Educational Adaptation of Cargo Container Design Features

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Abstract

Cargo container homes have become increasingly popular around the world in the last 30 years. Because cargo containers are modular in design, they can be used to create efficient, cheap homes. Repurposing cargo containers into homes is a sustainable construction practice due to the majority of the structure coming from recycled materials. Many design parameters of cargo container homes parallel those of standard home construction methodologies (cold formed steel framing/light wood framing) and from a structural standpoint, cargo containers are an effective building material. This paper aims to discuss the design parameters of cargo container home construction and an educational application of the concept. Problem-based learning (PBL) methodology was applied in order to create a discussion group. Building types were handed-out, scaled model and poster presentation were prepared by teams according to defined design parameters. Educational activity is evaluated by survey and critical points are determined to improve.

Keywords; Cargo container, problem-based learning, architectural engineering, reuse of structural material

Introduction

The concept of containerization has developed at great lengths over the past 300 years leading up to the modern cargo container. An American by the name of Malcom McLean is credited with the invention and patenting of the cargo shipping container. His success in owning the 5th largest trucking company in the United Sates (McLean Trucking Co.) allowed him to branch out to marine transportation. After purchasing the Pan-Atlantic Steamship Company in 1955, he began experimenting with different shipping methods. It was during his time as owner of the company that his idea for the modern cargo container came to existence. While it was not necessarily a new idea, the concept of an intermodal shipping container that could be loaded and unloaded with ease became very appealing to the U.S. military. Their influence helped to have the cargo container accepted as the standard for shipping lines all around the world. The cargo container was issued a patent in 1958 for an "Apparatus for shipping freight."

The cargo container is known by many names. When used for shipping, it is mainly referred to as a "shipping container," but can also be called an "ISO container," "Conex box," or "cargo container." When used as a construction material, however, it is referred to as an Intermodal Steel Building Unit (ISBU). Cargo containers are constructed from weathering steel. Weathering steel includes alloying elements that affect the materials corrosion process. Weathering steel forms an amorphous inner layer that protects the integrity of the steel. Figure 1 shows the placement of the layer as well as its composition. The continuity of the layer also adds to the protection of the steel[1].

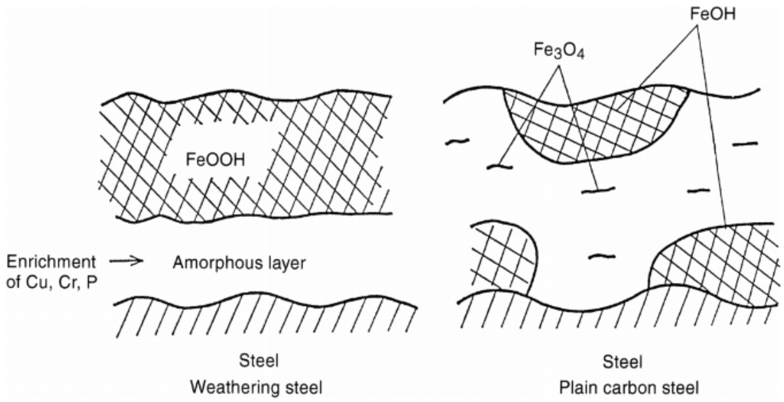


Figure 1. Schematic illustration of the corrosion product layers identified on steels exposed to rural and marine atmospheres for the periods of up to five years[1].

Furthermore, weathering steel is an ideal material for cargo containers due to their exposure to natural elements. Cargo containers spend the majority of their life outdoors on cargo ships, trains and trucks with little protection from moisture. The cargo container is an appealing construction material for a variety of reasons. First, their strength and durability provide both structural support and a long life span. Their weathering steel construction provides not only corrosion protection, but also strength. Also, with a movement toward sustainable construction practices, the recycling of unused cargo containers for construction material puts an unused product to use. Also, the cargo containers modular construction simplifies the design process. Much like bricks or CMU, cargo containers are designed to specific standards. Table 1 lists the dimensions of the standard sized containers.

Table 1. Standard cargo container dimensions[2].

