full-scale fighting over the region that resulted in the deaths of up to 38,000 people. The war ended in a ceasefire in 1994, with Armenia remaining in control of the Nagorno-Karabakh region and some of southern Azerbaijan. The former NKAO proclaimed themselves the Republic of Artsakh, which remains to this day as an internationally unrecognized state. Up until 2020, multiple small but deadly skirmishes would occur around the Armenia-controlled region of Azerbaijan, resulting in the deaths of about 3,500 individuals (Croissant, 1998).

2.3 2020 Nagorno-Karabakh War

Tensions had been growing between the two countries leading up to 2020, and on September 27th, full-scale fighting broke out once again. Armenia and Azerbaijan fought for the Nagorno-Karabakh region for six weeks resulting in the deaths of at least 5,970 people. On November 10th, a Russian-mediated ceasefire was signed resulting in the withdrawal of all Armenian forces from the Armenian-controlled regions of Azerbaijan that were gained in the 1988 War. Azerbaijan was also given parts of the Nagorno-Karabakh region. The Republic of Artsakh is now patrolled by a Russian peacekeeping force and is still governed by the Republic (Crisis, 2021).

The aftermath of the 2020 war left the large percentage of ethnic Armenians who were living in the Artsakh region to be dispersed across Armenia.

Figure 2.1: 2020 Map of the Nagorno-Karabakh region and the surrounding areas post war (Golden, 2021)

2.4 The Current Situation

Following the breakout of the most recent Nagorno-Karabakh conflict, many people from the region of Artsakh had to flee their homes and leave the Artsakh region entirely. Many of these refugees fled to the Republic of Armenia; “As of October 2020, Armenia hosted around 109,000 refugees and asylum-seekers. The vast majority, approximately 90,000 people, arrived between September and October that year as a result of the newly escalating conflict in the Nagorno-Karabakh region” (UNHCR-Armenia, n.d.). These refugees are concentrated in Yerevan and the region of Kotayk. As of May 2021, it was recorded that there are more than 36,989 people finding refuge in Armenia (Operational Data Portal, 2021).

Displaced, suffering emotionally, and have been lacking essential human needs such as adequate shelter and food, most of these refugees are women and children, as the men had to either fight in the recent war or help with renovation or construction in Artsakh. (Arkun, 2020) Many families have been grieving and experiencing trauma from the events that took place in Artsakh during the war. They have also lost their jobs and their homes (Saryan, 2021).

Charitable organizations and groups of people have provided aid to these refugees. Some churches, such as The Abovyan City Evangelical Church in Armenia, have aided refugees by giving them temporary places to stay. They have hosted refugees within the church itself, or provided them with hotels, restaurants, or private homes to stay in. Vazgen Zohrabyan, a pastor for this church estimated that there are more than 20,000 Artsakh Refugees still residing in Armenia (Arkun, 2021).

2.5 Armenian Crisis Needing Housing

The 2020 Artsakh War took place over 44 days, and it injured and displaced 110,000 people. This massive influx of refugees created housing insecurity in Armenia as people flooded into the country. The Armenian Human Rights Ombudsman affirmed last December that the most important task at hand is to "coordinate the process so that the homeless now in Armenia receive assistance in Armenia" (Muradyan, T., & Baghdasaryan, S., 2020). This conflict is relatively new, only spanning over the last year, but other crises in Armenia have created much longer periods of homelessness.

Armenia hosts not only refugees from the Artsakh war, but also from different social and environmental conflicts. Both Syrian refugees and Gyumri earthquake survivors are also facing instability and lack of housing in Armenia. More than 20,000 refugees from Syria have fled to Armenia in the last ten years seeking political stability. Syrian refugees have felt somewhat at home in Armenia due to their similar culture. However, despite these benefits, refugees still face income and housing challenges. Currently most Syrian refugees are renting houses which is "a short-term solution to the situation" and one "without any feasibility of lasting long". (Syrian-Armenians in Armenia: Problems and Prospects, n.d.). Rental properties however can still be unattainable to some refugees due to financial reasons.

An environmental cause for a housing crisis in Armenia has been The Spitak Earthquake. The Spitak Earthquake happened in Gyumri, Armenia in 1988, and the repercussions of this event are still felt to this day. The earthquake affected 40% of the country's land and approximately one million people. The Spitak earthquake also collapsed or damaged up to 8.9 million square meters of Armenia's housing. This created a housing crisis still unresolved to this day. Before its collapse in 1991, the Soviet Union built 5,628 apartments directly after the earthquake. In 2009, the Armenian government built 2,000 apartments while promising to build more. This promise however was not fulfilled, and there are still many homeless people in the Gyumri area even thirty years after the Earthquake. (Hayrapetyan, A., & Abrahamyan, G., 2013)

2.6 Humanitarian Architecture

Humanitarian Architecture is a form of aid for social and environmental disasters. It is the movement that provides those who have been impacted by a crisis – humanitarian or environmental– with shelter and improved physical conditions. There are three guiding principles that govern Humanitarian Architecture: the prohibition to inflict unnecessary suffering, the principle of necessity, and the principle of proportionality (S. Farzin, personal communication, Fall 2021). The prohibition to inflict unnecessary suffering is the pillar of Humanitarian Architecture. One cannot experiment with already vulnerable communities. Consequently, the question for humanitarian architects is only "How can we help?". The principle of necessity focuses on what the vulnerable communities need. Shelter is a basic necessity, and when it is not being met people cannot achieve anything else, as shown in Maslow's Hierarchy of needs. The principle of proportionality promotes projects that can be scaled to meet the needs of the people. Architect Nataniel Corum explained this principle by focusing on quality over quantity, as quality can be replicated on larger scales and with adaptability (Charlesworth, 2014).

Humanitarian Architecture is a type of aid that is for the people and thus must be in part done by the people; Humanitarian Architecture can only be truly achieved if local experts are part of the design team (Charlesworth, 2014). To create a sustainable impact, there must be long-term programs incorporated into the architectural design and the established community. This creates greater longevity of the project and makes the community more stable and sustainable (Aquilino, 2011). The project must go beyond simply erecting structures. Humanitarian Architecture is not just about providing housing; it is about creating communities and transforming lives. This can only be achieved if local people are involved in the project, and there becomes a sustainable element to the work, whether it be through a work program or maintenance of the structures.

There is great importance in the built environment. Those who are displaced have “socio-cultural needs, social-infrastructure needs, economic needs, physical infrastructure needs, governance needs and communities with special needs” (*A Built Environment Perspective on Post-Disaster and Conflict-Induced Displacement*, 2022). The built environment can be a key tool to address these needs and rebuild the community while focusing on livelihood, the economy and socio-cultural aspects. The buildings can also create cohesion between the refugees and members of their host countries (Amaratunga et al, 2020).

3. Framework for Design

3.1 Process of Design

In order to effectively provide and design a housing system, we came up with a well-thought-out design process. Our overarching goal is to provide permanent yet adaptive architecture for any type of housing crisis or refugee situation. Although we have designed this project specifically for Armenia, our hope is for this design to be adapted for other similar situations globally. We chose to take the route of modular housing design. Modular housing is a simple and efficient approach in which housing units or specific assemblies are prefabricated before construction, and then assembled into larger units on site. It also may be more cost effective in some circumstances. We chose to reuse shipping containers for the structural basis and skeleton of our units. Reusing shipping containers has been proven to be more cost efficient and sustainable than the traditional construction methods, such as timber frames or masonry blocks. Shipping containers are also available in many parts of the world. Due to their rectangular shape, they are perfect for modular design as they can be assembled together in many different ways.

Before designing the housing complex, we looked into selecting a site. We found a lot that is currently for sale in Yerevan, the capital of Armenia. Our site was chosen due to its prime location in the residential neighborhood of Nor Arabkir with many local resources, as seen in Figure 3.1. The site borders a hotel on its south side, with residential units surrounding the site. There is also a park down the street called Victory Park. Our proposed site sits close to other commercial establishments, with a grocery store one-half mile away, a hospital one-half mile West, and an elementary school. The heart of Yerevan is just one mile away and can be accessed by the various public transportation options surrounding the site, including a bus stop located on a street corner to the South.

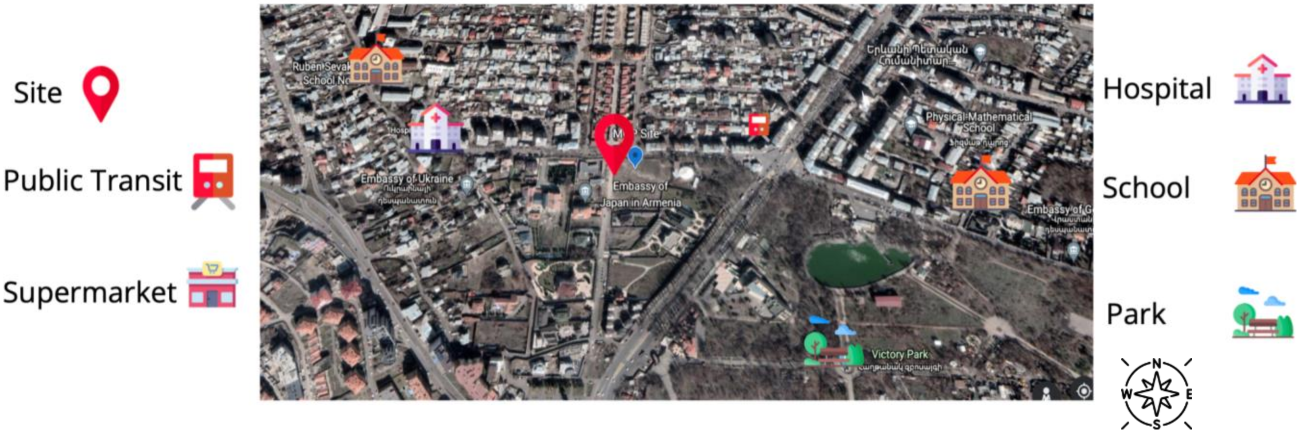


Figure 3.1: Site Map with Key Surrounding Features (Google Maps, 2021)

The site itself rests on a sloped area, seen in Figure 3.2. In this image, the contour lines get closer together as one moves northeast of the site, giving the terrain its slightly sloped feature. The lot is currently unoccupied but is walled in on both the north and west sides. The site also has road access on the east and west corners of the plot.

Figure 3.2: Contour Lines on Site Location

To obtain our climate information we used the Climate Consultant 6.0 software and an Energy Plus Weather (EPW) file for the Yerevan International Airport, located approximately 16 km or 10 miles from our site. We also utilized the setting of California Energy Code Comfort Model, 2013 as it is both the default, and it is the most intensive energy model.

Armenia, and Yerevan itself, is considered in the Mediterranean region of the world, sitting at approximately 46 degrees latitude and 20 degrees longitude. The average temperature drops to 37 degrees Fahrenheit in the winter and rises to 74 degrees Fahrenheit in the summer. There is little snow or rainfall in the location.

The temperature comfort zone is designated between 68 degrees Fahrenheit and 75 degrees Fahrenheit. In Yerevan, only June and September fit into this category. July and August have warmer average temperatures whereas the other months usually fall well below this comfort zone. The average monthly temperatures year-round are 25 degrees Fahrenheit to 65 degrees

Fahrenheit. The yearly average temperature is 55 degrees Fahrenheit. The sky is covered less than 50% year-round.

3.2 Concept

We then delved into the conceptual design for our proposed housing complex. As a team we designed the layout according to our concept which comes from the white pattern in the Artsakh flag, see Figure 3.3 below. This white pattern represents the connection between the Artsakh region and The Republic of Armenia. We thought this would give a deeper meaning to our apartment complex as it relates directly to the users and their current situation.

Figure 3.3: The Artsakh Flag from Pixelz (*Artsakh Flag*, n.d.)

3.3 Case Studies

We looked into various case studies that are relevant to the project in order to further develop our program and layout. The following case studies are examples of projects that have incorporated aspects of Humanitarian Architecture, modular permanent housing, and innovative sustainable solutions. Our team benefited from the project information and design process provided within these case studies.

The Habitat 67 apartment complex, as shown in Figures 3.4 and 3.5, is located in Cité-du-Havre, Montreal, Canada. It was designed by Moshe Safdie, and it consists of prefabricated housing units that are cantilevered in a non-uniform fashion and connected by steel cables. The housing units consist of one to four different modular configurations in order to create varied units in shape and size. This space was intended for "high-quality housing in dense urban environments" and consisted of "modular units to reduce housing costs and allow for a new housing typology." (*AD Classics*, 2013) We took examples from these innovative housing units and incorporated a very similar theme into our project.

Figure 3.4: Habitat 67 (*Hursely ,2022*)

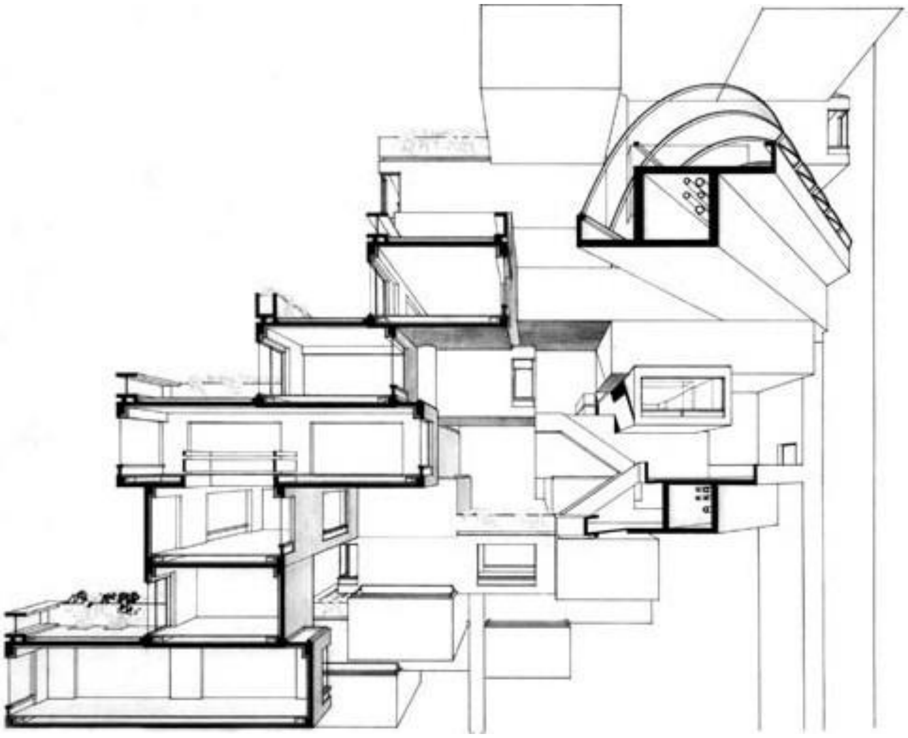


Figure 3.5: Shows a Cross-Section of Habitat 67 (*WikiArquitectura, 2020*)

Since our project aims to be sustainable and cost effective, we also investigated modular housing constructed from shipping containers. Keetwonen is a block of shipping container dormitories in Amsterdam, see Figure 3.6. This project provides thousands of affordable, modular dorm spaces for students. The shipping containers themselves each host two students in either a larger single room or a larger double room, plus one bathroom for each scenario (Forrest, 2015). The complex comprises six units, the total taking only nine months to erect. The project was originally a case study but became so popular with students that Amsterdam approved the dorms as permanent structures in the city (“A Thousand Strong,” 2014).

Figure 3.6: The blocks of shipping container units that make up Keetwonen ("A Thousand Strong," 2014)

Keetwonen was launched by the construction company Tempohousing. Tempohousing has built other shipping container complexes in Amsterdam. De Gooijer, the company's founder, showed frustration with the public's attitude toward shipping container construction being only for temporary use. He rebuffed their comments saying that shipping containers prove to be a "cost-effective solution" for housing large amounts of people (Forrest, 2015).

Habitat 67 and Keetwonen laid the groundwork for our project. They both showed how the modular design could be implemented to comfortably house many people. Habitat 67 utilized unique unit placement to create exciting and desirable architecture, while Keetwonoen used the modular design to implement effective use of space and create lower cost mass housing solutions.

3.4 Modularity

The units are modular in all aspects of their design. The building block of these homes are the rectangular units of the shipping containers, all with standardized sizes. These are arranged in different configurations to create the two different two-person units, single-family units, and the multigenerational-family units. The arrangement of the shipping containers to form the units can be seen in Appendix A. The units themselves can be arranged to form the overall design of the complex. With our specific instance, we took the containers to arrange them in a loose shape of the Artsakh flag. This design however can be easily transformed with different configurations of the homes depending on the culture and landscape of the site.

3.5 Cultural Design

As we decided upon a more detailed layout, we incorporated the cultural aesthetics of Armenian architecture within our design. In this housing complex the team aimed to create a familiar atmosphere for these refugees, which included architectural aesthetics that are commonly found in Armenia. Not only does the concept add to this goal; however, the interior and exterior details include commonly used materials and forms found in Armenia. For example, some of the units include arched, cased openings that widely adorn facades and doorways in this region as seen in Figure 3.7 below.

Figure 3.7: An example of traditional Armenian arches (Koretskiy, 2020)

The use of volcanic tuff is also prevalent in Armenia; therefore, the walkways and exterior facade are composed of a finish made of volcanic tuff. Since we are adapting shipping containers into these units, we incorporated the excess corrugated metal into a roofing system.

Armenia’s homes usually have asbestos roofing which has proven to have many negative health impacts. Therefore, the corrugated metal will act as a durable, yet aesthetic and culturally conscious replacement for asbestos roofing.

3.6 Community Space

The arrangement of the units to make our complex was based on the step-like pattern in the Artsakh flag. This configuration allowed us to create a large inner courtyard which is landscaped with native trees, greenery, benches, gazebos and tables. In this space there is the opportunity to gather and be outside. While this area will get a lot of sun, we have included trees to create shades along with gazebos to provide cooler places if residents so choose. One can also recreate outside with our extensive walking paths that stretch through the inner courtyard and around the complex.

We wanted to have a balance between private and public spaces while maintaining a sense of community. The communal aspect of living is something that refugees seek. Each unit has its own private green space. These green spaces will allow occupants to have some private outdoor time along with the potential to raise a garden. This is both a leisure space but could be used for supplemental and/or cultural additional food sources.

3.7 Massing Housing Units

After deciding upon the aspects we wanted in our design, we each created variations of the basic layout utilizing the Sketchup software. We limited our design to between two and three floors because our initial research showed that earthquakes have previously devastated housing in Armenia. We each created a two or three-story housing complex, working with modular units that had varied orientation and placement. In one case we even considered stacking the units in a pyramid-like shape with a passageway underneath. The other two variations were quite similar and followed the white pattern on the Artsakh flag quite closely as seen at the top of Figure 3.8.

