ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research, volume 475
Proceedings of the 3rd International Conference on Dwelling Form (IDWELL 2020)

Refurbished Shipping Containers as Architectural Module in Bandung

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ABSTRACT
This paper describes how old shipping containers can be modified and adapted into a new function such as building modules. Literature studies, study case (Day & Nite Eatery and Grocery, Bandung), as well as tracing back the shipping container through modification, storage, and inland depot were conducted to describe the life cycle of the container. Modern cities nowadays can flourish with the constant flow of goods from neighboring cities or even cities from across the world. Meanwhile, in the shipping industry, the demand for new containers is always high due to the changing regulations, economic trends, and the needs of the delivered goods. This situation leads to the pile-up of old containers at the port and the surrounding depots. Having an international standard that regulates size, material, durability, and strength of a container become both an opportunity and a challenge in designing container-based buildings. Situated 760 m above sea level, Bandung has a short dry season with an average annual temperature of 26.8 °C. While other studies showed that a shipping container's effectiveness in providing a comfortable indoor environment in the hot-humid tropics is not very convincing, the study case in this paper indicates that having a right local climate and landscape could provide comfortable indoor temperature without any additional insulation. The application of adaptive reuse presents an opportunity to reduce carbon footprint as well as waste in the landfill. Many potentials can be achieved by having the right climate, landscape conditions, proper planning, and a good understanding of the shipping container.

Keywords: *Shipping Container, Adaptive Reuse, Material Life Cycle, Modular Architecture, Sustainable Architecture, Thermal Comfort*

1. INTRODUCTION

Unlike the ancient cities, modern cities don't have to be established along river banks. With the concentrated collection of infrastructures like highways, railroads, and ports, it can flourish with the constant flow of goods from neighbouring cities or even cities from across the world [1].

These goods, particularly which come from places across the world, are delivered using a shipping container. Dated back from the 1960s, the International Organization for Standardization (ISO) and the International Maritime Organization (IMO) played a vital role in the success of international shipment and containerisation. They have developed an inter-operable transport system with around 20 million container boxes linking a global network of container terminals and depots [2] [3].

However, with the ever-changing regulations, fluctuation in the global market, the needs from the goods itself, and the foreseeable future of autonomous and environmental friendly shipping [4] [5] [6] [7], the high demand of a new, up-to-date shipping container lead to the pile-up of the old one.

Many studies showed that there is an abundance of used containers left in the major ports around the world, especially in the importing countries. It happens because the cost of a new container, especially in Asia, is relatively cheaper than sending it back to the origin countries [8].

Due to these situations, the increase of depot capacity is required. Not only to store empty containers that wait for the next shipment, but also to store old containers that are considered to be unfit because of damages or simply obsolete. Nevertheless, increasing depot capacity through expansion is a complex issue for most container depots in Indonesia [9]. Particularly in Jakarta, depots are situated in the middle of densely populated areas with a high risk of floods and land subsidence. Expansion through land acquisition around terminal or depot is really complicated.

Having a very systematic and regular shape, shipping containers could be reused into many types of functional spaces. ISO standards also regulate the strength, durability, and life span of a container. Due to its structural strength and twistlock system, shipping containers can be piled up to 9 storey. Not to forget that container was built to be easily transported and can be constructed in a relatively short interval of time with a reasonable cost. With all these benefits, many attempts using containers to create

interesting architectural spaces have been done around the world [10] [11] [12] [13].

Many terms are also used to describe those attempts such as: 'remodelling', 'retrofitting', 'conversion', 'adaptation', 'reworking', 'rehabilitation' or 'refurbishment. However, in this paper the term is known as 'adaptive reuse'. An essay by Plevoets and Van Cleempoel describes multitude design approaches of adaptive reuse with examples from around the world and throughout history. Those approaches that were explained are: typological, technical, programmatic, and strategic approach. [1] [14].

The emphasis of adaptive reuse is, that reusing existing material is a sustainable practice since the amount of resources needed for reuse being generally far less than those necessary for new constructions. In a world faced with climate change, increased resource scarcity, and other environmental challenges, shifting material life cycle from cradle-to-grave, into cradle-to-cradle opens access to new material resources and solve the costly disposal of waste [14] [15] [16].