		20′ container		**40′ container**		**40′ high-cube container**		**45′ high-cube container**	
		imperial	**metric**	**imperial**	**metric**	**imperial**	**metric**	**imperial**	**metric**
external dimensions	**length**	20′ 0″	6.096 m	40′ 0″	12.192 m	40′ 0″	12.192 m	45′ 0″	13.716 m
	width	8′ 0″	2.438 m	8′ 0″	2.438 m	8′ 0″	2.438 m	8′ 0″	2.438 m
	height	8′ 6″	2.591 m	8′ 6″	2.591 m	9′ 6″	2.896 m	9′ 6″	2.896 m
interior dimensions	**length**	18′ 8 13⁄16″	5.710 m	39′ 5 45⁄64″	12.032 m	39′ 4″	12.000 m	44′ 4″	13.556 m
	width	7′ 8 19⁄32″	2.352 m	7′ 8 19⁄32″	2.352 m	7′ 7″	2.311 m	7′ 8 19⁄32″	2.352 m
	height	7′ 9 57⁄64″	2.385 m	7′ 9 57⁄64″	2.385 m	8′ 9″	2.650 m	8′ 9 15⁄16″	2.698 m
door aperture	**width**	7′ 8 ⅛″	2.343 m	7′ 8 ⅛″	2.343 m	7′ 6″	2.280 m	7′ 8 ⅛″	2.343 m
	height	7′ 5 ¾″	2.280 m	7′ 5 ¾″	2.280 m	8′ 5″	2.560 m	8′ 5 49⁄64″	2.585 m
internal volume		1,169 ft³	33.1 m³	2,385 ft³	67.5 m³	2,660 ft³	75.3 m³	3,040 ft³	86.1 m³
max. gross weight		66,139 lb	30,400 kg	66,139 lb	30,400 kg	68,008 lb	30,848 kg	66,139 lb	30,400 kg
empty weight		4,850 lb	2,200 kg	8,380 lb	3,800 kg	8,598 lb	3,900 kg	10,580 lb	4,800 kg
net load		61,289 lb	28,200 kg	57,759 lb	26,600 kg	58,598 lb	26,580 kg	55,559 lb	25,600 kg

Cargo containers also feature corner assemblies that interlock the containers to one another, as seen in Figure 2. The locking mechanism provides stability when multiple containers are being used in the construction of a building. Cargo containers are designed to be supported from the four corners they sit on, which provides structural foundation advantages.

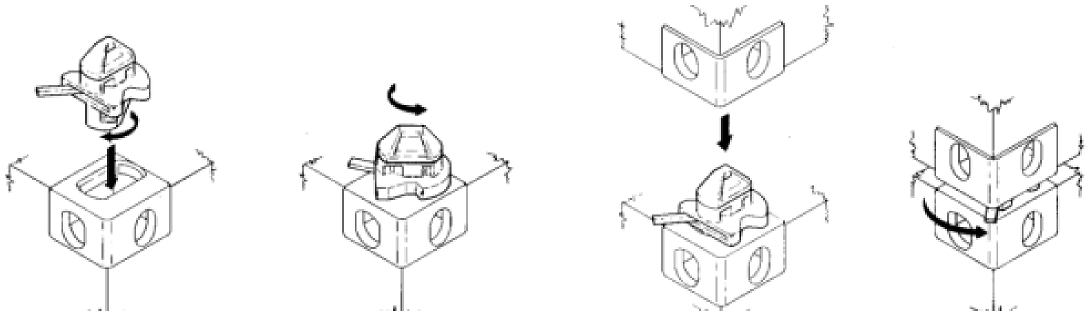


Figure 2 Illustration of corner locking mechanism[3].

Cargo containers are a useful construction due to their high availability. The cost of shipping empty cargo containers back to their starting location is higher than the cost of buying a new cargo container, so many containers are left sitting empty in ports all around the world. In 2012, according to Drewry Maritime Research, the global container fleet consisted of approximately 32.9 million TEU (Twenty-foot equivalent unit) [4]. That figure would estimate 32.9 million standard 20 foot containers, meaning that there is no shortage of cargo containers in the market today. Overall, the cargo container should be viewed as a valuable construction material.

1. Design criteria

1.1 Foundation

Cargo container homes require a foundation system just as any other residential dwelling would. While the design parameters for shipping container homes are constantly evolving due to the relatively young age of the technology, there seem to be two major methodologies in regards to a foundation system. Most cargo container homes utilize either a slab-on-grade foundation or a concrete pile foundation. A basement is possible with either of those two types of foundations, but because the cargo containers are intermodal containers (and thus can be moved easily) a basement would not be practical. Moving the containers would leave a large void that would be wasted. While a basement is possible, the scope of this paper will cover foundation systems for cargo container homes that do not have a basement.