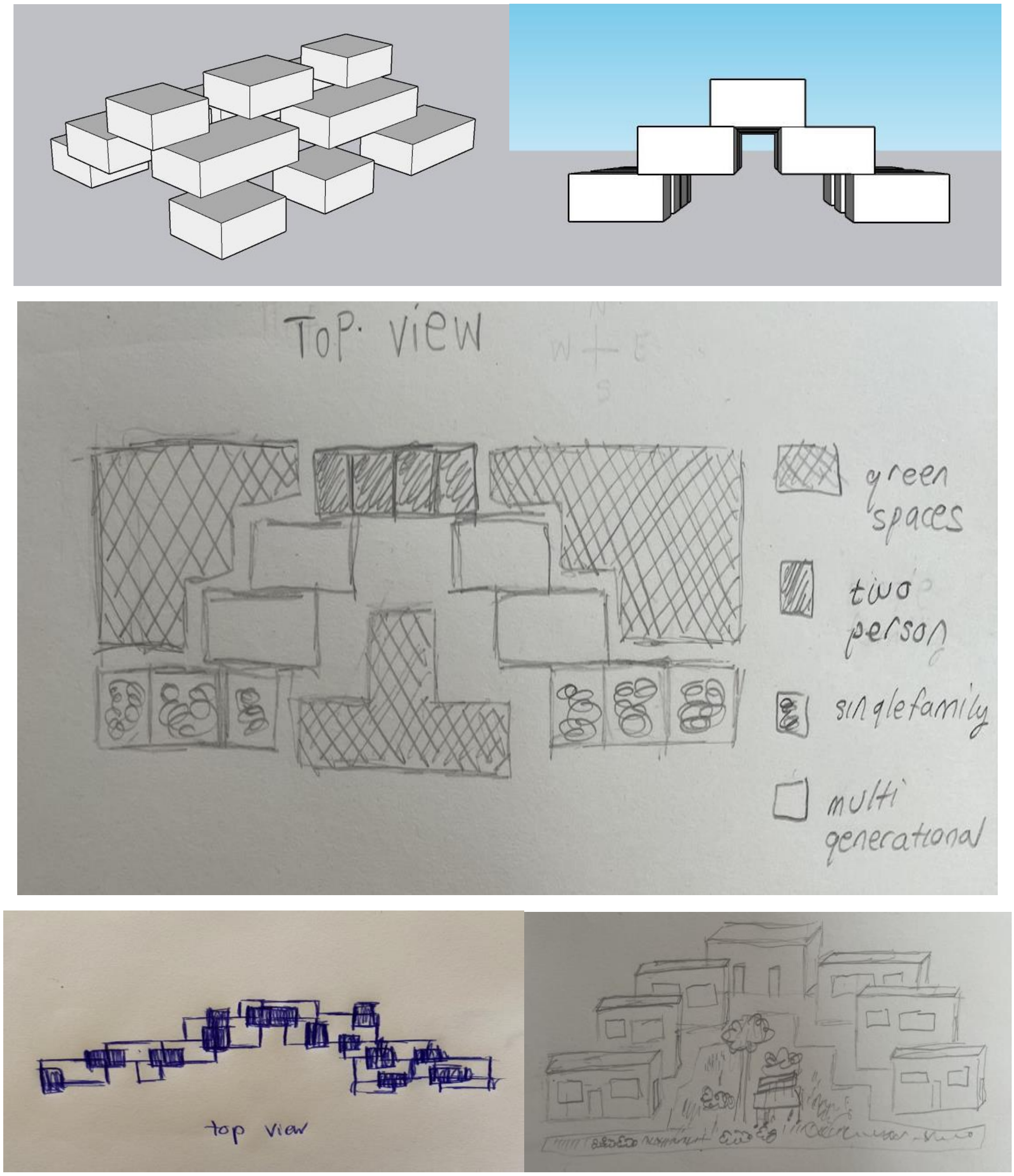


Figure 3.8: The top two images show the first iteration of the design, and the bottom three images show early drawn designs

After deciding to set up the layout according to the above figure, we created more variations with greater detail and a defined program flow, see Figure 3.9. In most cases green roofs and green spaces were included on the upper levels and throughout the complex. This is important as it aids in creating a community and has environmental benefits. The team also incorporated the surrounding architectural aesthetics of Armenia in our different variations, using the arches and local volcanic tuff mentioned in Section 3.5 Cultural Design. We then conducted voting on the aesthetic choices we liked and created our individual third iteration of the complex as seen in Figure 3.10. This allowed us to combine our ideas into the final program for the unit as discussed in the next section, 3.8 Program for Housing Units.

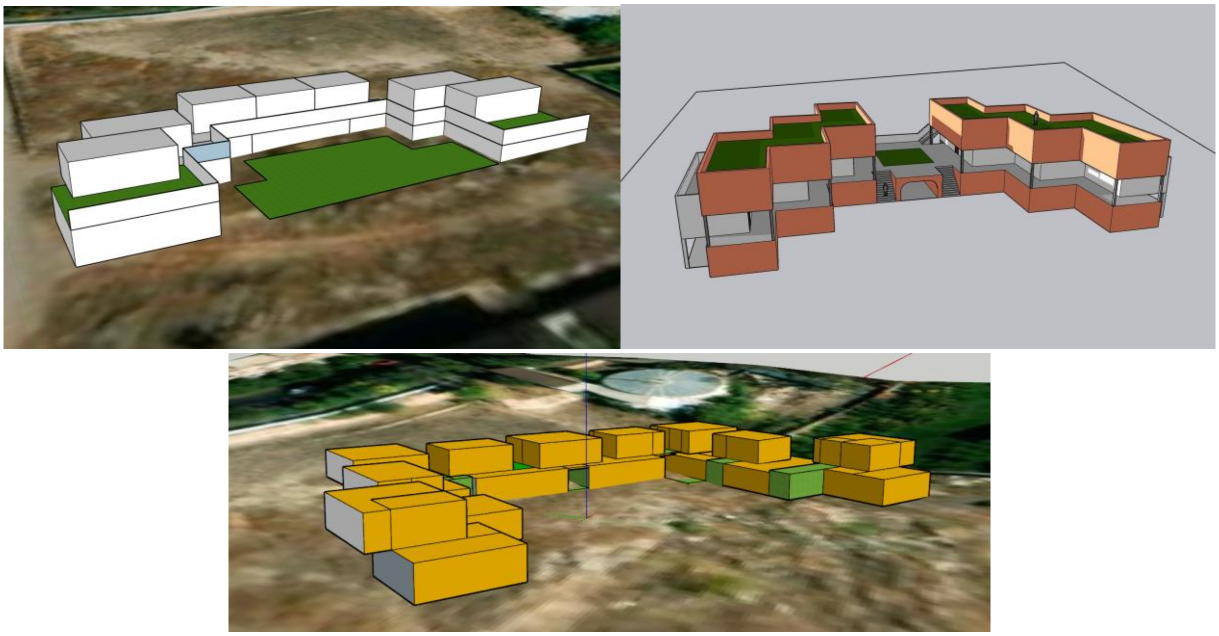


Figure 3.9: The three 2nd iteration designs for the complex

Figure 3.10: 3rd Iteration of Design Process

3.8 Program for Housing Units

Our building is a complex of shipping container units with varying layouts to accommodate different family sizes. The units are all based around the idea that shipping containers can be used as “LEGO blocks” that can be aligned together to create different spaces. Their different configurations can service different family groups. There are two levels to the complex; the first level has eight homes, while the second level has seven homes. Of the total fifteen homes, there are five two-person units, six single-family units, and four multi-generational units. Each unit consists of two to four shipping containers and has a bathroom, kitchen, common area, and bedrooms.

The building went through multiple iterations as seen in Section 3.7 Massing for Housing Units, while we worked to configure the best layout to balance privacy, community space, aesthetics, and accessibility, see Figure 3.11 below. We landed on having the four multi-generational units on the first floor; this will make it easier for older residents to access their units and not have to use stairs. The multi-generational units are shown in tan below and are dispersed on the first floor between four single-family units, shown in red. The five two-person units, seen in blue, are on the top floor, along with the other two single-family units.

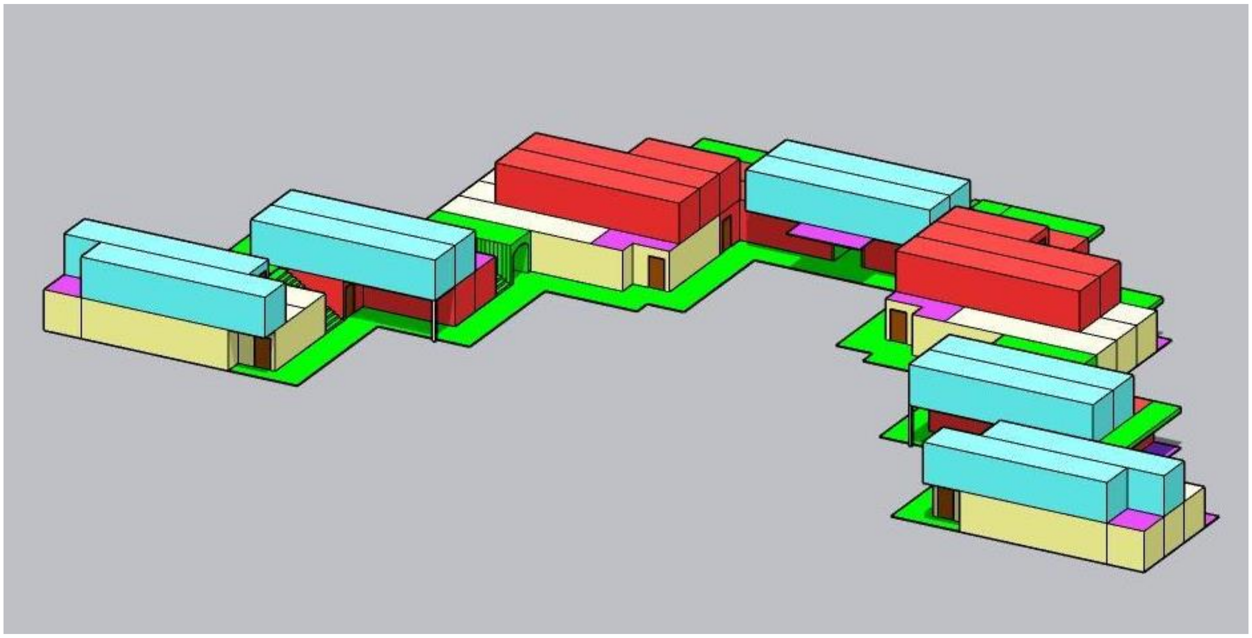


Figure 3.11: Program for the Complex

The program for the two-person unit can be seen below in Figure 3.12. This space features two bedrooms with a shared bathroom, kitchen, and common areas. The two-person unit was envisioned as a space for potentially two friends, two couples, or older siblings to perhaps share a space that while maintaining privacy, could also offer a community space as laid out in the center of the unit.

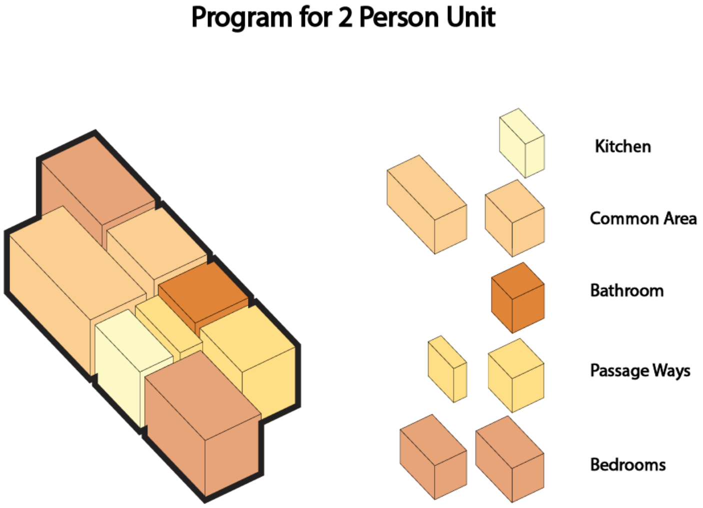


Figure 3.12: Program for Two-Person Unit

There are two layouts for the two-person units, however each features the same spaces with slightly different layouts. One of the units is two 20’ by 8’ units lined up to create a 40’ by 16’ space, see the floor plan below in Figure 3.13. This unit contains an open living/dining room and kitchen. From this open area, there's a single bathroom and two bedrooms that each feature a closet, queen bed, and window. There is also a general storage closet in the living room.

The other unit has its bedrooms on opposite ends for privacy. There is a private seating area with two windows and two couches, plus a dining room space with a table that seats up to eight. The unit also features a shared kitchen space. The floor plan of the unit can be seen in Figure 3.14. This layout shows the flow of the unit from the entrance into the hallway spilling out into the dining and living rooms, with the bathroom and bedrooms branching off.

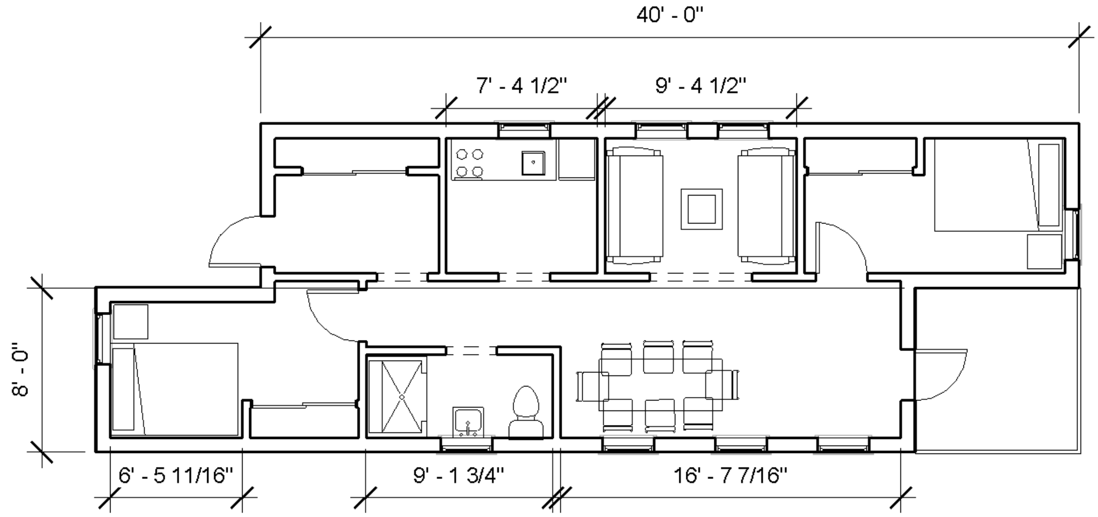


Figure 3.13: Floor Plan 1 for Two-Person Unit

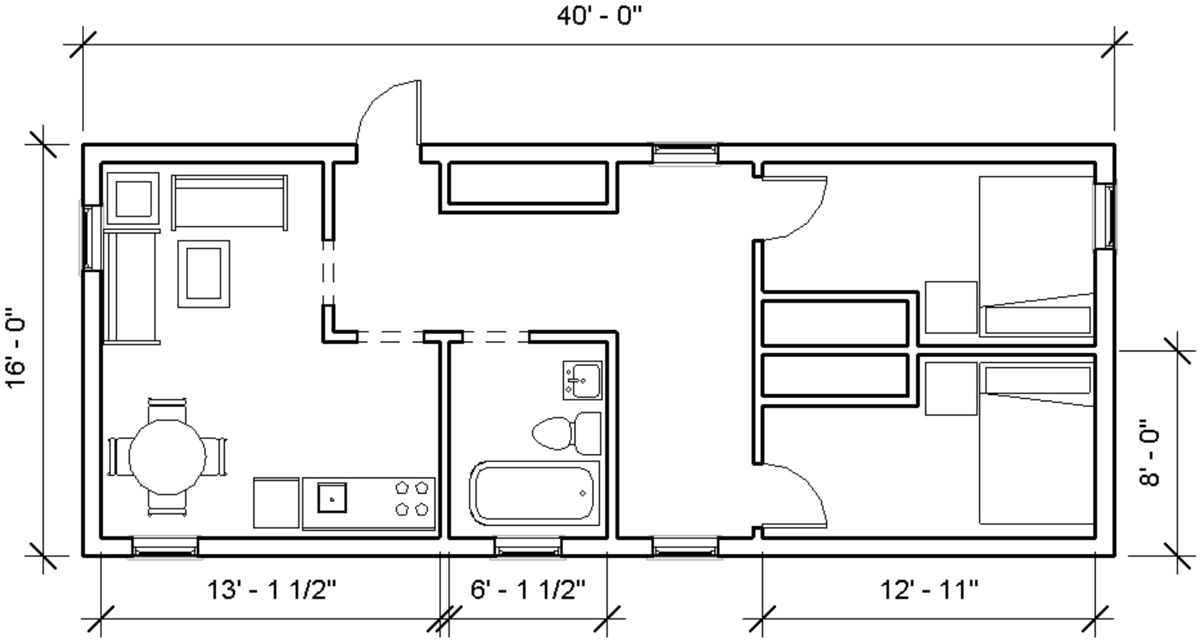


Figure 3.14: Floor Plan 2 for Two-Person Unit

The single-family unit was designed for one family, see Figure 3.15 for the full program of the unit. There is a space for a parental unit and two kids' bedrooms with the potential for accommodating three plus children. It is constructed out of two 40' by 8' shipping containers in combination with a 30' by 8' container. The unit has three bedrooms; one that we envision as a room for caretaker(s) and/or parents with a queen size bed and the other two rooms being for children with a bunk bed per room. The arrangement and type of beds however could be swapped around depending on the family configuration. There is also a combined living room, dining room, kitchen area along with a shared bathroom. The single-family Unit floor plan is illustrated in Figure 3.16.

