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# Adaptability Potentials of Existing Residential Buildings in India

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**ABSTRACT: For large scale infrastructure projects, provision of housing for employees with their families becomes essential for the period of setting up of project. This time span may extend to few years. This type of project housing may become redundant once the project is operational. Shipping Containers have been viewed as prefabricated modular units for various architectural applications, especially for housing. For project housing, shipping container can serve as ready to modulate prefabricated units that can be assembled quickly on site and disassembled and reused somewhere else after the project is over. The retired cargo containers can be up cycled through architectural intervention and used for housing purpose. Thus, it reduces environmental impact of steel container by extending its useful life.**
**With this view, an exploration was done in the fourth year housing studio in the design of container housing. The objective of the design studio was to make the students understand how to use prefabricated units after understanding its structural strength, how to modulate shipping containers for given architectural application and climatic context and how to achieve architectural variation using modular units.**
**This paper discusses efficacy of use of shipping containers to reduce the environmental and financial burden. It further elaborates on the methodology employed in the design studio and also, the challenges and opportunities in the use of containers for housing as faced by the students during the studio.**

**Keywords**: Container housing, Housing studio, Upcycling of shipping containers, project housing etc.

## I. INTRODUCTION

The active life of cargo containers for shipping purpose is viewed between 8-10 years.[1] After these years, they are retired for shipping purpose. However, there technical life is more and they can last for 20-25 years further if maintained properly. If not used, these containers will be dumped in dock yards and will pose huge burden on environment for recycling and disposal. These are made up of steel and steel involves a lot of embodied energy in manufacturing and recycling too. Reusing these containers is considered as environmentally friendly option. Shipping containers have been used for habitable spaces for more than a decade for its number of attractive perks. Firstly, it is a ready to use shell that can be modulated for architectural purpose. Secondly, it is structurally sound system that can easily take loads of habitable spaces. Other benefits include its seismic stability, modularity, transportability and demountability after the use. In container architecture, most of the most of the work is carried out off the site (upto 90% including interior works) and thus, it saves on time involved in on site job and labor.

In the beginning, this paper discusses geometrical and technical aspects of containers. Further it elucidates design and technical challenges involved in the adaptive reuse of these containers. It then presents case studies of container architecture in India and opportunities for the same in India. In the next chapter, it elaborates on methodology used and explorations done in forth year design studio in the design of container housing and outcome of the studio. At the end, it draws conclusions based on literature survey, case studies and studio outcome.

## II. UNDERSTANDING THE CONTAINER

Before one starts with a design process using prefabricated module, it is highly essential to understand that unit geometrically and technically. Geometrically, container is a cuboid that comes in different modules as given in Table 1

Among these, HCs (High Cubes) become more useful since they provide habitable space for architectural application. [3].

Structurally, containers are monocoque structures meaning that the exterior skin of the unit provides structural support. [4,5] Monocoque construction is an automobile design technique and it differs in load transfer from traditional framed construction [6] where in the traditional framed structure, the frame transfers the load and skin behaves as a partition to safeguard against weather.

**Table 1: ISO Container Modules.**

| Type | External Size | Internal Size | Weight of empty container |
|---|---|---|---|
| 20 GP | 20'x 8' x 8'6" | 19'4"x7'8"x7'10" | 2,330 kg |
| | 6.058 x 2.438 x 2.591 | 5.898 x 2.352 x 2.385 | |
| 20 HC | 20'x 8' x 9'6" | 19'4"x7'8"x8'10" | 2,350 kg |
| | 6.058 x 2.438 x 2.896 | 5.898 x 2.352 x 2.698 | |
| 40 GP | 40'x 8' x 8'6" | 39'5"x7'8"x7'10" | 4,000 kg |
| | 12.192x2.438 x 2.591 | 12.032 x 2.352 x 2.385 | |
| 40 HC | 40'x 8' x 9'6" | 39'5""x7'8"x8'10" | 4,200 kg |
| | 12.192x2.438 x 2.896 | 12.032 x 2.352 x 2.698 | |
| 10 GP | 10'x 8' x 8'6" | 9'3"x7'8"x7'10" | 1,293 kg |
| | 3.048 x 2.438 x 2.591 | 2.834 x 2.352 x 2.385 | |
| 45 HC | 45'x 8' x 9'6" | 44 4"x7'8"x8'10" | 4,740 kg |
| | 13.716x2.438 x 2.896 | 12.032 x 2.352 x 2.698 | |
| 53 HC | 53'x 8' x 9'6" | 52' 5'x7'8"x8'10" | 5,039 kg |
| | 16.154x2.438 x 2.896 | 16.022 x 2.352 x 2.698 | |