As applied to cargo container construction, a home utilizing a slab-on-grade foundation system would lay a foundation and set the cargo containers on top of the foundation. This foundation system is a very simple methodology for cargo container homes. The modular units are placed on the floor slab and secured with bolts or fixtures set in the concrete slab itself. The slab-on-grade foundation system offers a solid platform that will easily support a cargo container home. An alternative to the slab-on-grade foundation is a deep foundation system. Two common types of deep foundations are a pile system and drilled pier system. The difference between the two systems is evident in their construction. A pile is typically a precast concrete cylinder that is driven into the ground, while a pier is cast on site in a drilled well. Due to having less dead load of a low-rise housing unit compared to a commercial building such as; shopping mall, mid or high rise hotel/office building etc., precast pile have a better solution over drilled piers in consideration of cargo container homes. This foundation system is also referred to as a raised foundation that is created by using precast piles. The home pictured in Figure 3 is clearly supported only by precast piles.

Figure 3. Cargo container home using precast pile foundation[5].

1.2 Structural system

The cargo container's steel construction provides the strength to stack containers upwards of 7 high. That strength, however, is dependent on the entire steel frame/supporting walls intact. Many cargo container home designs require the removal of entire sidewalls of the container, which has an obvious effect on the strength and safety of the containers. Giriunas, Sezen and Dupaix performed a container model analysis using SolidWorks, Hypermesh and Abaqus/CAE to collect information on the effects of removing steel sections from cargo containers. Their computer analysis compared 5 different loading scenarios on both unaltered and altered containers. Their results validated the claim that containers with walls removed yielded before the required capacity specified in ISO standards. Also, they determined that the roof had little structural significance, and that the end walls were the strongest load resistive components when subjected to vertical loads. Their research will hopefully lead to standards and specifications for the use of cargo containers being used in non-standard applications, following full scale testing[6].

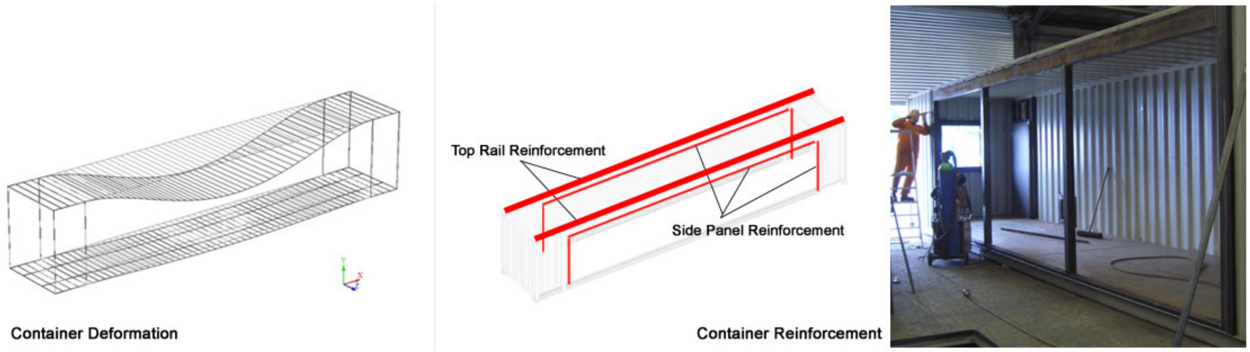


Figure 4. Deformation and prevention for cargo containers[7].

While there is very little literature currently available that discusses the statistical data and requirements for reinforcing cargo containers for residential use, there are many common methods that are used to both reinforce and secure the cargo containers in a safe and effective way. In regards to reinforcing, one concern is that the removal of major walls will cause sag. Figure 4 depicts both the potential deformation involved with the removal of walls, and a potential solution to the problem. Steel guardrails can be welded to the interior of the structure to provide additional support and stability for the container. The amount of reinforcement needed depends on the amount of material removed, and as previously stated, there are currently no set guidelines or building codes in regards to this issue. Along with the structural reinforcement, the connection of the modular units is a concern. Vertical connection is relatively simple, due to the nature of the container. Every container is designed with a fitting on each corner, originally intended to secure the containers in organized stacks during shipment. Those same corner connections prove essential in multi-story cargo container homes and can be used to secure the modular units together. This methodology is applicable when the containers are oriented in similar directions, as in Figure 5. Because the cargo containers are constructed from steel, welding can also be used to secure containers together in a permanent fashion. Securing the containers to the foundation is often successfully done by welding the containers to steel brackets cast in the foundation to provide a solid base for the home.

Figure 5. Cargo container home secured with original corner fittings[8].