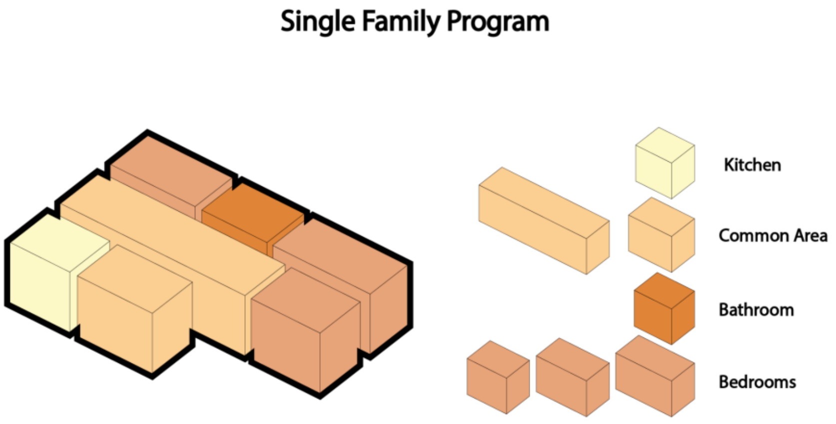


Figure 3.15: Program for Single-Family Unit

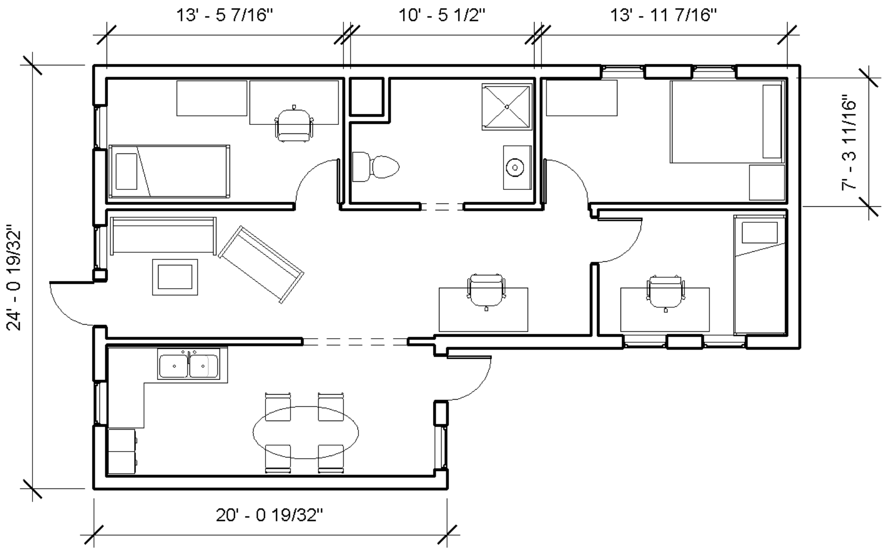


Figure 3.16: Floor Plan for Single-Family Unit

The multi-generational unit was designed to accommodate a wide range of family types and styles. The multi-generational unit is shown in Figure 3.17, while the detailed floor plan is shown in Figure 3.18. The space opens into a large mixed-use room with a dining area, kitchen and living room. There are three bedrooms and a bathroom opening off of the living room. This allows for a central, shared space with private areas one can retire to. There is a centralized kitchen, dining room and living room area. The three bedrooms and bathroom all branch off of this main living space.

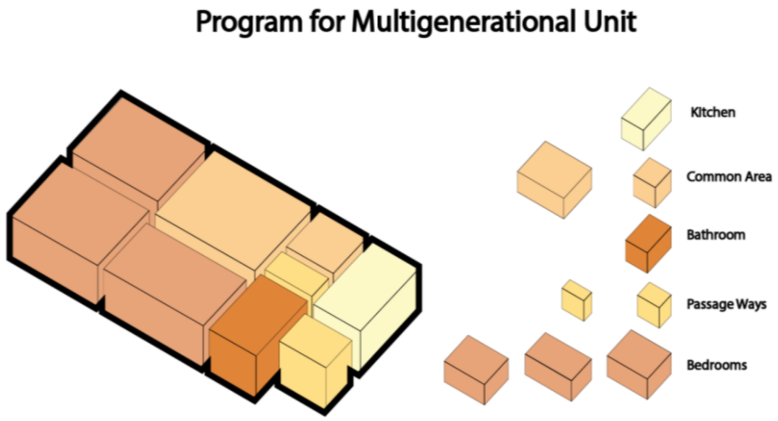


Figure 3.17: Program for Multigenerational Unit

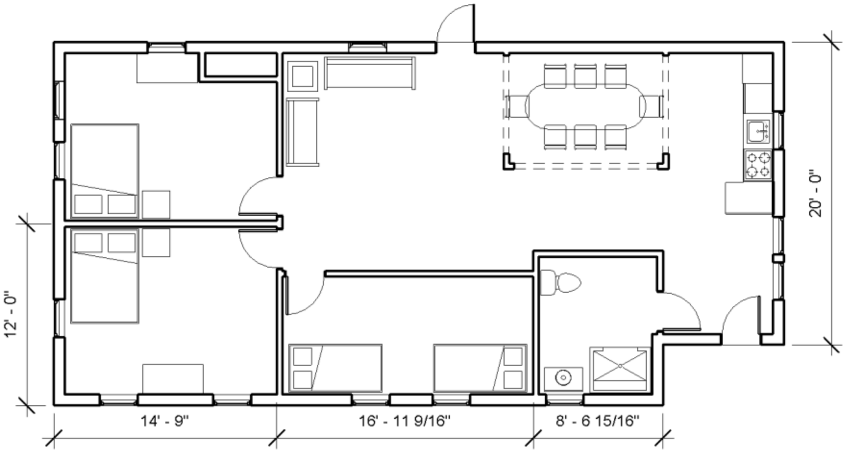


Figure 3.18: Floor Plan for Multi-generational Family Unit

Originally the units were based around the rigid structure of the shipping containers, 20’, 30’, 40’ by 8’, which is not wheelchair friendly when the wall details and furniture are placed into the space. However, from further research, we found that the structural support for the containers came from the steel posts at the four corners, and removing large sections of the shipping containers' corrugated steel walls would not affect the structural stability of the containers. We took this knowledge and opened up the units, which combined shared spaces into larger rooms with an open layout. This creates not only a nicer aesthetic look, but also more room for potential wheelchair/walking aide users to navigate these homes. Each of the bathrooms are ADA compliant with a wheelchair turn radius of 2’6” or a 5’ circle turn diameter, see Appendix C for the bathroom details.

3.9 Materials

We created our project under the framework of sustainability and low cost. When choosing our materials, we analyzed each product through these lenses. Our team split up the unit into its major components: walls, roof, and floor. For each of these categories, we researched materials to frame the pre-existing shipping container structure. The chart you see below is the analysis for each material with columns for R-Value and Cost. We wanted the material to have a balance between energy efficiency, i.e., the greatest R-Value, and lowest cost.

Table 3.1: Material Type Selection Table

Material	Purpose	Structure	Cost (per ft)	R-Value	Thickness
Wood 2x6	Studs	Wall	~$10.82 per 8ft	-	6"
Cellulose	Insulation	Wall	83 cents	3.0-3.7	6"
Sheep's Wool	Insulation	Wall	$1 per sqft	3.5 to 3.8 per inch	6"
Fiberglass	Insulation	Wall	$0.40-$1 per foot	3.1 to 3.4 per inch	6"
Drywall	Drywall	Wall	~$15 per 32 sqft	1 per inch	1/2"
Polyethylene Film	Vapor Barrier	Wall	$0.37 per sqft	-	6/1000"
Steel Studs	Studs	Wall	~$8.86 per 8ft	-	3-5/8"
Spray foam	Insulation	Wall	$1.00 per foot	3.7	1"
Cellulose	Insulation	Wall	$1.23-$2.11	3.0-3.7	6"
Fiberglass	Insulation	Ceiling	$0.40-$1 per foot	3.1 to 3.4 per inch	2"
Sheep's Wool	Insulation	Ceiling	$1 per sqft	3.5 to 3.8 per inch	6"
Epoxy	Waterproofing	Floor	$1-$2 per Foot	-	-
Foam Board	Insulation	Floor	$14-25 per 32 sqft	3.5 to 8 per inch	2"
Vinyl Wood Flooring	Top Layer	Floor	$2 per foot	-	2mm - 8mm
Fiberglass	Insulation	Floor	$0.40-$1 per foot	3.1	1"
Plywood	Base Flooring	Floor	~$29.50 per 32 sqft	0.155	3/8" - 3/4"

Based on the above table, we choose the types of materials for our walls, ceiling and floors. The walls already had a form based on the shipping container's rigid steel structure. However, we needed to frame the walls and provide insulation. We choose to utilize wood studs with batting insulation. We are also including waterproofing in the walls as directed in IBC section 1805.3.2. The ceilings were made out of wood framing with studs covered in a layer of gypsum board. This provides plenum space in the ceilings for wiring, potential HVAC systems etc. The floors of shipping containers already contain a plywood base. We applied a layer of sheet insulation and covered it with an epoxy as a sealant and finish. The epoxy also works as a waterproofing material as the IBC states in section 1805.3.1 that the floors should be waterproofed.

3.10 Final Design and Site Plan

The site layout, see Figure 3.19, was chosen with the purpose to create a comfortable layout with community components for the Artsakh people. We incorporated communal areas with green space so that people could gather together. The focus of our project and site plan layout specifically was to use the principles of Humanitarian Architecture and create a conscientious built environment. Final renderings of the complex can be seen in Figure 3.20 and 3.21 as well as Appendix E.

The orientation of our building on our site was done to take full advantage of passive solar and wind, as discussed in depth in Section 5.1, Section 5.2, and Section 5.3. The courtyard is laced with paths leading from every unit. The paths arch around the outside of the complex as well to connect with the parking lots. They also give a chance for residents to recreate within the comforts of their own home. The paths are constructed of smooth turf materials so residents with mobility aids can safely traverse them.

The interior courtyard consists of two gazebos with space for picnic tables and barbecues for recreation. We also envision chess tables under the gazebos as chess is a national pastime of Armenia and is compulsory to be taught in schools (Akhmeteli, 2012). This type of community space was implemented as we envision the central courtyard to be a place for gathering and blending of Artsakh and Armenian cultures.

The courtyard also is space for gardening with space to put garden beds. The trees located in the courtyard were used for aesthetic purposes along with serving to shade and cool the space during the summer months. The trees in the lot are native: Caucasian Maple, Rock Cherry, Orak and Oriental Beach. The road connects from the street and runs in a clockwise pattern. There is a parking lot on the north side of the lot and one on the south side, with each of these lots holding up to eight cars.

Figure 3.19: The Complex on the site, aerial view

Figure 3.20: Render of the Inner Courtyard

Figure 3.21: Render of Southeast side of complex

4. Structural Analysis of Shipping Containers as a Main Structural Component

4.1 Shipping Containers

Since their inception in the 1950s, shipping containers have standardized shipping on a global scale. In recent years, with the increase in demand for tiny living and sustainability in building materials, shipping containers have also seen new use within the construction sector. Shipping containers are made of steel, which is a common material for building structures, and many containers are left in shipping yards after they are replaced with new containers. These leftover containers can provide a sustainable option for modular construction and can be used as a building block due to their structural strength. When determining whether shipping containers would work for this project, a structural analysis of the containers and various stacking scenarios was completed. The team investigated how shipping containers work structurally and how best to analyze a shipping container structure using RISA 3D, a structural design software.

4.2 Parts of a Shipping Container

To properly test the structural integrity of a shipping container as it relates to this project, the team needed to research the mechanics of a shipping container. The container is made up of two main parts, the frame and the shell.

The frame of the container provides almost all of the load-carrying capacity, transferring loads through the top rails of the frame into the corner posts and finally down to the ground or footings. As seen in Figure 4.1, the frame consists of two smaller end frames of steel made up of corner posts and end rails to form a square 8’ x 8’-6’ support frame. These frames are connected to the flooring, which is built from two bottom side rails connected by cross members with plywood flooring on top. Lastly, two top side rails connect the two end frames to form the complete shipping container frame.

The shell of the container is straightforward. Large panels of corrugated steel are welded to the main frame of the containers. The paneling helps prevent the cargo inside from being tampered with or ruined during the shipping process. This corrugated steel doesn’t provide much for structural support but contributes to the structural integrity of the container by carrying a small amount of weight and retaining the shape of the container. All parts of the container are made of CORTEN-A weathering steel. CORTEN-A steel is a special kind of exterior-use steel alloy that has a greater corrosion resistance over traditional steel due to its development of a protective oxide film on the metal's surface which slows down future corrosion. (*What Is Corten Steel?*, n.d.)

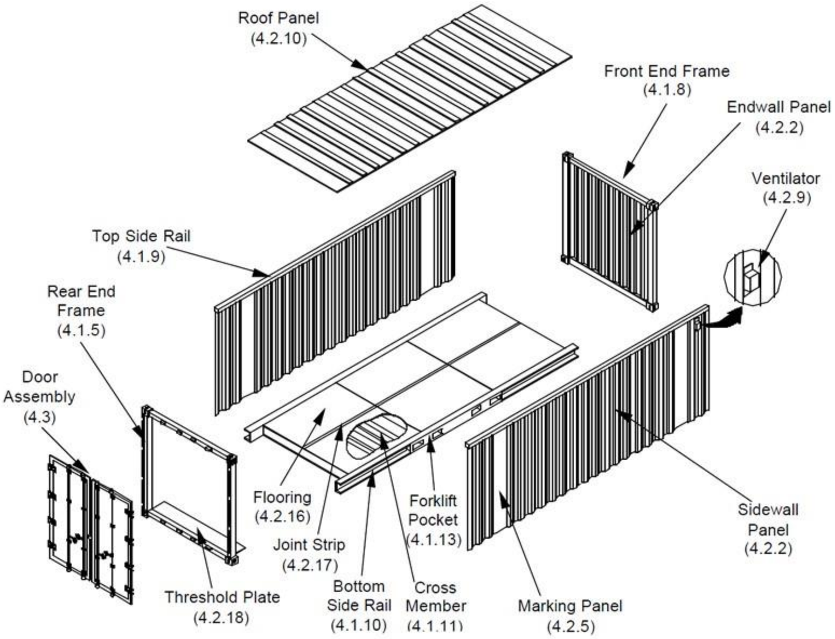


Figure 4.1: An exploded view of a standard shipping container showing the various individual parts (*Anatomy of a shipping container*, 2021)

4.3 ISO Standards for Shipping Containers

The first step in determining the structural integrity of shipping containers starts with the International Organization for Standards (ISO). To determine whether shipping containers are structurally suitable for use in shipping, new containers must first pass a series of thirteen tests defined by the ISO in ISO 1496-1:2013. In this publication, the ISO outlines various load tests, seen in the figure below, applied to the corners and posts of the container. The tests ensure that containers can be stacked and shipped while safely protecting the cargo inside.

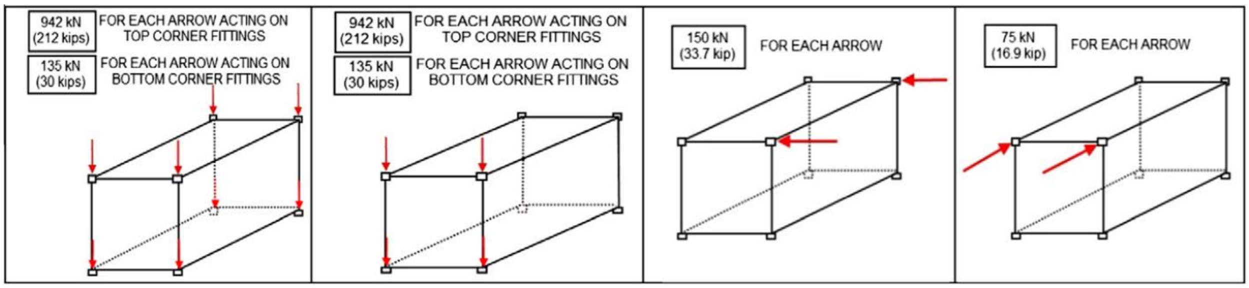


Figure 4.2: Simplified Graphic of ISO 1496-1 Test Loads (Giriunas et al. 2012)

There are many different types of shipping containers addressed in ISO-1496-1:2013. For this project, only two types of shipping containers were used. The most common container type in the complex is a 40’ x 8’ x 8’-6” general purpose steel dry cargo container, classified by ISO as a 1AA container. The second container is a 20’ x 8’ x 8’-6” general purpose steel dry cargo container, classified by ISO as a 1CC container. (ISO 668:2020).

When loaded on ships or stored in shipping yards, containers can potentially be stacked up to nine containers high (Figure 4.3). Because of this, the ISO needs to make considerations so that every container can be used at the bottom of the stack and thus support the most drastic loading. In addition, the containers on ships are subject to a large amount of movement both vertically and laterally. The load cases in Figure 4.2 above reflect this and are far greater than any load cases that would generally be applied to the containers in the context of a building structure.

Figure 4.3: Shipping containers stacked up to nine high on board a shipping vessel (Taylor, 2020)

4.4 Containers in the International Building Code

While the ISO states the maximum loading for shipping containers, these provisions only consider containers that are unmodified and ensure that each container will serve its intended function. However, when used in a building or other architectural settings, shipping containers need to be modified to create entrances, windows, and general openings within the space. Fortunately, with the increased use of containers in building construction, the *International Building Code* (IBC) has defined requirements for using shipping containers in building construction.

Chapter 31, section 3114 of the *2021 International Building Code* outlines the design procedures and limitations of shipping containers in buildings. Some of these requirements include: ensuring that the container has proper data plates to confirm legitimacy, complying with proper welding procedures to maintain structural integrity, and, most importantly, defining the allowable shear within the walls of the container. According to Table 3114.8.5.3 in the IBC, there are 84 Pounds per linear foot (PLF) of allowable shear in the sidewalls of the 40-ft 1AA containers and 168 PLF of allowable shear in the sidewalls of the 20-ft 1CC containers. Both containers have the same allowable shear of 843 PLF in the end wall. In addition to the allowable shear, the IBC also defines how many edits can be made to structural side panels before it is no longer compliant with the IBC.