The remainder of this paper is structured as follows. Section 2 provides a brief description about shipping container, its ISO regulations, and opportunities through modular architecture and adaptive reuse. Section 3 presents the manufacturing condition in the depot while section 4 is about the study case 'Day & Nite Eatery and Grocery' in Bandung. At the end, section 5 summarises the findings and its value to future researchers.

2. ISO REGULATION, MODULAR ARCHITECTURE, AND ADAPTIVE REUSE

The modern shipping containers have standards and regulation from the International Standards Organization (ISO), which include: ISO 1496-1:1990; ISO 668:1995; ISO 3874:1997; ISO 830:1999; and the latest one ISO 668:2020. There are a lot of things regulated by these ISO standards, but this paper focuses on the most common features that coincide with modular architecture design such as: size, strength, and material.

The most common containers sizes used since the introduction of ISO regulation are 20', 40', 20' High Cube (HC), 40' HC and 45' HC. However, many architects prefer to use High-Cube Containers since the internal height of those containers (2.7 m) enables a minimum ceiling height around 2.4 m. This ceiling height is common and comfortable height in many countries and there are spaces above the ceiling for utilities purposes.

General information of ISO based containers are shown in Table 1, with Floor Area calculated from the interior dimensions and Maximum Load is calculated by dividing Pay Load to Floor Area.

While the minimum live load for residential and office area ranged around 40 - 100 psf (1.91 - 4.71 kN/m^2) [17], it is easily recognized that container strength is capable to withstand the load of its general purposes. Other studies also provided evidence for effectiveness of container walls and roof in resisting loads [18]

With 2 mm corrugated steel panel walls and roof, ISO container is supported by four steel corner posts and I-beams structure for flooring that is covered with a plywood. The floor (28 mm thick) is supported by a steel grid, which constitutes the base structure. Corrugated steel can act as shear walls that also helps the steel frame to hold the load.

While serving its purposes on the ship, containers can be stacked up to 8 or 9 stacks. This common practice means that containers have the potential to become a multi-storey building. Containers also have advantages in transportability, with the ease of moving them from one place to another. They are popularly used as the main material in modular buildings that can reduce cost of construction [8] [10] [19] [20].

Not only in architecture, the term modularity has been studied and used in a wide variety of disciplines. Definitions and concepts of modularity generally include many aspects,

Table 1. ISO Container Properties

		20' High-Cube Container	40' High-Cube Container	45' High-Cube Container	20' Container	40' Container
Exterior Dimensions	Length	6058 mm	12192 mm	13176 mm	6058 mm	12192 mm
	Width	2438 mm	2438 mm	2438 mm	2438 mm	2438 mm
	Height	2896 mm	2896 mm	2896 mm	2591 mm	2591 mm
Interior Dimensions	Length	5898 mm	12032 mm	13556 mm	5898 mm	12032 mm
	Width	2344 mm	2344 mm	2344 mm	2344 mm	2344 mm
	Height	2695 mm	2695 mm	2695 mm	2385 mm	2385 mm
Empty Weight (Tare)		2320 kg	3950 kg	4800 kg	2200 kg	3800 kg
Net Load (Pay Load)		28160 kg	26530 kg	25600 kg	28200 kg	26600 kg
Floor area		13.82 m^2	28.20 m^2	31.78 m^2	13.82 m^2	28.20 m^2
Maximum Load		19.96 kN/m^2	9.22 kN/m^2	7.90 kN/m^2	19.99 kN/m^2	9.24 kN/m^2

but most of the studies always refer modularity to these three keywords: independency, interchangeability, and standardization [21] [22] [23] [24] [25] [26] [27] [28].

Already regulated by ISO standards, shipping containers are basically independent yet it is easily interchangeable in various combinations and can be reused with minor modifications. In addition, modular constructions considered more flexible to changes especially in the environment that swiftly evolved due to the rapid changes of economy, policy, and technology [1] [29].