Source: ISBU Association [2]

Thus, in the monocoque system, skin provides structural integrity to the unit and reduces the weight of the unit significantly without compromising its load carrying capacity. This clearly indicates that any modification in the skin of cargo container in terms of opening will affect the structural integrity of the container. Although, containers have potential to provide a habitable space dimensionally, they are not manufactured for architectural application. They are meant to transport cargo from one place to another by road, air or waterways. Since they are transported through open ships and stacked in open yards, they are designed to withstand extreme climates. They are made up of CorTen-steel that develops a protective layer against weathering action [7,8]. Also, containers are watertight and airtight structures since they have to carry goods over a long distance for longer duration. Thus, they are necessarily closed structures having doors for loading and unloading on one of the shorter side (Fig.1).

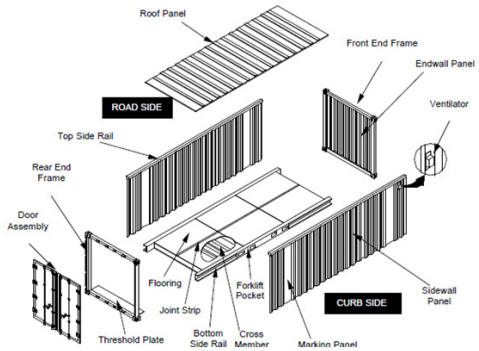


**Fig. 1.** Components of cargo container.
Source: http://containerauction.com

As far as load transfer in cargo containers is considered, vertical load is transferred directly through the corner columns, which are restrained laterally against buckling by the steel infill panels [Fig. 2].

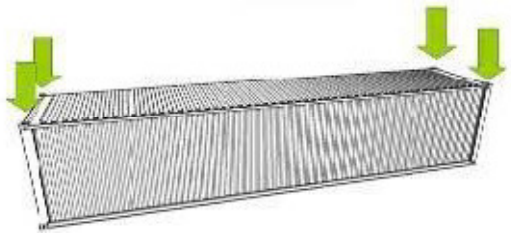

**Fig. 2.** Load transfer in containers, Source- [1].

Horizontal loads are transferred through the sidewalls of the containers for buildings up to 11 stories or for higher buildings through a combination of braced steel cores and the container walls [9].

## III. DESIGN AND TECHNICAL CHALLENGES IN MODIFYING CONTAINERS:

*A. Dimensional constraints*

By its virtue, container is not designed for architectural purpose. Therefore, it needs a lot of modification to convert it to habitable unit. The design challenges in using containers for architectural application especially for housing arise out of its dimensional configuration as also from technical configuration. The functional requirements in a house necessarily require certain dimensions of spaces. All the modules of containers have not more than 2.438m width which internally reduces to 2.352m. This is a too tight space for rooms like living rooms and bed rooms. This necessitates joining of two containers along its length so that width of the space can be increased. This in turn requires removal of skin of container on its longer side that poses a threat to the structural integrity of container [5].

For larger units, where 3 containers are joined together along its length, the middle container loses both of its side panels and undergoes buckling of the roof panel. (Fig.3).