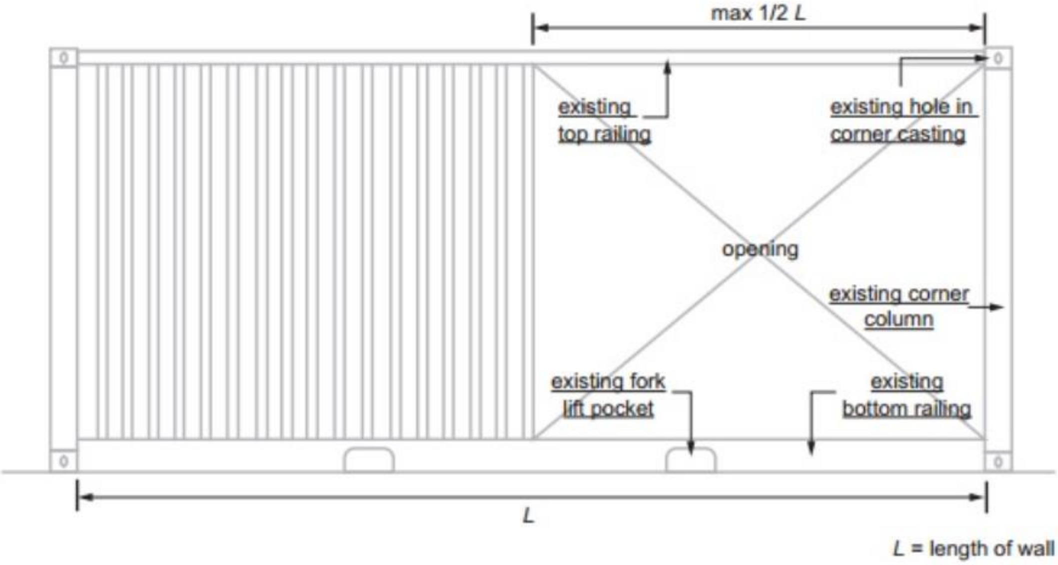
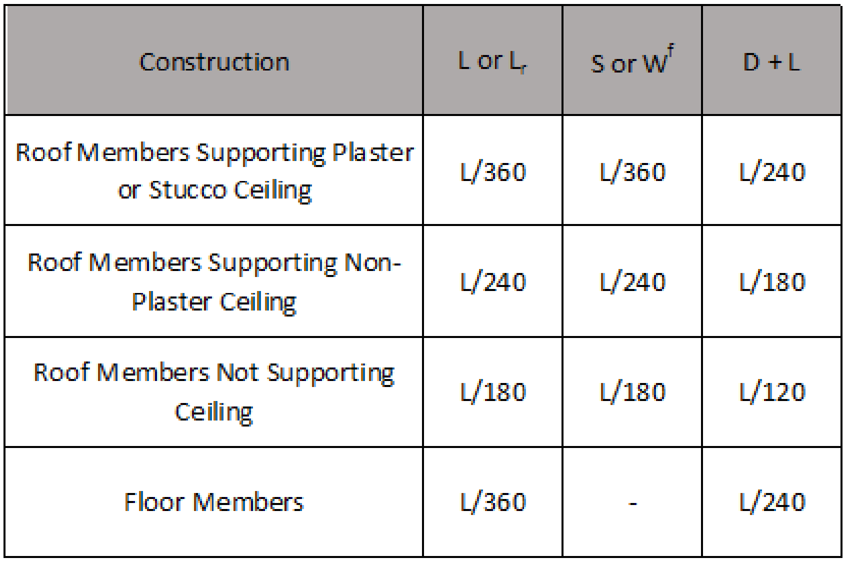


Figure 4.4: Figure 3114.8.5.3(1) from IBC showing allowable removable container shear wall

Figure 4.4 above shows the maximum allowable wall removal for the given allowable shear values from Table 3114.8.5.3. Chapter 31 of the IBC also states that any wall removed must be reinforced, and the cross-section and material grade of the reinforcement must be equal to or greater than that of the section removed. Using this information together with the maximum allowable loadings from ISO helped the group develop an understanding of how to construct and test a structural model for the shipping container complex.

To determine whether or not a structural analysis will return a successful result, there has to be set limitations that the structure cannot exceed. These limitations are all outlined in the *International Building Code* (IBC). These limitations are mainly focused on member deflection limitations outlined in Chapter 16 of the IBC, specifically in Table 1604.3.

Table 4.1: List of deflection limits related to the RISA model from IBC Table 1604.3



Construction	L or L_r	S or W^f	D + L
Roof Members Supporting Plaster or Stucco Ceiling	L/360	L/360	L/240
Roof Members Supporting Non-Plaster Ceiling	L/240	L/240	L/180
Roof Members Not Supporting Ceiling	L/180	L/180	L/120
Floor Members	L/360	-	L/240

4.5 Structural Cases for the Complex

Before any structural analyses were completed, the team first had to understand the specific loading conditions that would be present in our proposed housing complex. Due to the large, vertical stacking capacity of shipping containers, the team needed to look closest at those situations in which the corner posts of the shipping containers did not line up and thus could not pass weight and force through the structure as easily. The cases for analysis all involved stacking, and the more intense cases involved some degree of overhangs.

The first case for analysis is a single-family unit stacked partially on a multi-generational family unit and another single-family unit, as shown in Figure 4.5. The reason that this case raises some concern is due to the fact that multiple corner posts for the top unit do not line up with the corner posts of the units below it. Due to this, extra stress is applied to the top side and end rails of the bottom units.

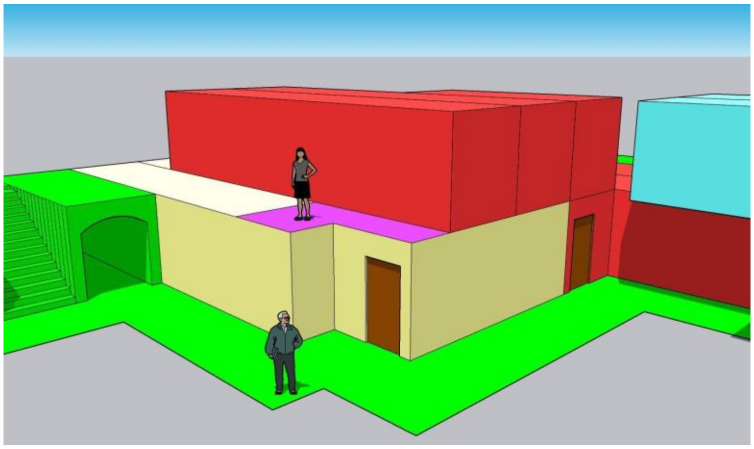


Figure 4.5: A SketchUp model depicting a stacked single-family unit

The second case for analysis involved a single-family unit stacked on top of a multi-generational-family unit as seen below in Figure 4.6. As in the previous case, this second case also involves offset corner posts and the lack of a direct load path through the posts to the ground. This case also contains a small overhang. The overhang is a 4’ x 8’ section totaling 32 sq ft. Since there are only two containers stacked on top of four others, there should be no issues with loading in this scenario other than the small overhang, which in itself will not be a code issue.

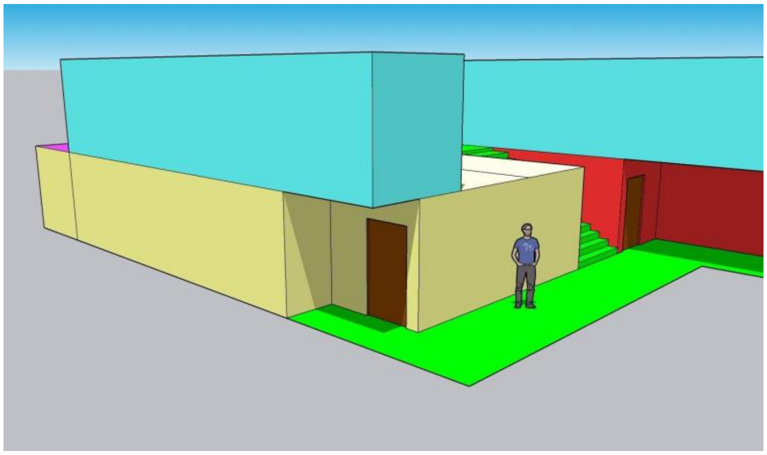


Figure 4.6: A SketchUp model depicting an offset single-family unit stacked on top of a multi-generational unit

Last, the most structurally demanding section of the complex requiring the most attention is the single-family unit stacked on top of a single-family unit. Appearing twice in the complex, this loading scenario has an overhang of 20’x 8’ or 160 sq ft as seen in Figure 4.7. To ensure that the overhang can be properly supported, the team decided from the start that a structural steel column would be required on the corner of the overhang. Without the column, this overhang most likely would not be possible without a significant amount of reinforcement on the bottom side and end rails. This loading scenario was the main focus of the analysis in RISA 3D because it is by far the most structurally demanding and most likely to require reinforcement of some kind.

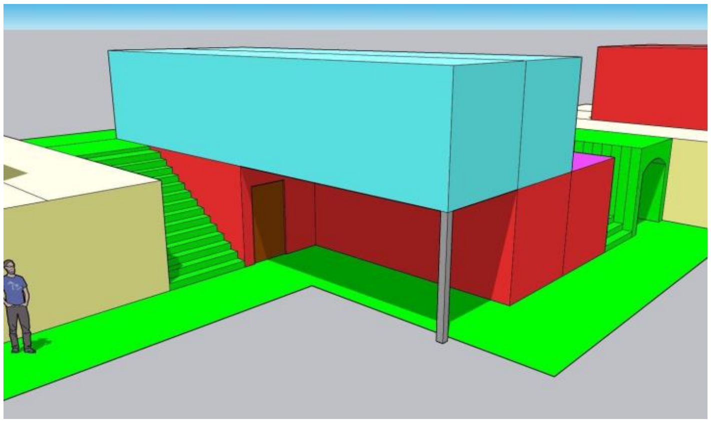


Figure 4.7: SketchUp Model depicting the most structurally demanding section of the complex

4.6 Structural Assessment Using RISA 3D

Once the team had a better understanding of what structural cases would be present in the complex and how shipping containers were constructed, the structural analysis could begin. The first step was determining whether the use of 3D structural modeling and analysis software would prove to be a viable solution for analyzing the complex compared to hand calculations. The team searched online for examples of individuals performing structural analyses using 3D computer software to see if there was a precedent for this type of analysis.

The first example of a shipping container analysis using 3D software the team found was a master's thesis in Civil Engineering for the University of New Hampshire completed by Dzijeme Ntumi (2018). The thesis sought to prove that a simplified beam model of a shipping container could be used as a viable option for performing structural analyses involving shipping containers as the primary structural system. A simplified beam model is a model comprised of columns with rectangular cross sections, beams with rectangular and channel sections and three panels attached to the two long sides of the container and one on the side opposite the door. The simplified beam model also adopts the correct material properties for the members and panels to best simulate a simple container. Using AbaqusCAE, an analysis software that has been applied to both the modeling and analysis of mechanical components, Ntumi was able to conclude that for a 20-foot container, the maximum percent difference of displacements using the simplified beam method compared to the more complex AbaqusCEA method was 10%. Additionally, the maximum percent difference of the stresses using the simplified beam method compared to the AbaquaCEA method was 15% (Ntumi, 2018). Although Ntumi states that the analysis is intended for only the 20-foot container, the team believed that the results should not vary too greatly on a 40' container and that a simplified beam model, in the right program, should be able to provide a good structural representation of the shipping container building system.

The second example for shipping container analysis that the team was able to find was by an MQP team from WPI for a project completed in 2021, "Collaborative Sustainable Campus Design for Macaneta Beach, Mozambique." (Correia et al., 2021) This project report was a great case study for the team to analyze because their proposed structure was far more complex and utilized shipping containers as the main structural element. Additionally, the Mozambique MQP team also used RISA 3D, and their structural analysis helped the team navigate the computer-based modeling and analysis process.

4.7 Testing Load Cases on Harshest Structural Case

When testing the structure of the complex in RISA, it was important to look at the worst-case structural scenario that will cause the most loading problems. The only loading scenario in the complex that is structurally demanding is the stacking scenario with an overhang of 20'x 8' or 160 sq ft. Unlike the other cases the team knew from the beginning that extra supports on the corner of the container's frame. This was taken into account when the complex itself was designed and was also incorporated into the RISA model. For more information on how the models for this section were created in RISA 3D, see Appendix F.

The first step for the RISA analysis was to determine the Self Weight Dead Load, the Applied Dead Load, the Assembly Live Load, the Wind Load and the Seismic Loads of the section of the complex where the large overhang would occur. Using calculations seen in Appendix G, the team was able to determine the loadings on a single container and were then able to apply the calculated loads to the loading scenario. These loads can be seen in Table 4.2.

Table 4.2: IBC Deflection Limitations for Harshest Case Loadings and their Maximum Deflections in RISA 3D

Load	Load Magnitude	Member	Size(s)	IBC Deflection Limitation	RISA Model Max Deflection
Assembly Live Load	-0.4 Kips/Foot Along top side rails	Top Side Rail (Supporting Non-Plaster Ceiling)	40'	-2.00"	-0.83"
Assembly Live Load	-0.4 Kips/Foot Along top side rails	Top Door Rail (Supporting Non-Plaster Ceiling)	8'	-0.41"	0.00"
Self Weight Dead Load	-2.108 Kips per Corner Post	Top Side Rail (Supporting Non-Plaster Ceiling)	40'	-2.00"	0.00"
Self Weight Dead Load	-2.108 Kips per Corner Post	Top Door Rail (Supporting Non-Plaster Ceiling)	8'	-0.41"	0.00"
Applied Dead Load	-0.1 Kips/Foot Along all top rails	Top Side Rail (Supporting Non-Plaster Ceiling)	40'	-2.00"	-0.02"
Applied Dead Load	-0.1 Kips/Foot Along all top rails	Top Door Rail (Supporting Non-Plaster Ceiling)	8'	-0.41"	-0.02"
Wind Load	16 psf on Container Panels	Top Side Rail (Supporting Non-Plaster Ceiling)	40'	-2.00"	0.00"
Wind Load	16 psf on Container Panels	2nd Floor Member (Supporting Non-Plaster Ceiling)	8'	-0.41"	-0.05"

The first loading scenario was the Self Weight Dead Load. As seen in the figure below, the self-weight dead load had very little effect on the structure. The beams marked in purple have not changed shape or deflected at all. This was what the team had expected to happen, due to the stacking tests previously discussed in the set ISO standards. Within the member deflection spreadsheet, the team also determined that no members came close to deflecting past the IBC Table 1604.3 limit.

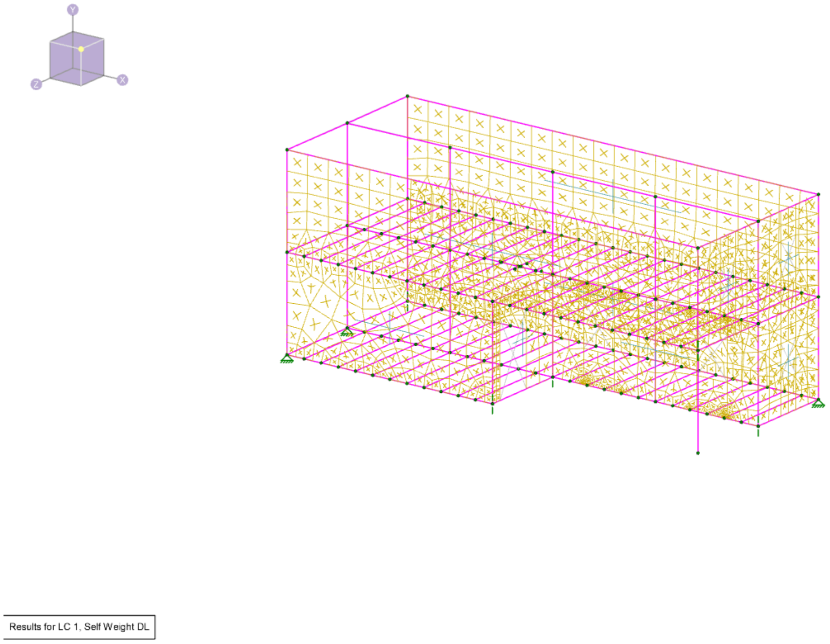


Figure 4.8: The RISA model of the harsh structural scenario showing member deflection with the Self Weight DL applied.

The second loading scenario was the Applied Dead Load. Seen below, the Applied Dead Load considers a heavier roof structure than what the team planned to have. This leaves room for extra material to be added to the roof if need be, such as panels to cover the skeletal structure and/or gutters. The loading for the Applied Dead Load had some minor deflections as seen in the central beams but did not exceed the IBC deflection limitations.

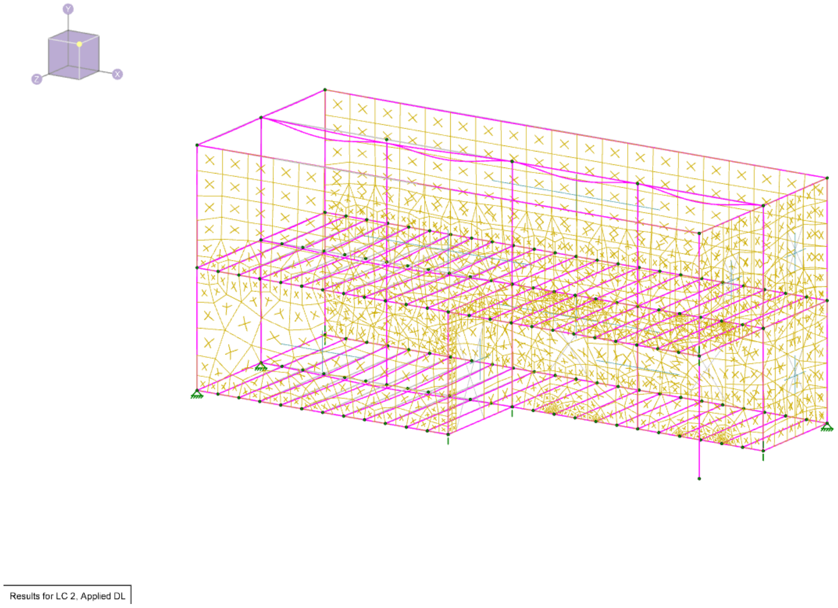


Figure 4.9: The RISA model of the harsh structural scenario showing member deflection with the Applied DL.

The third scenario was the Assembly Live Load. The Assembly live load was calculated using the IBC section 1607.1. The team wanted to plan for a conservative estimate for the Assembly Live Load and thus used the loading case for “Other” which is 100 psf. The complex will likely never experience loads of this magnitude and will likely experience loads more around 40-60 psf. In Figure 4.10, the middle top side rail looks to be deflected a substantial amount. However, when checking the beam deflection spreadsheet in RISA, the beam is still well under the allowable deflection limits outlined in the IBC.