ISO containers are made of corten steel. A group of steel alloys that are more resistant to corrosion than normal steel. However, in terms of thermal conductivity, it has way higher value compared to other common material used for building's facade (corten steel: 42.7 W/mK, red brick: 0.6 W/mK, concrete: 0.8 W/mK, wood: 0.12 W/mK). It becomes a major challenge to achieve a sustainable yet comfortable condition when a designer tries to readapt a shipping container [8] [12].

While adaptive reuse is widely known as a method for working with existing or heritage building, according to the study by Plovets [14], container based buildings revealed mostly one aspect of the method which is the technical approach. Container based building imposed more technical challenges on the designers to produce newly adapted spaces. There is little to no consideration of conservation. It is as simple component reuse, where parts or all of an old building are reused and supplemented by other reclaimed components [15] [30].

However, this simple approach still have a big impact to our environment since melting 3.63 ton shipping container requires 8000 kWh of electrical energy to convert them into steel blocks, while the process of reusing that entire 3.63 ton of shipping container into a home building takes only 400 kWh of energy, which is only 5% of the energy required to melt it [19].

3. DEPOT, MODIFICATION, AND CONTAINER DISTRIBUTION

A depot is a storage area for empty shipping containers. Particularly in Jakarta, many depots are located around Tanjung Priok Port, especially alongside the highway as an inland container depot (ICD). Apart from storage, they also provide a wide scope of individual services such as cleaning, reparation, fumigation, commercial warehouse, and container sales.

There are two depot that were surveyed for this paper: PT. Malaka Jaya Abadi and PT. Bestindo Central Container. The latter is located right beside the highway. Both depot are in 10 km radius from the port to provide security and assurance for road transport to the port as well as from the port [31].

Ten years old containers are considered purchasable, while containers which are not yet 10 years old but already leaking, damaged, and unfit for use can also be bought. At PT. Bestindo Central Container, newly arrived containers will be inspected and damaged containers will be taken to a designated workshop area to be repaired.

In addition to storing and repairing, PT. Malaka Jaya Abadi also offers the opportunity to modify containers for the

Figure 1 Satellite Image of North Jakarta

purposes of warehouse, café, or office. This company acquire containers or its parts from other depots or dry ports, especially containers that are no longer suitable for shipping purposes.

All the modification works are by the request of customer/ architect and containers are stored in the company's property. Having all the modification being done in this workshop (Fig. 2) will reduce cost and workload on the actual construction site. However, located 2 km from the nearest highway (Fig. 1) makes distribution with freight trucks challenging due to the travel distance and road width.

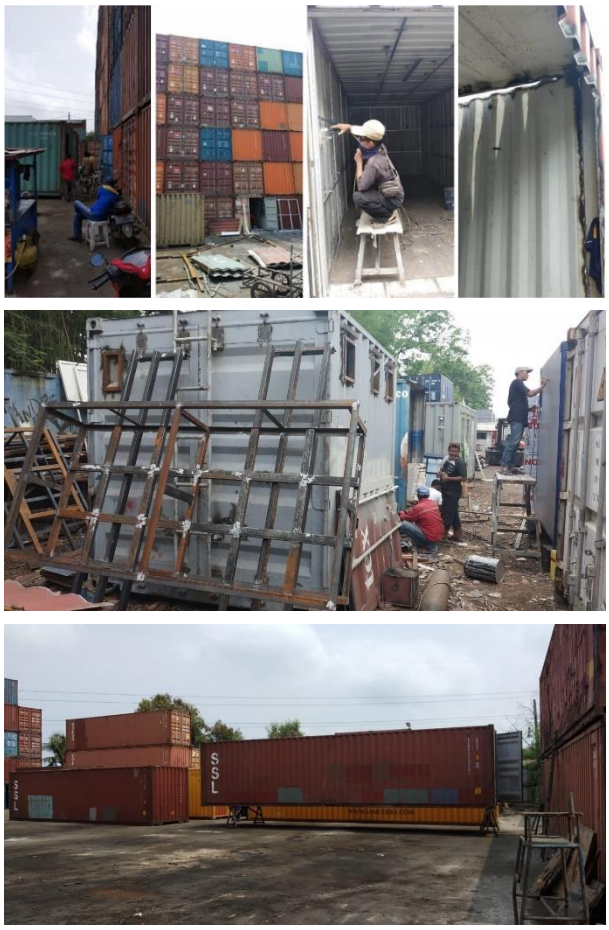

Figure 2 Workshop Condition

4. DAY & NITE EATERY AND GROCERY

Day & Nite Eatery and Grocery is located at Dago Atas, Bandung, and 9.5 km from the city center. Situated about 760 m above sea level and classified as tropical wet (Am) in the Köppen-Geiger climate classification, Bandung has a short dry season with the average annual temperature of 26.8 °C [32]. A study by Karyono about Bandung thermal comfort indicated that respondents' neutral temperature was 24.7 °C in terms of air temperature [33].