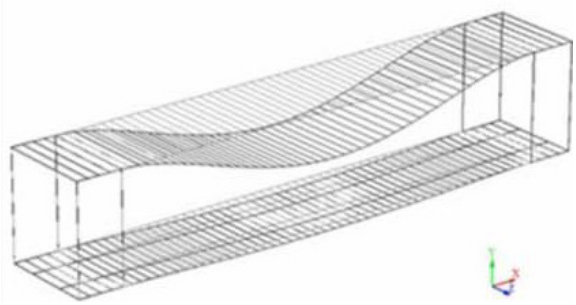

**Fig. 3.** Deformation of container roof in case of removal of side panels.

To avoid this, top rail reinforcements as well as vertical supports are required to be added. These vertical supports may pose constraints on internal spatial planning.

*B. Openings*

Similarly, adaption of container is required to create openings for light ventilation and access. Whenever an opening is created in side panels, steel framing is required to frame out the opening (Fig.4).

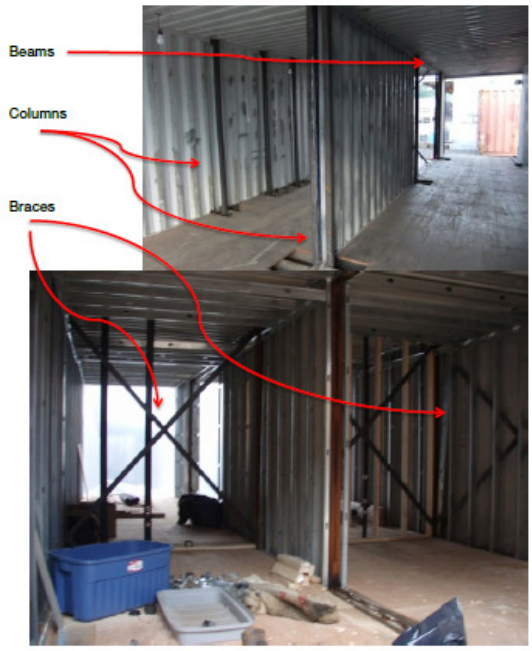


**Fig. 4.** Modifications in container, addition of reinforcement. Source: JTW consulting [4].

The important point to be noted here is, the opening in end panel, reduces the structural integrity of container significantly as compared with side panels. Also, especially in Indian climate, these openings on the skin are required to be furnished with weather-sheds to a corrugated panel of skin. Providing a weather-shed on a corrugated panel and making it watertight is quite a design and technical challenge and demands critical detailing. Modification to the containers involves a lot of steel cutting, addition of supports and welding process.

*C. Thermal and Acoustical Insulation*

As mentioned above, containers are not manufactured with an intention to be used for architectural purposes. All of its structural components are made up of steel that is good conductor of heat and sound. Therefore, its acoustical and thermal characteristics do not satisfy requirements of habitable space. Containers have been widely used globally for different architectural uses in different climatic conditions like humid temperate climate (Scotland and Keetwonen Student Housing in Amsterdam), temperate oceanic climate (Container City I and II, London), hot temperate climate (two-storey Redondo Beach House which was built in 2006 in Southern California, US and Container of Hope built in 2011 in San Jose, Costa Rica) and cold climate (Chalet Du Chemin Brochu in Quebec, Canada and Nackros Villa in Sweden)[3]. As mentioned by Ismail et.al [3], implementation of containers for architectural use in hot and humid climate is not widely spread because of number of uncertainties including negative perception of its acceptability in this type of climatic condition. However, he emphases that these constraints could be outweighed by its advantages in terms of modularity, transportability and durability, provided that appropriate installation and modifications are made to the container building to ensure its comfortable indoor environment. For providing this comfortable indoor environment, roof and side panels of containers need to be acoustically and thermally insulated. Also, before laying the insulation and surface paneling, all the electrical, plumbing and drainage services have to be laid as per requirements. For this purpose, architectural plans along with furniture layout have to be critically worked out envisaging the future requirements that may arise over a longer period of time. Thus, container architecture requires different kind of detailing than regular structure since the shell is composed of metal [10]. Another important point that one has to consider is that all these services have to be carried through ceiling and side panels and not through the floor. The reasons for this consideration are: The floor to ceiling height is already limited. Therefore, laying services in both the ceiling and the floor would further reduce the clear floor height significantly. Secondly, Roof panel requires false ceiling for acoustical and thermal insulation. Therefore, one cannot compromise with the false ceiling. On the other hand, floor can be finished with minimal thickness of any floor finish like carpet or any type of floor tiles.