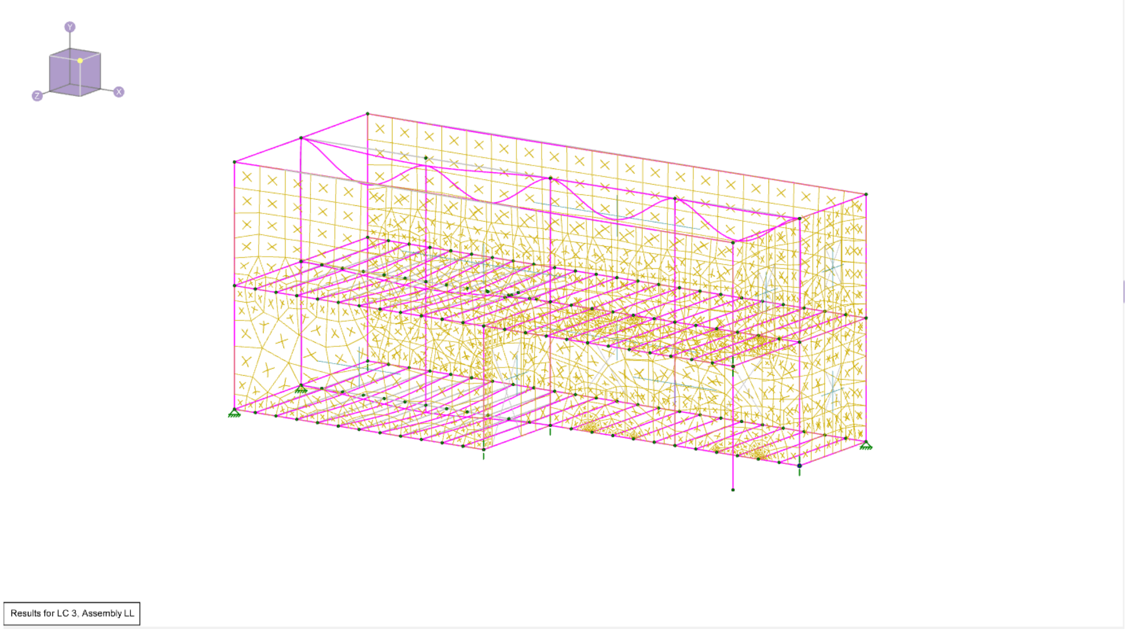
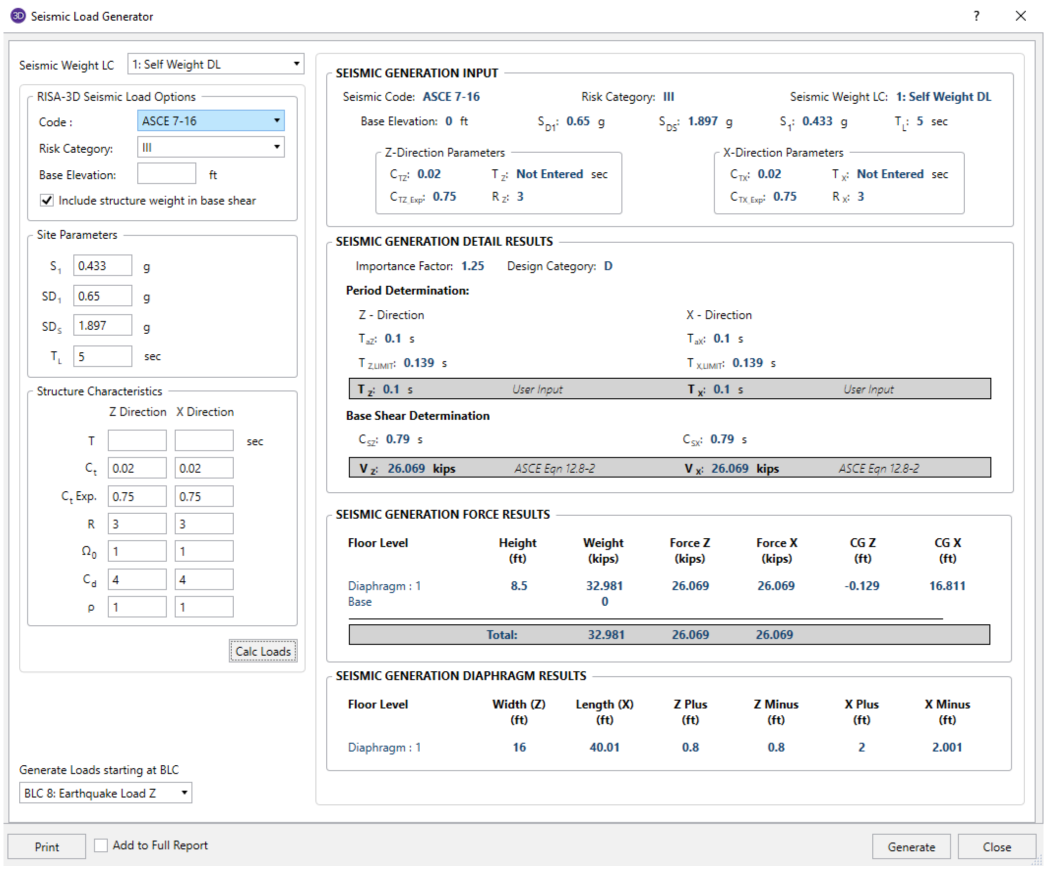


Figure 4.10: The RISA model of the harsh structural scenario showing member deflection with the Assembly LL.

The fourth scenario was the Wind loads. The wind loads for this area, even considering the maximum average, do not exceed 2.25 psf; however, the building was tested for 16 psf, considering an 80-mph wind gust. Even at 16 psf, there is little to no deflection in the members or in the side panels as the force acting on the sides of the structure are not enough to make a difference. This is also something the team predicted as shipping containers are specifically designed to endure high winds and harsh weather on the open ocean.

Lastly, the team needed to consider the Seismic loads acting on the structure. Seismic loads are very important for this complex, especially with Armenia's history of devastating earthquakes. To determine what the seismic loads acting on the structure would be, the team utilized RISA 3D's built-in seismic analysis tool (Figure 4.11).



Seismic Weight LC: 1: Self Weight DL

RISA-3D Seismic Load Options
Code : ASCE 7-16
Risk Category: III
Base Elevation: ft
☑ Include structure weight in base shear

Site Parameters
S_1: 0.433 g
SD_1: 0.65 g
SD_S: 1.897 g
T_L: 5 sec

Structure Characteristics

	Z Direction	X Direction	
T			sec
C_t	0.02	0.02	
C_t Exp.	0.75	0.75	
R	3	3	
Ω_0	1	1	
C_d	4	4	
ρ	1	1	

Generate Loads starting at BLC: BLC 8: Earthquake Load Z

☐ Add to Full Report

SEISMIC GENERATION INPUT

Seismic Code: ASCE 7-16
Risk Category: III
Seismic Weight LC: 1: Self Weight DL
Base Elevation: 0 ft
S_{D1}: 0.65 g
S_{DS}: 1.897 g
S_1: 0.433 g
T_L: 5 sec

Z-Direction Parameters
C_{TZ}: 0.02
T_Z: Not Entered sec
C_{TZ_Exp}: 0.75
R_Z: 3

X-Direction Parameters
C_{TX}: 0.02
T_X: Not Entered sec
C_{TX_Exp}: 0.75
R_X: 3

SEISMIC GENERATION DETAIL RESULTS

Importance Factor: 1.25
Design Category: D

Period Determination:

Z - Direction
T_{aZ}: 0.1 s
$T_{Z,LIMIT}$: 0.139 s
T_Z: 0.1 s *User Input*

X - Direction
T_{aX}: 0.1 s
$T_{X,LIMIT}$: 0.139 s
T_X: 0.1 s *User Input*

Base Shear Determination

C_{SZ}: 0.79 s
V_Z: 26.069 **kips** *ASCE Eqn 12.8-2*

C_{SX}: 0.79 s
V_X: 26.069 **kips** *ASCE Eqn 12.8-2*

SEISMIC GENERATION FORCE RESULTS

Floor Level	Height (ft)	Weight (kips)	Force Z (kips)	Force X (kips)	CG Z (ft)	CG X (ft)
Diaphragm : 1	8.5	32.981	26.069	26.069	-0.129	16.811
Base		0				
Total:		32.981	26.069	26.069		

SEISMIC GENERATION DIAPHRAGM RESULTS

Floor Level	Width (Z) (ft)	Length (X) (ft)	Z Plus (ft)	Z Minus (ft)	X Plus (ft)	X Minus (ft)
Diaphragm : 1	16	40.01	0.8	0.8	2	2.001

Figure 4.11: Seismic Load Generator in RISA

To use this tool the team needed to gather some extra information about the region that we would be constructing the complex in, specifically the spectral acceleration coefficients of the Yerevan region. Using a research paper on the seismic zones and parameters of Turkey (Işık et al., n.d.), the team was able to draw a few conclusions about the region we are planning to construct the complex.

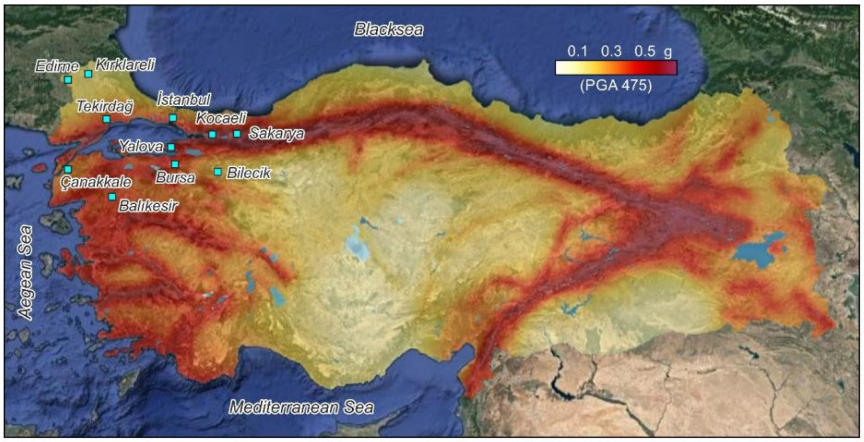
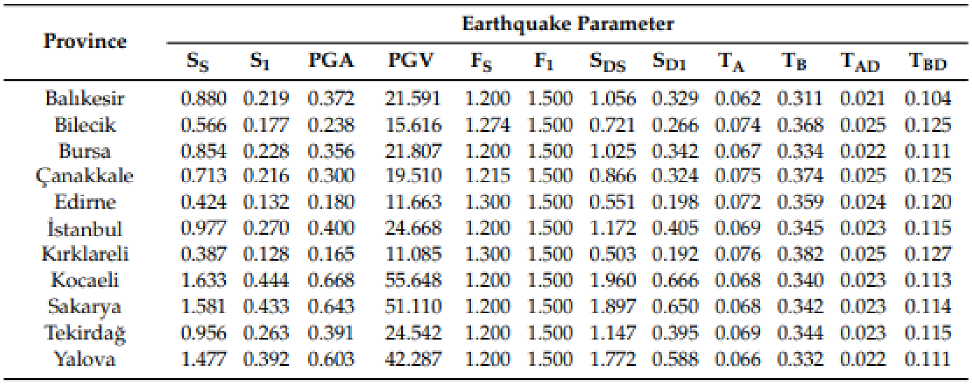


Figure 4.12: Turkish Earthquake Hazard Map (Işık et al., n.d.)

Though Yerevan is not on the map in Figure 4.12, we do know that Yerevan is located along the same rift outlined in red. There are two other Turkish cities, Kocaeli and Sakarya, that are also located along the red-marked rift region. Because of this, we can assume that they will have similar earthquake parameters (seen in Table 4.3 below) to Yerevan and thus, using the parameters provided for Sakarya in the RISA analysis should suffice.

Table 4.3: Earthquake Parameters of various Turkish Cities (Işık et al., n.d.)



Province	**Earthquake Parameter**											
	S_S	**S_1**	**PGA**	**PGV**	**F_S**	**F_1**	**S_{DS}**	**S_{D1}**	**T_A**	**T_B**	**T_{AD}**	**T_{BD}**
Balıkesir	0.880	0.219	0.372	21.591	1.200	1.500	1.056	0.329	0.062	0.311	0.021	0.104
Bilecik	0.566	0.177	0.238	15.616	1.274	1.500	0.721	0.266	0.074	0.368	0.025	0.125
Bursa	0.854	0.228	0.356	21.807	1.200	1.500	1.025	0.342	0.067	0.334	0.022	0.111
Çanakkale	0.713	0.216	0.300	19.510	1.215	1.500	0.866	0.324	0.075	0.374	0.025	0.125
Edirne	0.424	0.132	0.180	11.663	1.300	1.500	0.551	0.198	0.072	0.359	0.024	0.120
İstanbul	0.977	0.270	0.400	24.668	1.200	1.500	1.172	0.405	0.069	0.345	0.023	0.115
Kırklareli	0.387	0.128	0.165	11.085	1.300	1.500	0.503	0.192	0.076	0.382	0.025	0.127
Kocaeli	1.633	0.444	0.668	55.648	1.200	1.500	1.960	0.666	0.068	0.340	0.023	0.113
Sakarya	1.581	0.433	0.643	51.110	1.200	1.500	1.897	0.650	0.068	0.342	0.023	0.114
Tekirdağ	0.956	0.263	0.391	24.542	1.200	1.500	1.147	0.395	0.069	0.344	0.023	0.115
Yalova	1.477	0.392	0.603	42.287	1.200	1.500	1.772	0.588	0.066	0.332	0.022	0.111

After completing the seismic analysis in RISA 3D, the structure behaved as expected. Since shipping containers are very wide and the complex is not exceptionally tall, there was little to no deflection in the members of the structure. As previously stated, this is the predicted behavior, as shipping containers in stacks up to nine high can remain stable aboard cargo ships at sea.

4.8 Conclusion

From the structural analysis that the team completed, a few conclusions can be drawn. First, considering that using a simplified beam model for the structural analysis is an acceptable method as proved by previous studies, we can conclude the harshest structural loading scenario will not violate any IBC limitations. However, the model we utilized does not include a few important features. The paneling on the container model we created had to be modeled as flat paneling and cannot be corrugated like a typical shipping container. Additionally, the paneling rested on the exterior rather than being welded between the top and bottom rails of the container. Even so, the simplified structure remains stable with all the given loading scenarios.

4.9 Foundation

The foundation, Figure 4.13, was designed to make use of the locking mechanisms already present on the bottom of the shipping containers. This mechanism is traditionally used to secure containers together on cargo ships. The foundation is composed of four concrete pilings reinforced with steel which are placed on the corners of the shipping containers where the locking mechanism is in place. The lock is secured with a metal plate. The plate is bolted into a concrete piling. There are six-inch-long steel ties that go into the 1’deep concrete piling. Beneath the shipping container itself and the ground, the concrete base is used to ensure that minimal moisture gets under the units. Filling this gap also eliminates the crawl space where animals could form a habitat. There would also need to be formal soil testing done to confirm what soil type is present specifically on our site. From these findings, the specific foundation could be determined

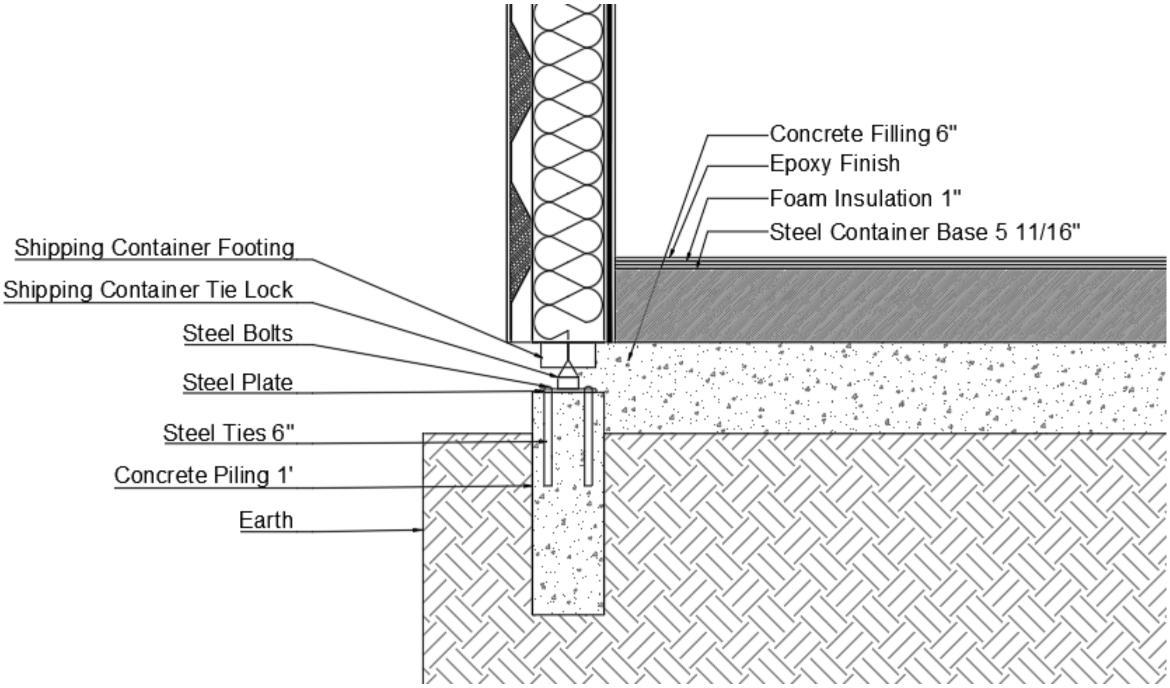


Figure 4.13: Foundation Detail

5. Mechanical Outline

5.1 Solar Strategies

The Climate Consultant software guided our solar study strategies. As shown in Figure 5.1, the sun path for the selected site moves southeast to southwest, with a longer path in the summer and smaller path in the winter. We oriented the individual apartments and the entire complex facing the sun lengthwise. This allows the maximum sunlight to penetrate the apartments during the winter. We implemented shades throughout the building in order to lower the amount of solar heat gain in the summer.

Figure 5.1: The Sun Pattern in the Winter and Summer along with the Wind Pattern

Yerevan is cold in the winter, and so capturing sunlight is very important for passive heating systems, HVAC cost efficiency, mental health and wellbeing. Passive daylighting strategies permit solar light and sometimes energy to enter interior spaces through windows and shades based on a specific lighting design (*Passive Solar Home Design*, n.d.). This type of lighting and heat capture is important because it reduces electricity and HVAC usage and costs. Sunlight is also proven to increase serotonin and boost quality of life (Trilling et al., 2017).

5.2 Sunshades

Sunshades are utilized to take advantage of the passive solar heat and energy. The shades allow lower angled winter sun to penetrate into the building through the windows, providing light and heat to the unit, see Figure 5.2 below. During the summer the shades block the sun as it is at a higher angle.

Sunshades were installed above every window in the apartment complex. The sunshades are made from scrap pieces of corrugated steel from the containers that were removed for different interior wall spaces. This reuses the material, cutting costs, and also matches the typical corrugated asbestos roofing of homes in Armenia. The shades are one-foot deep and extend one-half foot to either side of the window. Please see Appendix B for the detailed calculations to support the design.