Construction started in 2013 divided into two phase, with the final design finished in 2015. Contrasting hilly green landscape with robust industrial material creates a unique atmosphere to this place.

The building is composed of 23 HC containers from South Korean STX and Taiwan's EVERGREEN. They were obtained from Cakung (North Jakarta) using freight trucks. The original colours are kept and composed architecturally

Containers are composed in two ways: horizontal and vertical. Some of them are stacked and twist locked, while others require additional welding. Horizontal composition are mainly to create spaces for human activities such as: shops, restaurants, café, open plan office and co-working spaces. Open plan spaces requires some modification such as the removal of container wall and adding I-beams for structural support. While on the other hand, more private spaces require additional wall partition and door. Additional support beam also required on over hanged containers.

In the initial design, first floor was only a coffee shop. Later it was extended by adding a new container for grocery store. Next to it, there are ‘Bromelia Pavilion and Bird Park’, a small natural amusement park with an aviary in it.

Second floor are initially for exhibition hall. However, the exhibition space can be used for offices and shops to sell souvenirs. Its function can be changed as needed.

The third floor is intended for offices and beer house. However, the beer house is also occasionally used as a game room. On this floor, containers are lined up and the walls are removed so that space becomes more extensive and optimizes many activities. Additional I-beams are located in this area.

As vertical accessibility, containers are composed vertically and acted as building cores. The composition of these high cube containers created access to the upper floors by stairs. Utilities in the form of pipes, cables, and toilets are also located here to make maintenance easier. A new structural steel frame are required for the elevator shaft that also covered by corten steel wall.

Although exposing the corten steel, the room temperature is considerably comfort. This is due to the benefits from the site condition. Bandung is known to have a cool weather compared to other big cities in Indonesia. This building itself located far from the city center, which reduce the possibility of urban heat island phenomena.

Natural elements such as trees and hills become a shade screens that reduce heat gain from the sun. In his book, Jan Gehl first studied the influence of microclimate on outdoor activities by counting people sitting on sunny and shady benches. Shady spaces in tropical wet climate improve outdoor thermal comfort and provide opportunity to interact with the environment. It attracts large numbers of people, which in terms of commercial business, the building will become economically profitable. [34] [35] [36] [37]

Room temperature are recorded for 10 days with HOBO MX1101 device (Fig. 6) that are placed around 1 m height in three different location: office space on the first floor, office space on the third floor, and the roof terrace. Each

Figure 3 Day & Nite Eatery and Grocery: Landscape Condition and Exploded Diagram

location have different direct and non-direct exposure to the sun, resulting a different heat gain. Comparison between the recorded temperature on each location, along with the average temperature and weather condition in Bandung [32] are shown in Figure 4.

Temperature in office first floor maxed at 24.53 °C at noon time. In relation with human activity, average temperature in normal working hours (08:00 – 17:00) is 22.78 °C. Office third floor have higher maximum temperature at 28.27 °C while its average working hours is just slightly higher at 25.08 °C. Recorded temperature on roof terrace have a high fluctuation due to its location as an outdoor spaces. Usually peaked around 12:00 with the maximum of 31.48 °C.

As predicted before, office in the first floor have a lower average temperature due to the low direct exposure of the sun, while office on the third floor have more direct exposure specially from its roof. Recorded temperature on roof terrace are conducted for comparison with the general recorded climate and weather condition of Bandung at that period of time.