1.3 Infill system

A cargo container home's infill system is one of the most functional and aesthetically pleasing aspects of the building. The infill system consists of the MEP system (Mechanical, Electrical and Plumbing), as well as aesthetical components. The home's insulation is also included in the infill system. In many ways, a cargo container home's infill system is similar to that of a home build from a traditional steel or timber framing system. Cargo container homes, however, have many more spatial limitations, as compared to a normal home or building. The design challenges are most prevalent in this portion of the design process because while the same families of components are necessary in a cargo container home, there is much less space to place them.

It has become a very common practice to first construct a non-loadbearing frame around the inside of the cargo containers. Both cold-formed steel and light timber can be used, and the framing system parallels that of a standard home. This internal framing offers both a means to hang drywall or gypsum board as well as a cavity to locate insulation and components of the MEP systems. Figure 6a depicts the construction of an internal steel framing system to separate rooms of the cargo container home. Also, voids can be cut into the container and framed in to allow for standard windows and doors. After the framing is complete, the electrical and plumbing systems can be installed. Again, the wiring and routing of plumbing is very similar to that of a standard home, with the exception of spatial requirements. Ventilation/central heating and cooling is a major challenge due to the height restrictions of the containers. A standard ventilation system is possible, however, with the usage of shallow ductwork concealed within a slightly suspended ceiling. Also, radiant heating and cooling systems require less space because of their use of hoses instead of metal ventilation ducts. The insulation methodology is again, similar to that of a home constructed by a standard methodology. Both insulating foam and blown insulation are possible insulation methods, and due to the internal framing, space is available to do either method. Many cargo container homes have become very successful in creating a modern, appealing interior design. Figure 6b features the interior of a cargo container home. The application of drywall, hardwood flooring, standard appliances and furniture, and lighting creates a home that is very similar to a modern home constructed using a standard methodology (i.e. without using cargo containers).

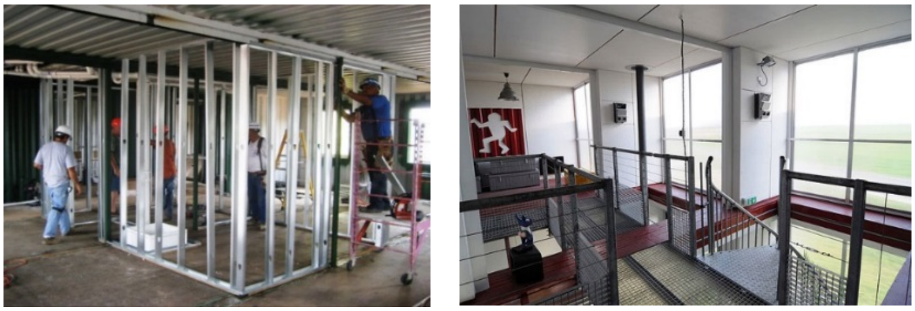


Figure 6. (a) Internal framing system for cargo container home[9], (b) Cargo container home interior[10].

2. Educational adaptation

"Materials and Methods of Building Construction" (Curriculum code; ArchE2103) course in Missouri S&T Architectural Engineering Program covers a variety of educational methodologies such as; traditional lectures, assigned supplementary reading, documentary movies, demonstrations (material test, site visit, and brick masonry wall mock-up assembly), discussion group and hands-on learning experiences. Among these methodologies, a discussion/work group was created consisting of three or four students working together completing hands-on tasks. The discussion/lab section of the course was divided into four modules. One of these modules focused on the implementation of cargo containers as a structural unit for an office space design. The duration of this study was three weeks with eleven teams.

Cargo containers are of particularly interest as a design platform because of their emerging popularity worldwide. They are very versatile because of their durability and relatively low cost, thus make for an interesting subject in showcasing the possibility of modular design.

Problem-based learning (PBL) methodology was applied in this section on cargo container implementation and in the latter module, which focused on residential home building utilizing conventional structural systems with variable floor layouts. Prior to introducing the "*PBL blocks*", a series of "*preparatory learning blocks*" were offered. This allows the students to become more acquainted with the subject. Preparatory blocks should provide students with knowledge they can apply in PBL blocks, and the PBL blocks motivate students to explore further in-depth study[11]. The "discussion group" study is also grouped in second module of the course and it can also be classified as preparatory learning block. In introducing this topic to students, a short presentation was given providing an overview of this design concept as well as details into the specification of the cargo containers' design. Getting a little more specific, this short presentation included the information regarding materials of construction, standard dimensions, load capacity, limitations, reason of usage in construction industry and lastly some built-up samples. This problem is being introduced to the class to be identified, formulated and solved as a real life problem with architectural engineering practice. One of the challenges of this assignment is determining the boundary or scope of work. This study, which is rather open ended, allows for students to purse the idea further with their own research or imagination.