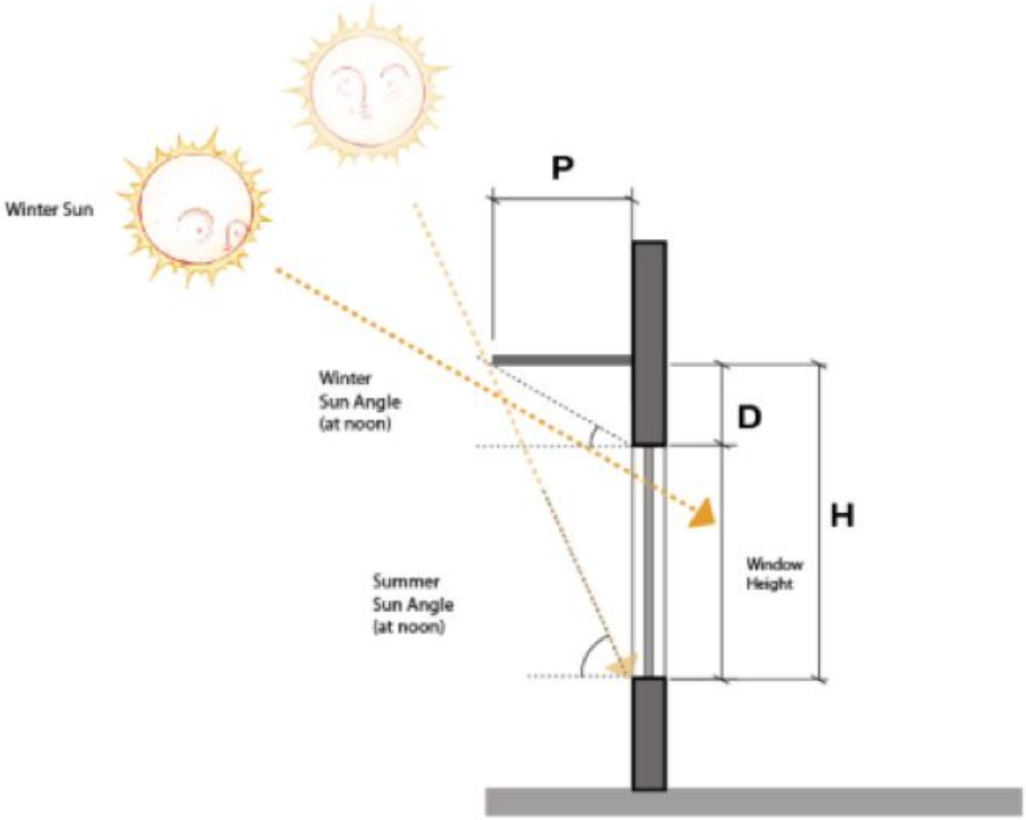


Figure 5.2: The Effect of Sun Shading on Winter and Summer Sun from Climate Consultant

5.3 Ventilation

Wind flows through the complex generally from the northeast to the southwest. The housing units were oriented to take advantage of not only the sunlight, but the natural ventilation. Wind is allowed to move though the long passageways and into the buildings from east to west. The corridors between units will channel the breeze into the open courtyard, creating a nice cooling effect for those in the outdoor areas.

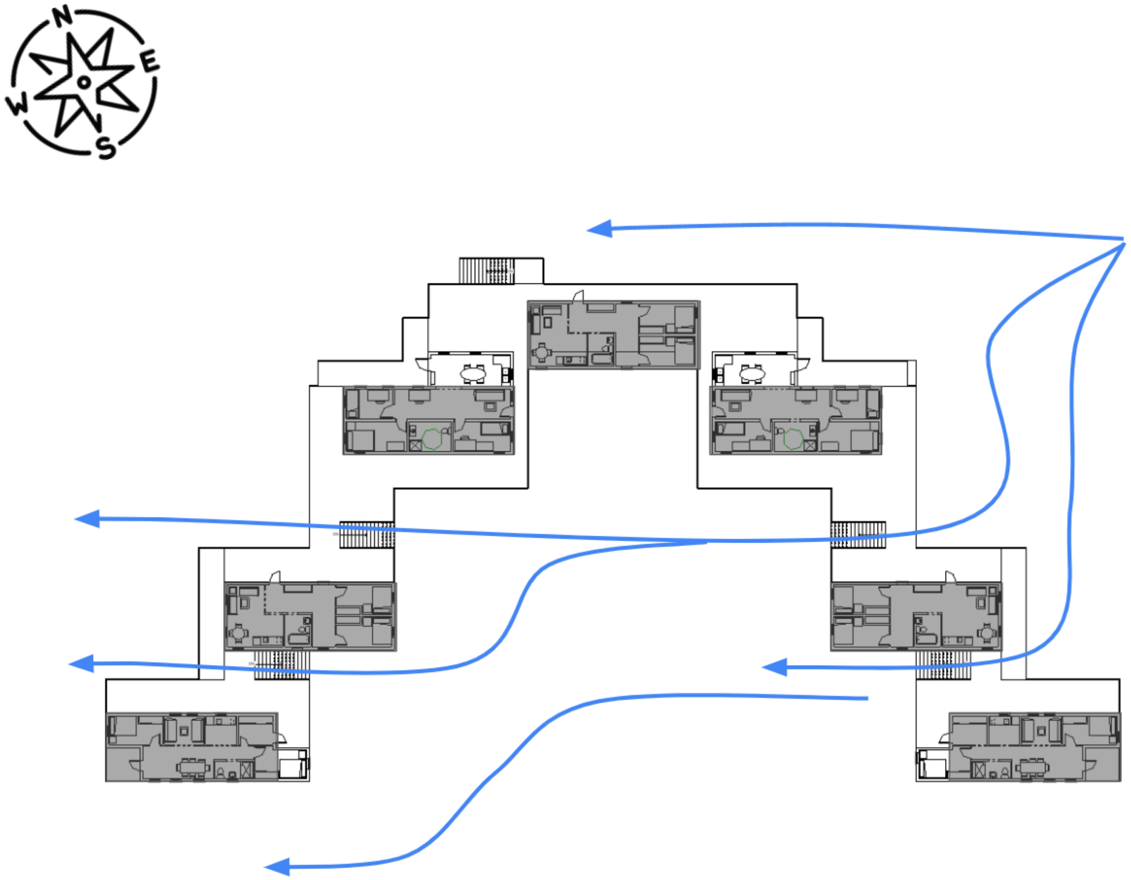


Figure 5.3: Wind patterns for the complex's site

5.4 Building Envelope Design

Provided that shipping containers serve as the basic structure of our homes, we had to come up with innovative solutions to integrate the corrugated steel within the building envelope. In order to develop a suitable building envelope, we integrated a system of wall, floor, ceiling and roof assemblies. The material properties of the layers within these assemblies determine the performance of the overall building envelope. Since our design is intended for domestic use, we made sure to incorporate materials and details that would make the space comfortable for living. Excessive air leakage could pose a threat to the comfort level in any space, especially in the winter. Sheet goods such as drywall, sheathing, and decking are used for the ceilings, walls and floor assemblies, as they effectively stop air leakage (*AIR SEALING Air Leaks and Save Energy!*, 1999). Moisture is also another major challenge when designing the building envelope. Due to this, vapor barriers are used to prevent any moisture from getting into the space. If the moisture isn't eliminated, then the space is at risk of mold and water damage. The vapor barrier in any space should be “Installed close enough to the insulation in order to prevent condensation” as well as “on the warm side of the floor, wall, or ceiling” (Eco Spray Insulation, 2021).

In this project, there are two main types of wall structures: the interior walls (or partitions) and exterior enclosures (See interior wall detail below, Figure 5.4). The interior wall is the only wall type that does not integrate the corrugated steel from the shipping container. The layers of the interior walls consist of gypsum board on both sides where drywall is applied. For structure there is wood stud framing that is placed six inches apart in order to place insulation in between. Even though these walls don't serve as a protection from exterior air leakage, it is important to include insulation for noise elimination.

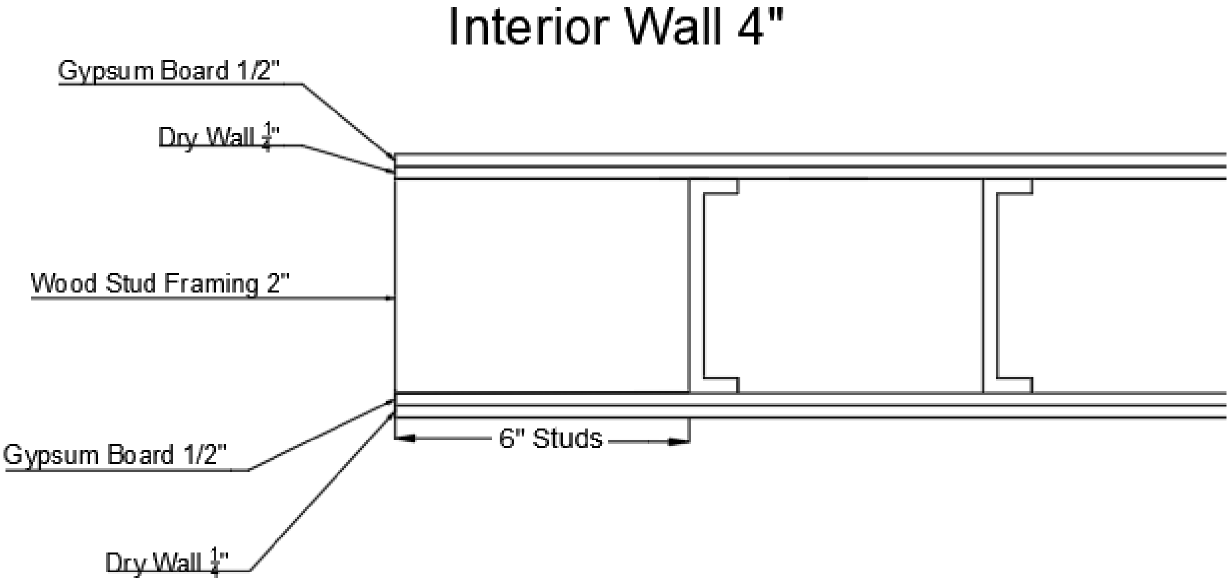


Figure 5.4: Interior Wall Section

The exterior walls integrate the corrugated steel shell of the containers where openings would be cut for windows and doors that are framed into the corrugated steel. Doors would be hung with metal brackets around the perimeter of each opening. (See Figure 5.5 and 5.6) On the exterior side, a veneer made of volcanic tuff is used. The spacing in the steel corrugation is used to place a wood filling for insulation purposes and to even out the surface. In the center, where the vapor barrier resides, wood studs and insulation are placed on the interior side of the wall to stop condensation. Lastly, the gypsum board and drywall are applied to the interior side of the wall.

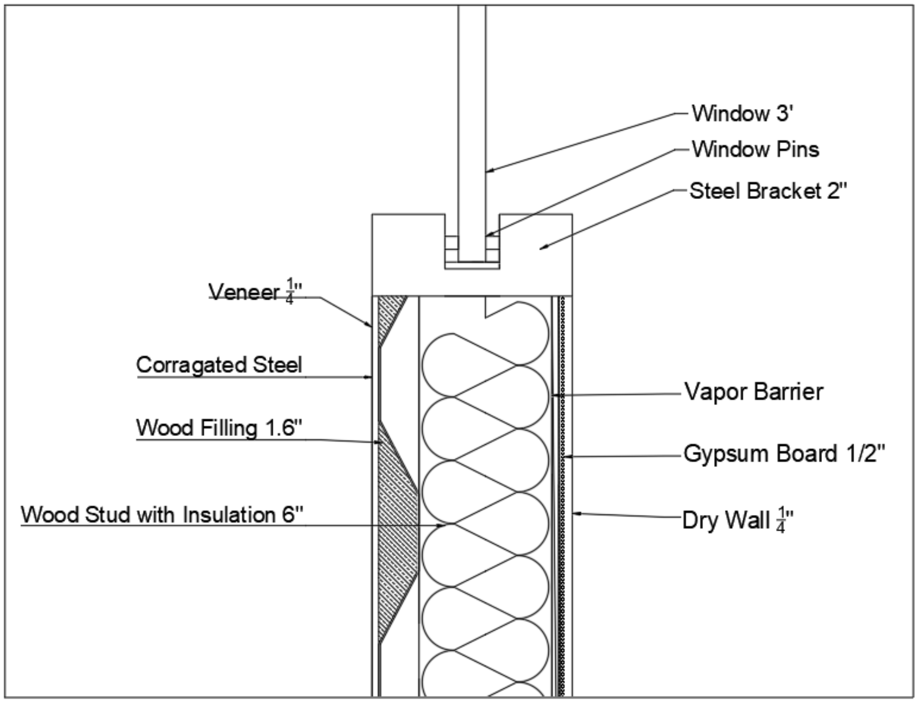


Figure 5.5: Detail of Window in Exterior Wall

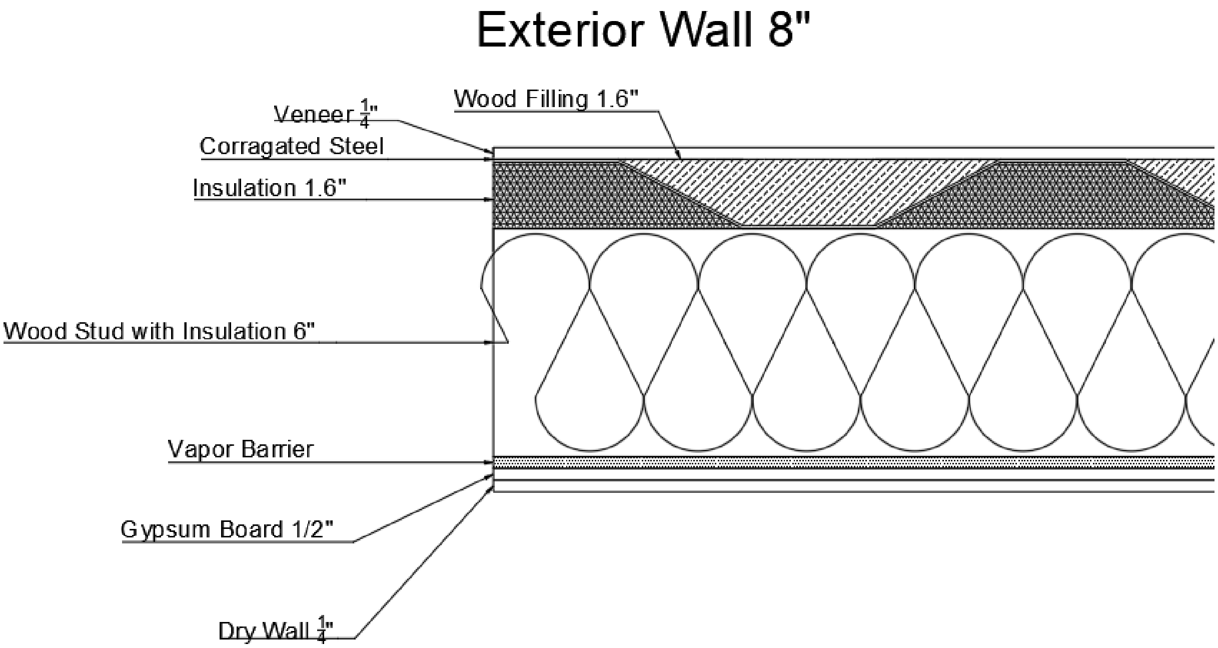


Figure 5.6: Exterior Wall Detail

The connected wall is a special case that is only found in a few units of the project. (See the figure below) Its purpose is to join two units, where one unit has an exterior wall and the other has an interior wall. In order to simplify this process, we treated both wall types as exterior walls, where the vapor barrier is continuous. The corrugated steel comes together with wood filling acting as insulation. The layers of drywall and gypsum board are applied similar to the other wall types.

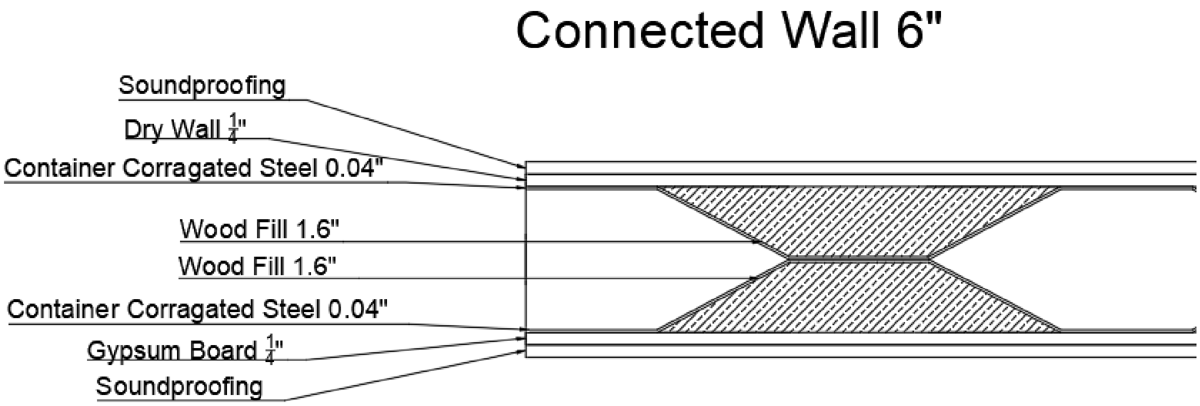


Figure 5.7: Connected Wall Detail

In Figure 5.8 below, the different wall types are shown throughout half of the complex on the first floor. The same principle follows on the other half as this complex is very symmetrical. For the second floor, there are no special cases where there are connected walls, therefore only exterior and interior wall assemblies are used.