**Fig. 5.** Insulation to ceiling and walls. Source: JTW consulting [14].

*D. Stacking of Containers*

Another design and technical challenge in the design of container buildings is stacking of containers horizontally and vertically. As mentioned above in III.A, to increase the width of the habitable space, containers need to be stacked side by side along its length. Or a single unit design, if containers are stacked perpendicular to each other or along its width it leads to a lot of wastage of space in passages. There are no structural issues in connecting containers horizontally. However, there are spatial concerns (interior layout and space making) in arranging them horizontally. Once the housing units are ready, there are a lot of opportunities in playing with their horizontal arrangements to make community spaces.

The next challenge is how to stack them vertically. There seems to be ambiguity in the available literature as to how many containers can be stacked above each other. According to Karam M, 6 units of fully loaded containers can be stacked above each other [3]. Whereas, Robinson M and Swindells S [9] states that buildings upto 11 stories could be built by stacking containers one above the other. While during the interview with designer Dhara Kabaria and visit to Jawaharlal Nehru Port Trust, authors found that generally 9 containers are stacked above each other in ships and 5 containers are stacked above each other in the dock yard. In India, 5 storied buildings are possible with containers due to lifting limitations of crane. Containers are stacked along same axis while shipping. Although there are no issues of structural stability if containers are stacked one above the other along the same axis, it limits the innovation and creativity in building design [3] and also, this kind of arrangement gives the visual impression of a dock yard. Many of the case studies of housing containers indicate that containers can be stacked in different manners. Designed by CG Architects in France, a container house is built where containers are stacked in cross manner. (Fig. 6). Although, it is possible to stack containers in cross stack configuration, it requires significant and expensive engineering to take care of structural safety [11].

**Fig. 6.** Cross stacked home, France. Source: [11].

Along with structural stability, the other concern in stacking of containers for multi-unit housing is co-ordination of services. Use of containers allows positioning of wet areas (kitchens, utility areas and toilets) anywhere as per requirement within one unit. However, when it comes to multi- unit housing, design of service core becomes critical to minimize cost of laying service lines. Thus, stacking plays a crucial role in the design of service cores for container housing projects.

*E. Labour*

Working with containers requires skilled labor for modulating it for habitable use. Cutting, welding, addition of structural members, fixing up services, door and window fixtures, weather-sheds, insulation and finishes to corrugated metal sheet is indeed a skilled job. Training labor for this purpose is essential where container architecture is seldom practiced. Sometimes labor cost increases to 15-20% as time involved is more than conventional fabrication works. [10]

## IV. ARCHITECTURAL PROJECTS USING CONTAINERS IN INDIA-AN OVERVIEW

Use of containers for architectural projects is observed seldom in India. A Pune based designer and founder of design firm named Studio Alternatives Dhara Kabaria

has experimented with containers for handful of projects. These include Farm-house, Vocational training school for village teenagers, Activity center for an NGO for village school, Driver's waiting area, Toilet block, Mobile Machinery Display and Office Space etc. [10] Studio Alternatives have executed these projects very recently between 2014 and 2016 (Fig. 7-9).According to Dhara Kabaria, the concept of container housing in new in India and people are still taking time accept this form of housing.