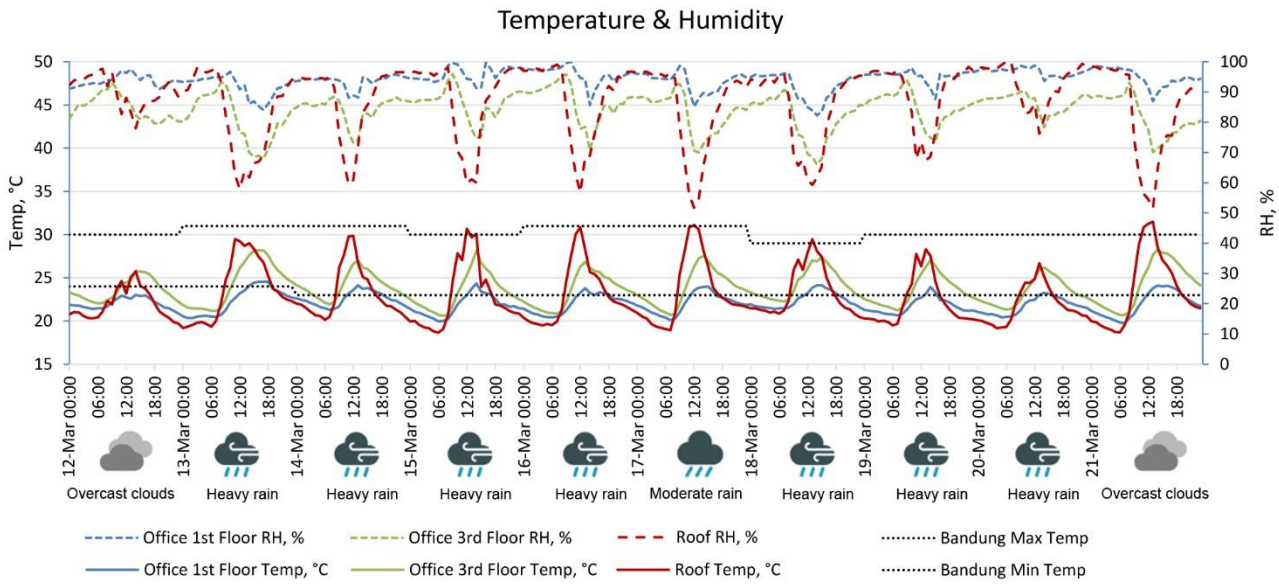

Figure 4 Temperature and Humidity Measurement

Figure 5 Interior Condition and Isometric Plan

Figure 6 HOBO Device

Compared to the study by Karyono [33], there are no more than 1 centigrade differences between average temperature in first and third floor office than the respondents' neutral temperature. This mean that the room temperature are still considered comfortable. This is also supported by the fact that office on both floor doesn't have any additional insulation and air conditioning unit.

However, it is important to note that this condition could happen also due to the heavy rain that occurs mostly during the recording period.

5. CONCLUSION

Standards and regulations of shipping industry creates a robust, durable, and modular shipping containers. These properties create a big opportunity for adaptive reuse and transform them into a new and interesting function. Attempts to reuse those containers, not only reduce the pile-up in depot and ports, but also can reduce energy and resource consumption from construction industry.

In the study case, understanding the technical properties of the container become the main point of concern. The Day & Nite Eatery and Grocery strives with its modularity from various container treatments. Construction can be divided

into 2 phases thanks to the interlocking feature and modular behaviour of the containers.

Although there are only limited module size due to ISO regulation, room flexibility that happens on the first, second, and third floor still can be obtained from the ease of modification and combination of containers.

Shipping containers have a big potential to be reused as other function, but similar projects cannot be done easily in other cities especially cities with higher average temperature. Advantages from Bandung's climate minimize the usage of air conditioning and the modification needed in these containers in terms of heat insulation.

Landscape condition also have a big contribution on reducing heat gain inside the building. High trees reduce radiation from the sun and help to achieve higher level of thermal comfort in tropical wet climate. Natural ground cover surrounding the building reduce the amount of heat that comes from the urban heat phenomenon.

In this study case however, recorded temperature was only spanned for 10 days. A full year observation would be helpful to see the whole condition throughout various seasons. Energy consumption to transport containers from North Jakarta to Bandung also unaccounted. This calculation would be important to determine how much embodied energy a refurbished container building have.

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