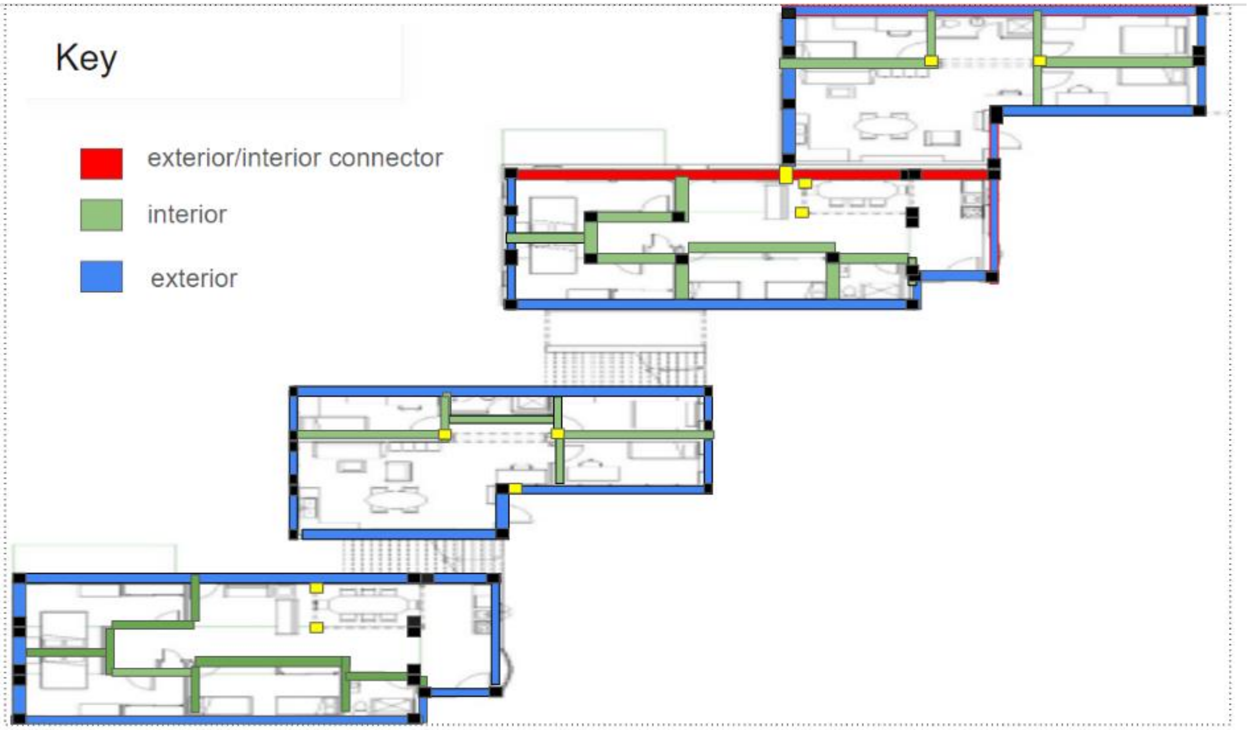


Figure 5.8: Various wall types on the first floor of the complex

There are two floor sections that we considered: the first-level floor and the floor to ceiling section of the first and second levels. The team focused on the floor-to-ceiling section as it is a special case where the corrugation and shipping container floor are adapted into a residential floor system. (See Figure 5.9) Within the floor-to-ceiling section between the first-floor ceiling and second level floor, there is an epoxy finish on top of a vapor barrier. The already existing shipping container floor from the second level sits on the corrugation leaving the gaps open for air. For the ceiling portion of this system there is wood stud framing with insulation and gypsum board for the finish.

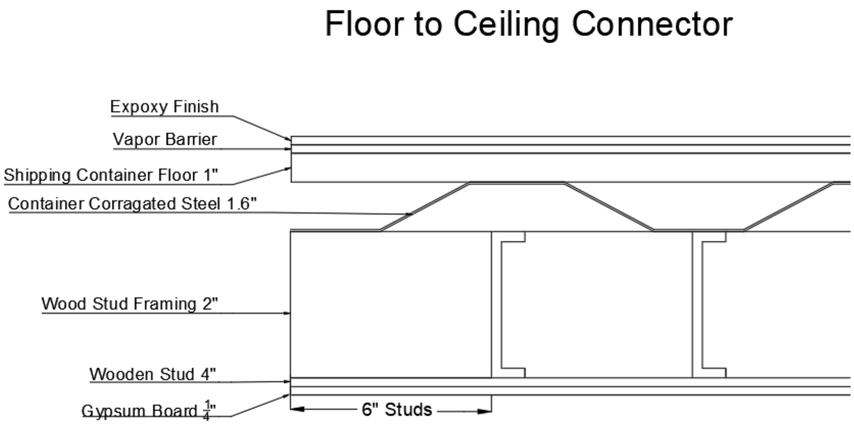


Figure 5.9: Floor to Ceiling Connection

The roofing system for these units is made of corrugated steel sheets that have been cut out for other areas of the complex. It is framed with steel purlins that are fastened to the edge of the containers. Under the corrugated steel the roof is not fully enclosed in order to allow for air to pass through and to lower material costs. The roof is sloped toward the south in order to minimize effects from the sun, see Figure 5.10.

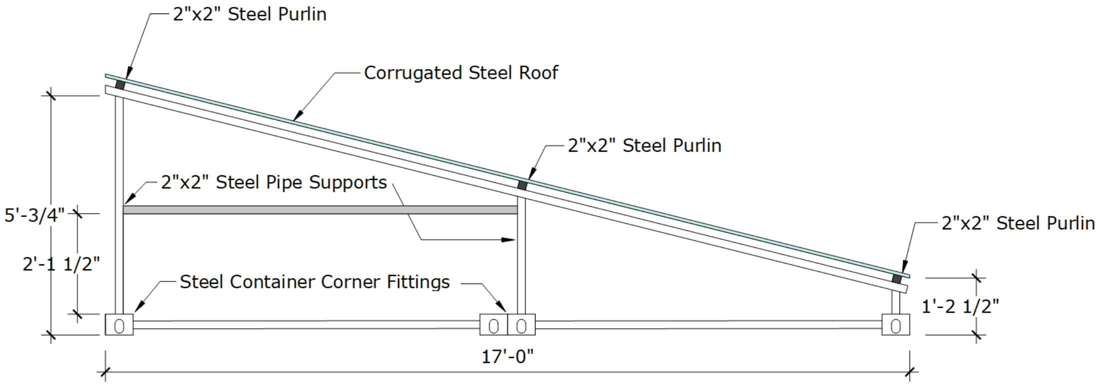


Figure 5.10: Roof Structure Detail

5.5 Building Energy Simulation

Building energy simulation is the computerized analysis of a building, which focuses on energy consumption and utility costs (Energy Models, n.d). We conducted our energy simulation through Revit and Autodesk Green Building Studio, which allowed us to determine the peak heating and cooling loads and the Energy Usage Intensity (EUI). The peak heating and cooling loads affect the amount of energy usage and the costs involved. These are the loads necessary to heat and cool the building. They are calculated in the hottest and coldest months of the year. The Energy Usage Intensity is the energy usage per square foot yearly, which is calculated in kBTU/ft^2 yearly (Energy Star, n.d.). Since our project is geared toward low-income families, it is important to minimize energy and production costs as much as possible.

Before conducting the simulation, we made sure that all the wall, floor, and ceiling structures within the model were composed of the correct materials and thermal properties, please see Table 5.1. We also set the windows to be double glazed with a Solar Heat Gain Coefficient (SHGC) of 0.76. The SGHC determines the amount of solar radiation through the glazing and is a number between zero and one. A lower number is preferred in order to decrease unnecessary heat (DAWSON, 2022). We also chose a packaged single zone for our HVAC system which proved to be more energy efficient than a Fan Coil System. We then created an energy model in order to be exported for energy analysis. We utilized the Autodesk Green Building Studio in order to perform the energy analysis. The overall energy usage intensity of our building is 122 kBTU/ft^2/year. This is very close to the baseline EUI of 118 kBTU/ft^2/year for Multi-Family Housing (Energy Star, n.d.)

Table 5.1: R-Values and U Factors for various parts of the complex

Assembly	R Value (°F·ft 2 ·h/BTU)	U Factor BTU/(h*ft^2*°F)
Roof	R-60	0.0151
Ceiling	R-38	0.029
Exterior Wall	R-38	0.0272
Interior Wall	—	0.2595
Floor	R-38	0.03
Double Glazed Windows	—	0.4

For this project, the peak cooling load was 130,482.9 BTU/h and the peak heating load was 84,341.1 BTU/h. There is a required 3509 hours for mechanical cooling. It is apparent that our building requires an abundance of energy that is dedicated to cooling. The cooling load was calculated in August which is the hottest month of the year in Armenia. Higher cooling loads tend to be a result of the number of rooms and their proximity to each other. (Energy Star Portfolio Manager, 2015) Both heating and cooling loads may be greater due to the materials used in the building envelope and their thermal properties. A higher R value or thermal resistance for the insulation and overall building envelope may result in lowering the amount of heating and cooling loads. Therefore, it is necessary to lower the amount of cooling loads as much as possible in the summer. There are some passive strategies that could help, such as an increased amount of cross ventilation. Making sure that the material on the exterior of the shipping container is reflective of sunlight and has minimal thermal conductivity is also important. (Container One, 2021).

In shipping container homes there is a larger threat for thermal bridging due to the metal’s high thermal conductivity (U factor). It is beneficial to use insulation with higher R values. (Discover Containers, 2022)

Table 5.2: Peak Heating and Cooling Loads for the Complex

	Peak loads (BTU/hr)	Load Density (BTU/hr*ft^2)	Set point Temp (F)
Heating	84,341.1	12.17	74
Cooling	130,482.9	18.84	70

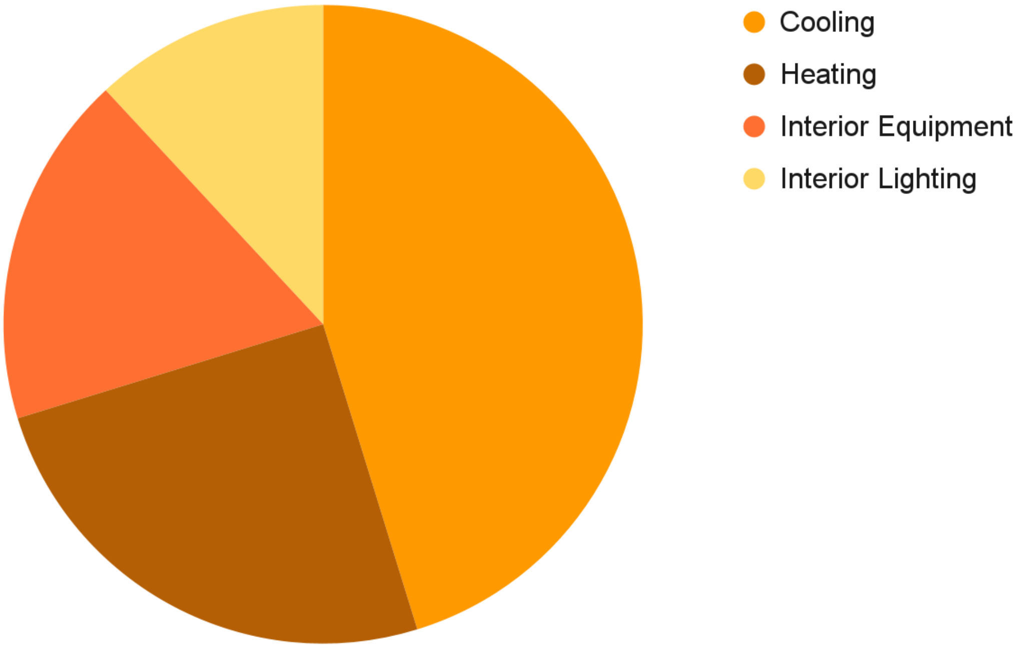


Figure 5.11: Pie chart showing the breakdown of estimated energy loads for the complex

5.6 Cost Analysis

The overall cost of the complex has been proven to be much lower than the construction of a typical apartment building. Shipping containers are quite cost effective for use considering they are the main structural component and basis of each unit. A used forty-foot container is approximately $3,589, and a used twenty-foot container is $2,471 (EVEON Containers, n.d.). In our design there are a total of 34 forty-foot containers and 10 twenty-foot containers. Therefore, the total cost of shipping containers is 146,736 dollars. The total cost for a shipping container-based unit is much lower than that of a typical apartment unit. Each unit that we designed would cost about 7,000 to 12,000 dollars not including other materials and labor. Even though this does not factor in materials and labor, the cost is still considerably lower compared to a typical apartment unit, which would cost about 75,000 dollars in total to construct.

6. Conclusion and Recommendation for Future Work

6.1 Implementation Plan

We applied this project to a specific lot that is currently for sale in Armenia. Through our research and design process we found that this project could be feasibly implemented in Armenia and in any other country with housing crises.

Since the beginning of this project, Artsakh has gone under even more attacks (Avedian, 2022). Russia has also invaded Ukraine, and there is tragically an ever-increasing refugee crisis across Europe and the rest of the world (Vierlinger, 2022). Shipping container units are a global commodity and are used in many parts of the world to transport goods. They can be a solution for affordable refugee housing.

Our guidelines could be applied to many different situations. The modularity of the units means that they can be reconfigured for a number of arrangements and situations. They are essentially Lego pieces that can be adapted for any situation and any site housing as many people as necessary. The beauty of the shipping container model is that they provide a structurally sound dwelling that can be used in all parts of the world.

It would be necessary however if this project were to be implemented in any way, that licensed engineers more familiar with the region look at the structural plans. The engineers would need to confirm, elaborate and consult on the plans and the calculations for implementing this project.

6.2 Alternative Materials and Methods for Sustainability

There are other materials and ideas that we researched but did not choose to pursue in this project. We see these alternative solutions working well in our apartment complex, especially to reduce overall impacts on the environment and costs of the project.

Our buildings could be insulated via sheep’s wool. Armenia has a high population of sheep and using sheep's wool would support local sheep herders (Nazaretyn, 2020). The material is geographically close, cutting down on transportation costs. Sheep’s wool is mold resistant, breathable and regulates humidity (Business News Wales, 2022). Sheep’s wool is also selfextinguishing. It has a competitive thermal factor to other insulation materials with its R-value at approximately 3.6 per inch of batt with an R-value of 4.3 per inch for loose fill. Sheep's wool is also a sound absorber ("Sheep's Wool", n.d.).

Figure 6.1: Sheep's wool as insulation courtesy of Havelock Wool

A Green Roof could also be implemented on top of the shipping containers. This would provide the heat cooling, insulating effect. Green Roofs have an aesthetic purpose to them along with the technical benefit of maintaining a temperate environment for those inside the building. This could be perfectly implemented into our complex as, "the steel roofing of a shipping container offers a perfect "substrate" to build a living roof." This alternative could cut overall costs by lowering the HVAC costs (*5 beautiful container homes with green roofs | Container Living*, n.d.).

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Appendix A: Floor Plans with Shipping Container Overlays

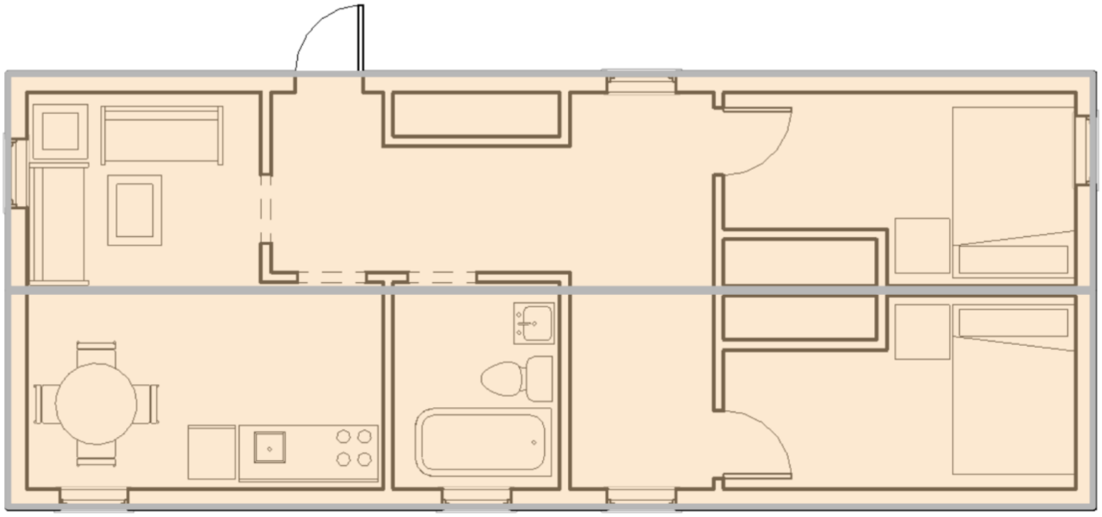


Figure A.1: Overlay of Two Person Unit 2 with 40’ by 8’ Shipping Container

Figure A.2: Overlay of Two Person Unit 2 with 40’ by 8’ Shipping Container

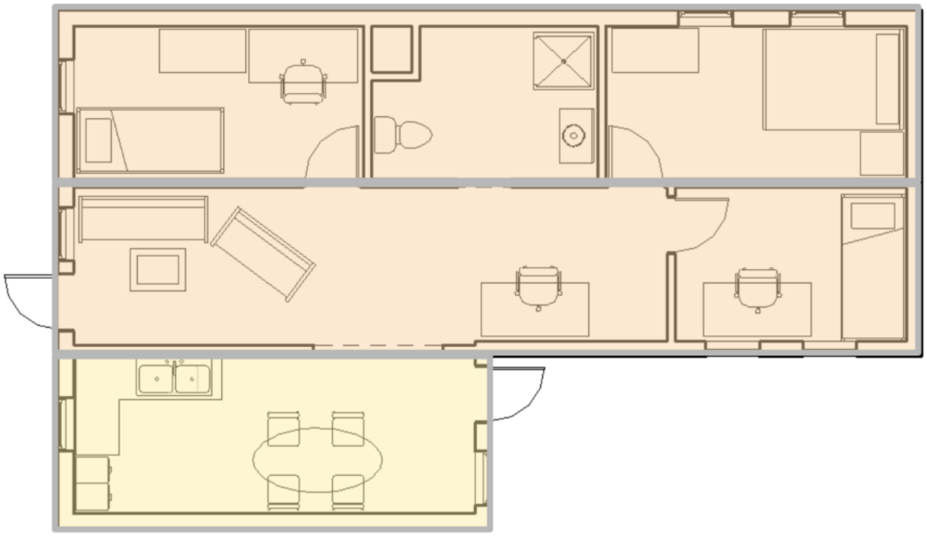


Figure A.3: Overlay of Single-Family Unit with two 40' by 8' Shipping Containers with one 20' by 8' shipping container