**Fig. 7.** Farm House by Studio Alternatives
Photo courtesy: Dhara Kabria.

**Fig. 8.** Alternative Home, ready to install farmhouse
Photo courtesy: Dhara Kabria.

Another company called Container Solutions India is a Bangalore based venture, specializing in the use of shipping containers to create cost-effective structures for regular use. [12] Kameshwar Rao, has built his house using four scraped shipping containers in Banglore. [13] (Fig. 10).

**Fig. 9.** Activity Center for NGO, Uchat Village
Photo courtesy: Dhara Kabria.

**Fig. 10.** House of Mr. Rao, Banglore
Source: [12].

There are other very few companies who deal with ready to install residential units and office spaces.

In India, 20'x8' standard used container costs around INR 56,000 to 65,000depending on its condition whereas 40'x8' High Cube used container costs around INR 96,000 to 1,25,000 [10]. The container provides ready to modulate shell at cheaper cost compared with conventional framed construction. Considering the cost of adaption, one can save upto 20% on the cost of the shell.

In the California, US, Regulations (IR) are formed to define the requirements for the conversion of cargo containers to modular school buildings. In these regulations, code of construction and safety is defined for such adaptive reuse of cargo containers. The norms are defined for visual and technical scrutiny to check whether the containers are structurally sound to be reused for architectural purpose [14].

As against this, in India, National Building Code does not address the issue of adaptive reuse of shipping containers. Therefore, the safety and structural integrity is solely left to the designer's consciousness. Generally, the containers are inspected by professionals visually and reports of the damage/repairs are scrutinized before buying the container by the designers. However, it is important to note that there is no codal provision in India in this regard.

## V. OPPORTUNITIES FOR CONTAINER H OUSING IN INDIA

India is surrounded by ocean on her three sides. India has 7500km length of coastline. There are 213 ports in India in total out of which 13 are major ports and 200 are non-major sea ports. Enormous amount of trade takes place at these ports. The transportation cost of sending the empty containers is higher than using new containers for export.

The dock yards are full of empty cargo containers that are ready for sale. If not reused, these containers will pose environmental issue of recycling them. In such a case, reusing or up-cycling them is the best option.

Also, there are number of manufacturing companies of cargo containers in India. All these facts indicate the opportunity for container architecture in India where access to housing is considered to be the constitutional right.

As discussed in point III, there are number of constraints in designing with containers. The modular nature, fast construction, portability, demountability, saving on resources and time as also the ready to install spaces bring out various opportunities for using shipping containers though.

## VI. DESIGN STUDIO- PREMISE

Infrastructure development of India is on the priority list of the Government of India. Numerous large scale infrastructure projects are being set up in various parts of the country. Most of these projects are away from the urban areas or even large settlements. But the scales of the projects are such that they employ thousands of people at the site of the project. These people represent a cross section of society in that they include people with very high skill sets, professionals, consultants, and contractors, supervisors, to skilled and unskilled labourers. All of these work on the project for a long duration often extending to a few years. Due to this reason, they prefer to move in with their families if proper facilities are provided near the project sites. Such sites develop as project townships and are set up by the government/ companies at large project sites. These are mostly developed for the duration of the project but a part of them continues to remain and grow even after the project is operational.

The Jaitapur atomic power project in Konkan area of Maharashtra is one such mega project initiated by the Government of India. It is in the process of being set up and will take around twenty years for its to be completed and fully operational. A large team of people ranging from scientists, engineers, managers, various specialised consultants, contractors, administrative personnel, supervisors, skilled workers and labourers are working on the project currently and more will be required in the future as the project progresses into its subsequent phases.