2.1 Details of design

Due to time limitation of three weeks, typical building layouts are handed-out to the students at the beginning. Therefore, it was not a design studio activity, but an activity for each team to discuss the subject and make an assessment of requirements mentioned in the rubric. Results of the activity were submitted as assignments. From the construction of the models, the groups learned the design features, critical points, construction methods and building envelope of the cargo container. Design criteria were defined as;

a) An office or retail space with maximum 2 stories
b) Modular cargo container unit dimensions are;
   - Unit 1: (l x w x h) (20’ x 8’ x 8’ 6’’) (6.058 m x 2.438m x 2.591m)
   - Unit 2: (l x w x h) (40’ x 8’ x 8’ 6’’) (12.192 m x 2.438m x 2.591m)
c) Building types (Figure 7)

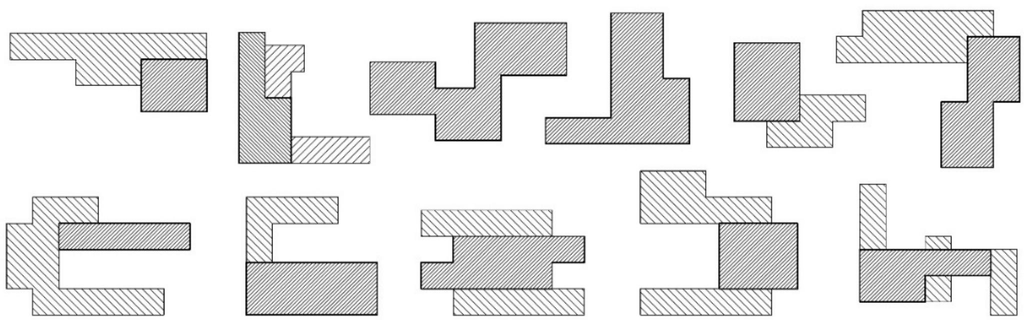


Figure 7. Building types.

2.2 Content of the assignment

Each team submitted the results of discussion on;

a. 20’’ x 30’’ foam board as ***“Poster Presentation”*** (including text and images). (70% of grading)
b. ***Scaled model*** with cardboard (1/50 scale) (30% of grading).

Expectation from the discussion groups and the content of the poster presentation is mentioned in rubric. In the future, the groups could present their work as an authority on the subject of cargo container design, which would help encourage group collaboration and further discussion. Scaled models were assessed as sufficient or insufficient. The minimum requirements for successful completion of the cargo container design are a complete consideration of all of the design challenges presented in their poster. The posters were graded as per handed-out rubric. These items were to be addressed as if the group were to implement a particular solution to this problem and for addressing the challenges of completing an inhabitable and marketable office space.

2.3 Results of the activity

The grade of the group is reflected by the successful completion of two different tasks, the poster which has details of the solution for successful design completion and the scaled model of the building/site made from prescribed materials, which in this case was foam board and corrugated paper. Samples of poster presentation and scaled models in 1/50 are shown in Figure 8 and 9. These models were graded on their accuracy, workmanship, and design vision and are a great method for understanding the 3-dimensional space of each building layout.