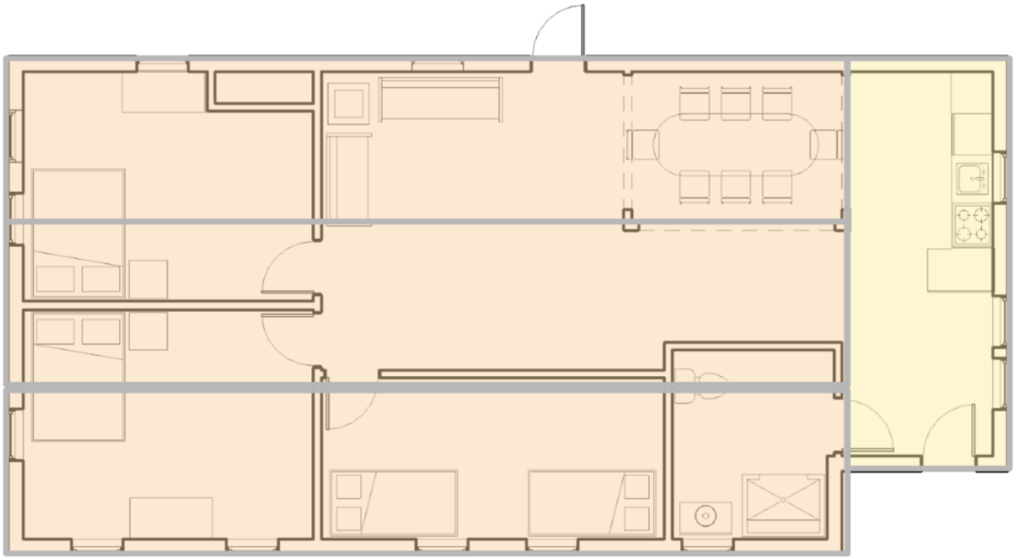


Figure A.4: Overlay of Multigenerational Unit with three 40' by 8' Shipping Containers and one 20' by 8' Container

Appendix B: Sunshade Calculations

P=H/F
Latitude is 40.1872° N
Use the F Table from 2030 Palette
P=3’/ (3) =1-foot overhangs

A factor of H/2
Side Width=3/2=1.5 feet over each side

Appendix C: ADA Bathroom Details

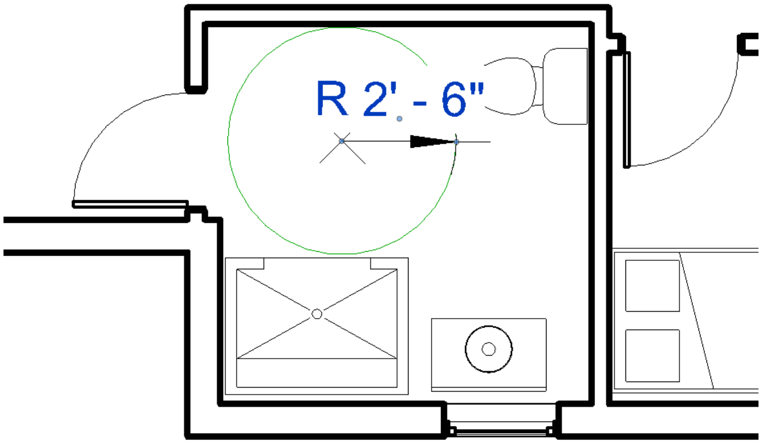


Figure C.1: 2 person Family Unit ADA Compliance Bathroom

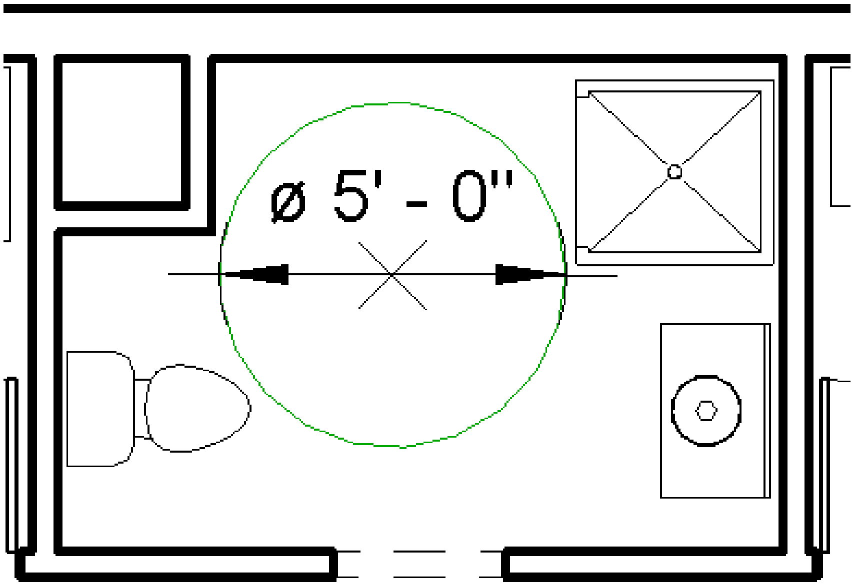


Figure C.2: Single Family Unit bathroom

Appendix D: Roof Structure Details

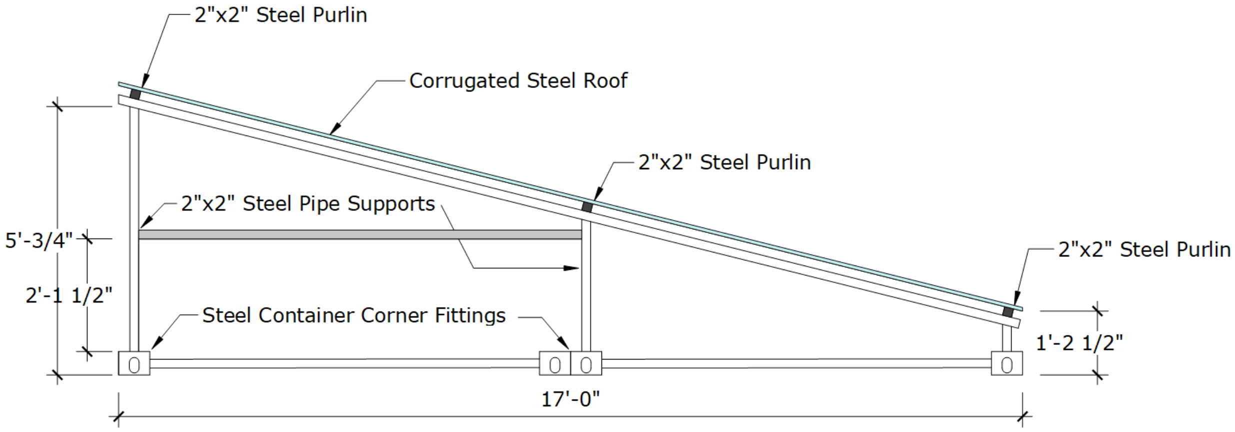


Figure D.1: Detailed Roof Section

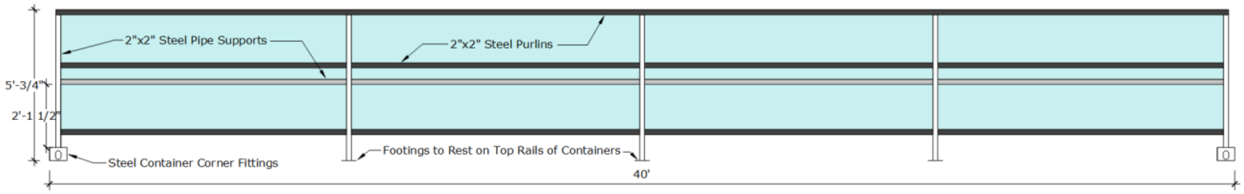


Figure D.2: Roof Detail

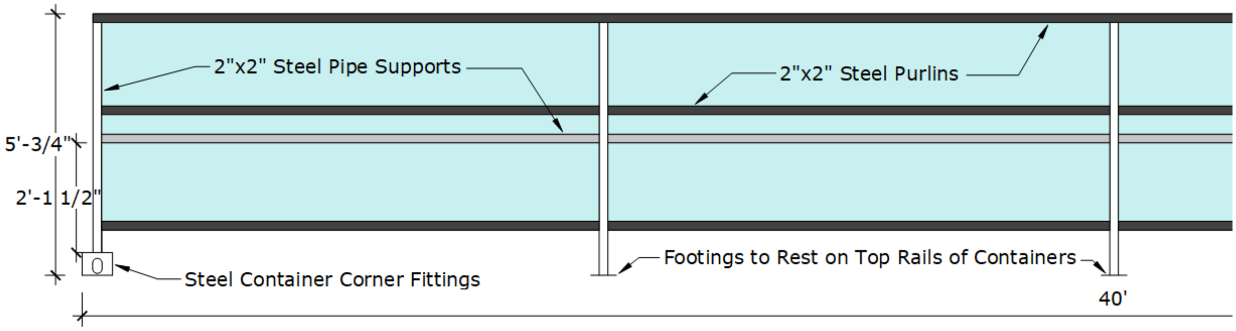


Figure D.3: Roof Detail zoomed in

Appendix E: Complex Renders

Figure E.1: Shows courtyard from left side of the complex

Figure E.2: Under pavilion looking out onto courtyard

Figure E.3: View from Southwest parking lot on left side

Figure E.4: Rear-side of Complex


Figure E.5: Northern, right-side parking area


Figure E.6: View of courtyard from balcony of one of the units

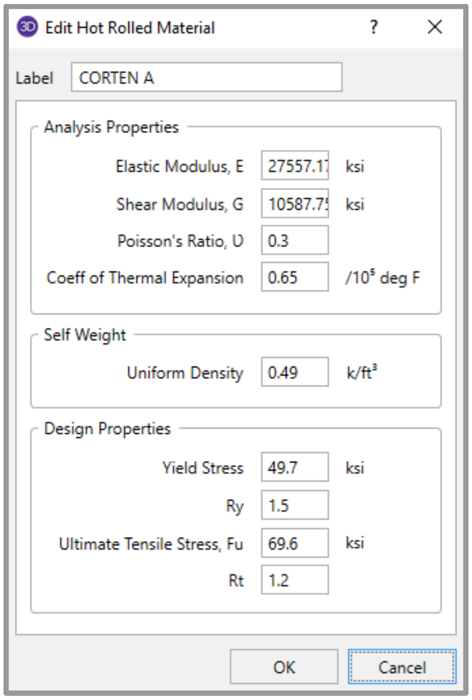
Figure E.7: View from Balcony looking south into the courtyard

Figure E.8: View into Courtyard from walkway underpass

Appendix F: Creating a Standard Shipping Container in RISA 3D

The first step required to test the structural system in RISA was to create a basic, unmodified container. Using RISA to analyze the effects of the building loads on an unmodified container provided a baseline for the performance of a structurally sound system. To model and analyze the container in RISA the team needed to research the dimensions of all components in the container, including the material properties of CORTEN A steel which is used for all parts of the container including the shell and the frame.

Starting with CORTEN A steel properties, the team was able to determine all the required properties required for RISA 3D as seen in Figure F.1 ("EN 1.8945 (S355J0WP) Weathering Steel"). These properties are necessary for RISA 3D to properly simulate the engineering performance of the materials used in the structural system.



Label: CORTEN A

Analysis Properties
Elastic Modulus, E: 27557.1 ksi
Shear Modulus, G: 10587.7 ksi
Poisson's Ratio, υ: 0.3
Coeff of Thermal Expansion: 0.65 /10^5 deg F

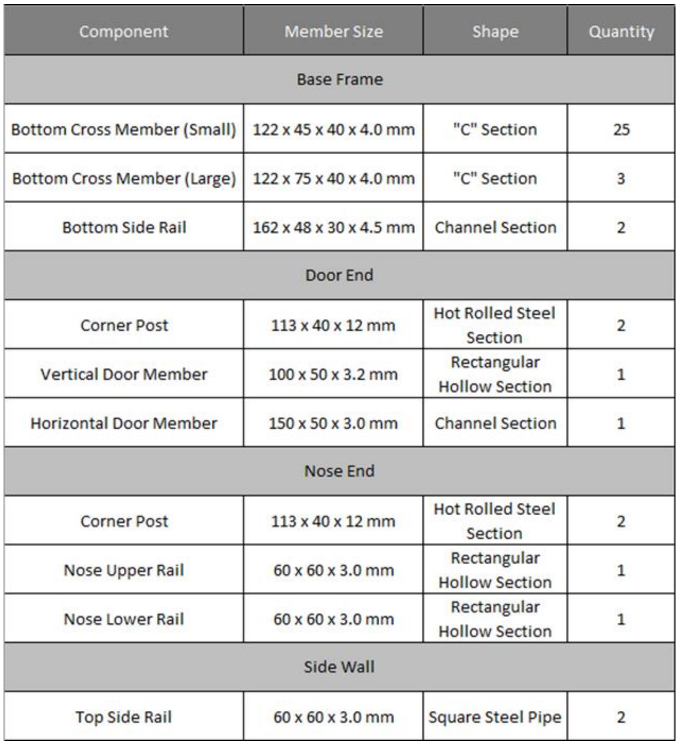
Self Weight
Uniform Density: 0.49 k/ft^3

Design Properties
Yield Stress: 49.7 ksi
Ry: 1.5
Ultimate Tensile Stress, Fu: 69.6 ksi
Rt: 1.2

Figure F.1: RISA 3D's Material Creation Window

Next, the dimensions for each member of the shipping container's frame were needed. While the information on shipping container specifics can be difficult to find, the Mozambique MQP team linked to a German shipping container distribution company, Steinecker Containerhandel, which proved to be a valuable resource (*Technical Specification for a typical 40'x 8'x 8'6" ISO Type Steel Dry Cargo Container*, 2012). Their website provided links to strict technical dimensions for members of both 1AA and 1CC shipping containers. The Steinecker specifications listed the shape, cross-sectional dimensions, and quantity of each member in a single shipping container.

Table F.1: Standard member sizes in a 1AA shipping container



Component	Member Size	Shape	Quantity
Base Frame			
Bottom Cross Member (Small)	122 x 45 x 40 x 4.0 mm	"C" Section	25
Bottom Cross Member (Large)	122 x 75 x 40 x 4.0 mm	"C" Section	3
Bottom Side Rail	162 x 48 x 30 x 4.5 mm	Channel Section	2
Door End			
Corner Post	113 x 40 x 12 mm	Hot Rolled Steel Section	2
Vertical Door Member	100 x 50 x 3.2 mm	Rectangular Hollow Section	1
Horizontal Door Member	150 x 50 x 3.0 mm	Channel Section	1
Nose End			
Corner Post	113 x 40 x 12 mm	Hot Rolled Steel Section	2
Nose Upper Rail	60 x 60 x 3.0 mm	Rectangular Hollow Section	1
Nose Lower Rail	60 x 60 x 3.0 mm	Rectangular Hollow Section	1
Side Wall			
Top Side Rail	60 x 60 x 3.0 mm	Square Steel Pipe	2

The first 1AA container created in RISA can be seen in Figure F.2 below. The team utilized the "Member" tool to create beams and columns of the exact size and material needed. It was also important that the proper connection types were used between connected members to ensure they would act as expected in a simulation. This meant using moment connections at the corner posts for the internal stability of the frame. Pins and rollers were defined at the bottom corners of the frame to simulate simple supports.

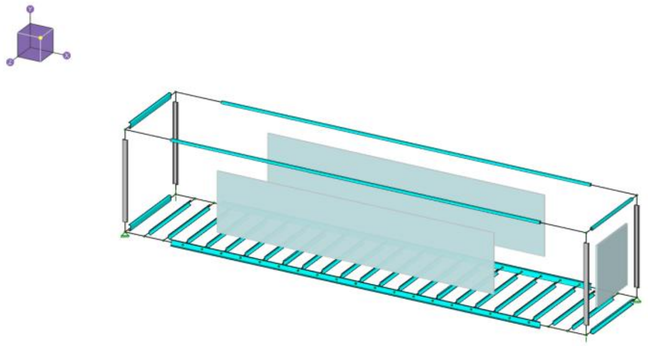


Figure F.2: A complete 1AA shipping container in RISA 3D

The model of the container is fairly accurate to a real container with the exception of a few things. The first is that there is no paneling on the top of the container or on one of the end walls. This is because neither of these areas contribute to the structural integrity of the container. The end wall without paneling considers that the doors of the shipping container will not contribute to the structural system. The roof of a shipping container also provides very little structure to the container, with all roof loads being delegated to the top side rails and end rails. The second approximation in the team’s RISA 3D model is that the corrugated surface of the shell cannot be modeled in a simple manner. Since all the wall panels of a standard shipping container are corrugated, a new approach was required to make a suitable alternate within RISA. The team decided that using panels with the same thicknesses as the original (Table ??) but with no corrugation would be a workable replacement for the original container panels. This simplification underestimates the vertical bending stiffness and axial stiffness of the walls.

Table F.2: Various 1AA panel thicknesses

Component	Depth
Front End Wall	45.6 mm
Door Panels	36 mm
Side Wall	36 mm
Roof Panel	20 mm
Floor Plywood	28 mm

Appendix G: Structural Loading Calculations

<u>Self-Weight Dead Load:</u>

(Container Weight) / 4 Corner Posts per Container = Load at Corner Posts

- For 40’ Containers:
    - Max Payload = ~58,642 lbs to 59,130 lbs (Steinecker)
    - Tare Weight = ~8,554 lbs to 8,070 lbs (Steinecker)
- For 20’ Containers:
    - Max Payload = ~62,390 lbs (Steinecker)
    - Tare Weight = ~4,810 lbs (Steinecker)

Self-Weight for 40’ Container = 8.07 kips / 4 Corner Posts = **2.0175 or 2.018 Kips per Post**

<u>Applied Dead Load:</u>

Assuming Roof Weight of ~30 psf

Roof Load x Roof Area = ADL

30 psf x (40’ x 8’) = 9,600 lbs = 9.6 kips

9.6 / (40’ + 40’ + 8’ + 8’) = **0.1 kips per foot on top rails**

<u>Assembly Live Load:</u>

Top side rails each support (40’ x 4’) 160 sqft

IBC Loads 1607.1 - Using Loads for “Other” which is a conservative 100 psf

100 psf x 160 sqft = 16,000 lbs or 16 kips

16 kips / 40’ = **0.4 kips per foot on top side rails**

Wind Load:

Fw=½ pv^2A where p =Air Density, v = Air Velocity, and A = Surface Area of Face

Average Max Wind Speed in Yerevan (March) = ~11 mph or 4.917 m/s

Conservative Wind Speed = 30 mph or 13.4 m/s

On a 40' x 8'-6" (12.192 m x 2.5908 m) Side of Container at 30 mph:

Fw = 0.5 x 1.2 kg/m^2 x $(13.4 \text{ m/s})^2$ x (12.192 m x 2.5908 m) = 3403.1 N x 0.224809 lbf/N = 765.038 lbf / (40' x 8'-6") = **2.25 psf**

On a 40' x 8'-6" (12.192 m x 2.5908 m) Side of Container at 80 mph:

Fw = 0.5 x 1.2 kg/m^2 x $(35.76 \text{ m/s})^2$ x (12.192 m x 2.5908 m) = 24.235.67 N x 0.224809 lbf/N = 5,448.4 lbf / (40' x 8'-6") = **16 psf**