The Jaitapur Power Corporation has already designed housing for the people working on the project along with basic amenities like convenience shops, dispensary, club, entertainment centre, sports facility, etc. The small village nearby also provides basic services to this colony. This housing will be developed in phases as the work on the power plant proceeds to advanced stages. While a part of this housing will be a permanent colony for people employed in the power plant after its commissioning, one part of the housing is meant for people working on the site of the plant during its construction and commissioning phase. This housing is for such personnel who will be at the project site anywhere between five to twenty years. After that, these personnel will not be required at the site and will move elsewhere. But for this duration, they would be expected to move in in this proposed colony with their families and will be allotted a well-equipped residence for the duration of their stay.

Taking into account the duration of the housing required and its redundancy once its purpose is served after twenty years, we proposed the idea of building a housing that may be durable for a period not exceeding twenty five years or else transportable to some other site if it serves its purpose at this site earlier. Such a criteria according to our study can be fulfilled by experimenting with used shipping cargo containers for housing units. The fact that the power project is located on the Arabian sea coast and containers can be shipped to the nearest port also strengthened the decision. We proposed a two stage process for the sstudio.

## VII. METHODOLOGY AND CHALLENGES OF THE STUDIO

The first step was to understand the process of transforming the containers into habitable spaces. A site visit to Studio Alternatives, where there is a workshop to adapt containers into spaces usable for human activities, gave the students an insight into the practicality of the whole exercise. Here they saw containers being opened up for making larger spaces, windows and doors being cut into the container sides, insulation being installed along walls and the ceilings and services being introduces inside these newly conceived spaces. Queries about selecting the right containers, transporting them, stacking them and their durability were also answered.

The second step was to actually start putting containers together on paper and exploring how to make good domestic spaces from them. The challenge here was to break away from the rigour of the 8’ grid of the containers and expand spaces beyond it so as not to compromise on the working dimensions of household activities. The other challenge was to vertically stack these units in a structurally logical pattern. At the end of the second stage, it was expected that the student designers submit a detailed design including internal furniture and service layouts, details of making doors and windows, partitions, roof and ceiling, etc. to convert a shipping container into a residential unit.

The third step was to form clusters of housing units such that the stack of containers and thereby the entire housing development does not appear like a container yard but has the ambience of a housing neighborhood. At the end of this stage, the student designers had to submit detail designs of various sizes of units (32 sqm, 48 sqm, 80 sqm, 112 sqm, 144 sqm) along with their structural, service and construction details and internal furniture layouts, design of clusters, and design of the entire housing colony along with its open spaces and amenities.

It is expected that the designs are not only technically sound but also take into account basic aspects of housing and community building thorough design so that the project results into livable and enjoyable neighborhood. It should facilitate integration of the employees into a harmonious community.

The cadres of personnel for which this housing was to be designed were in the range of Supervisors, Junior Engineers, Senior Engineers and Consultants, Project managers and Scientists, Directors, Heads of Departments, etc.

## VIII. STUDIO OUTCOME

The following observations were made from the 30 design proposals that the student designers submitted:

a. Mixing two sizes of containers (i.e. the 20'and 40' length) not only gave better layout possibilities due to the stagger, but also resulted in interesting massing compositions when stacked.

b. Containers were joined laterally rather than longitudinally to get better interior spaces. Staggered arrangement of containers reduces the necessity of intermediate supports while also allowing smaller spaces like toilets and kitchen utilities to be separated from living spaces.

c. Placing containers or pairs of containers perpendicular to each other rather than placing them all in one direction in plan led to a better configuration of internal spaces.

d. Containers were also joined vertically to form duplex houses. But very few students made an attempt to place a container vertically to form the staircase shaft.

e. Terraces were formed by staggering containers thereby breaking away from the yard like stacking and creating a more humane and interactive house cluster.

f. Despite the geographical context of the project being the coast of Maharashtra, and despite the predominance of the local vocabulary of houses with sloping roofs due to heavy rains, most of the student designers preferred to keep the top containers as they are with their flat tops.