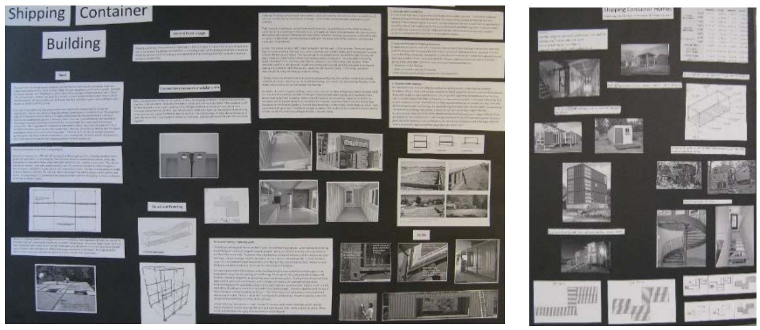


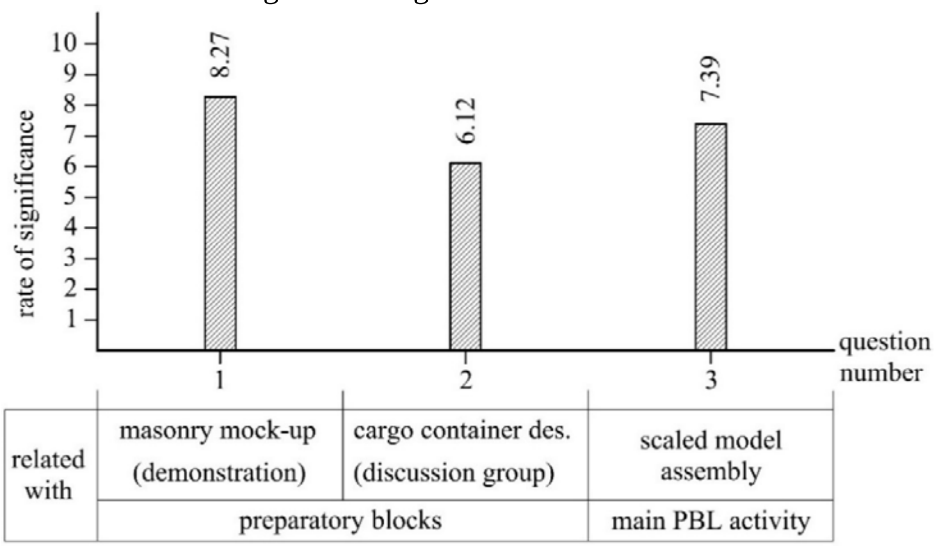
Figure 8. Samples of poster presentation.

Figure 9. Samples of scaled model in 1/50 scale.

2.4 Survey

The results of multiple educational methodologies have been evaluated by survey during the semester (Table 2). The survey was completed by students two times as before and after the term project. But, both were after the cargo container design activity and therefore the average of both survey is being reflected on this paper. There were 36 participant at 1st survey and 25 participants at 2nd survey. 73 percentage of participants' academic standing was sophomore and 54 percentage of participants had no construction experience. The rate of significance of this discussion group as cargo container design activity was 6.12 out of 10 and this rate was the lowest rate among other similar activities. These activities are compared to find out the critical points and improve the educational value of cargo container design activity. A partial masonry wall mock-up has been assembled by each team in a two weeks study. Drawings of the demo wall and assembly instructions were handed-out the students prior the activity. It was a task that each steps were clearly defined initially. Therefore, students' feedback was fairly positive as 8.27 out of 10. Similarly scaled model assembly as term project was a task project having clearly defined hand-outs (design guide) prior the activity. Whereas, students have to think outside the box in cargo container design activity. In Table 2 number 1 and 3 activities can be named as the task projects, but number 2 – cargo container design activity - was a discipline project. This can be the possible reason of having lowest rate of educational significance. In terms of analogy of a football game, this means that playing field is specified, some overriding guidelines are given for the game, but the ball has not been kicked off and thus the group must enter the field and set the game into play. The freedom on design or studied subject is increased and limitation on PBL is decreased in discipline project than the task project[12].

Table 2. Average rate of significance of educational activities.



In order to increase the rate of significance of this educational activity, critical points are determined and some improvements are proposed herein.

a. *Link between poster presentation and the scaled model;* separated studies were run at both assignment by teams but, more powerful link shall be maintained between two assignments.
b. *Design flexibility on building types;* design flexibility can result in handling more responsibility and sense of ownership over students instead of handing-out pre-defined building types.
c. *Duration of the activity;* the activity lasted 3 weeks as part of the lab and it was not a term project. It is recommended to do this activity in longer time and/or as a term project.

3. Conclusion

Cargo containers are a valuable modular construction material to be considered when designing a home. They have the structural capability and design parameters to produce a standard, living home in a variety of ways. Cargo container homes are both sustainable and cost effective due to the repurposing of the container itself. Container homes can be designed very similarly to a standard home, and should be heavily considered in today's market. Design standards like those presented in this paper should be standardized in order to create an efficient design process to produce cargo container homes on a larger magnitude. In order to increase the popularity of this reusable modular construction units, future architectural engineers shall be promoted and they have to be competent over basic design features. By using existing design parameters of cargo containers, a discussion group project has been created as a real life problem. The discipline project as part of problem-based learning lead the students to think outside the box which was the main goal of this educational adaptation. Student survey shows that positive feedbacks received from the students but improvement is necessary to increase the effectiveness of this activity.

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