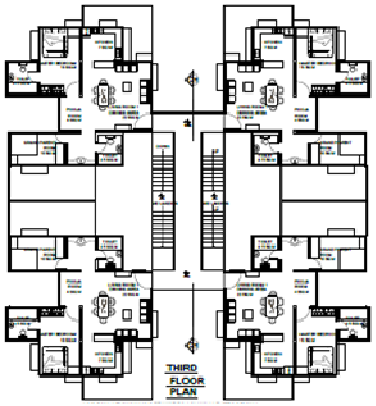


**Fig. 11.** Container Housing. Source: Vishakha Deshmukh.

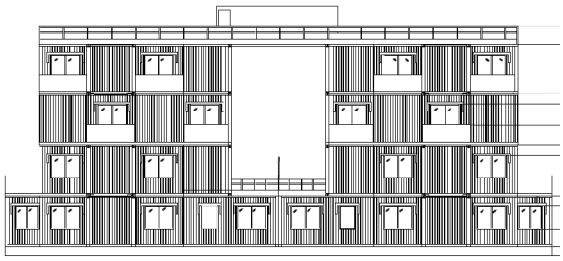

**Fig. 12.** Container Housing. Source: Vishakha Deshmukh.

Discussions about this issue held forth two reasons for this preference:

i. The reluctance to add structural clutter to a clean and straightforward prefab unit

ii. The preference of retaining the visual character of the container rather than masking it or making it look like something it is originally not supposed to be.

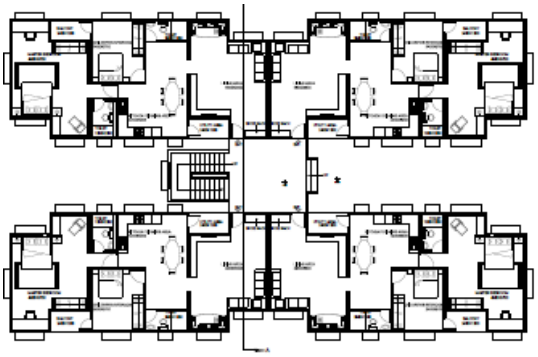

**Fig. 13.** Container Housing. Source: Siddhi Solanki.

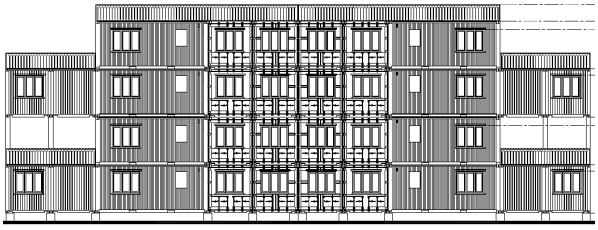

**Fig. 14.** Container Housing. Source: Siddhi Solanki.

Very few student designers chose to externally clad the containers with any finishing material. Most of the projects retained the container look. Massing was the main tool used to break away from the feel of a container yard rather than any material addition to the containers.

Important technical issues like sealing gaps between vertically stacked containers, fixing weather sheds to containers, water proofing the terraces, and strengthening of structural members of the container after removing sides were poorly addressed by the student designers. Though discussions were held on these issues and working solutions showcased through case studies, the emphasis of the designers remained on space making rather than technical detailing of the modified containers.

## IX. CONCLUSIONS

There is a limited research done so far in the field of shipping container architecture since this field is relatively new. With the overview of studio outcome and case studies in India, it can be concluded that there is a lot of scope for explorations and research in this field. Looking at the opportunities for container architecture in India and the incentives it can bring, there is need to explore this form of architecture in India. Also, a study of post occupancy evaluation of container users is required to be done in Indian context to understand the issues related with users' comfort and preferences. This study will give insight into users' perspective of container architecture. The current study was limited to exploration of unit, cluster and neighborhood design using containers and especially to ascertain whether housing as per Indian space requirements and typology is possible to be designed using this prefab unit. The studio amply demonstrated that housing using upcycled containers can be explored in practice as a viable option in India.

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