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Review paper

DIFFERENT ASPECTS OF THE APPLICATION OF OLD SHIPPING CONTAINERS IN THE CONSTRUCTION OF MULTI-STOREY BUILDINGS

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Abstract

Application of old shipping containers in the construction of different kinds of buildings is increasingly popular in the world and in our country as well. This is an economically and ecologically sustainable option. Containers, which were originally designed for transportation, after they have served their purpose, can be used to build modular buildings due to their high resistance, speed of construction and relatively low cost. These buildings are modern and flexible solutions in the construction, which use containers as modular units. Containers can be combined according to different modular schemes, which enable creative and functional architectural solutions. The paper discusses the application of old shipping containers in the construction of multi-storey buildings from several of the most important aspects in architecture and civil engineering.

Key words: *Shipping Containers, Container Buildings, Modular Construction, Multi-Storey Buildings, Sustainable Architecture*

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1. INTRODUCTION

The application of old shipping containers in the construction of different kinds of buildings is an innovative approach that offers very fast, cost-effective and environmentally friendly solutions. This construction method has experienced its expansion at the beginning of the 21st century. Shipping containers that were originally designed for transportation now are used as large modular blocks for building construction.

Shipping ISO containers, Standard 20' and Standard 40', with their lengths of 6.06 m and 12.2 m, and width of 2.45 m, allow flexibility in design. Their own steel structure makes them very strong and resistant to various kinds of loads. The container walls can be cut, which enables creation of larger spaces. The only design limitation is their height, which is 2.59 m, but there are also tall containers that have a height of 2.89 m. It is an innovative and economical way of construction, which enables creative and functional solutions. It is possible to build different types of buildings, from houses and cottages to business spaces, industrial and residential complexes. Solutions with large glass areas and roof terraces are popular, too. There are many examples of the integration of green roofs, which have shown significant environmental benefits, creating spaces that improve both aesthetic appeal and ecological balance, by promoting energy efficiency. The sustainable potential of buildings made of old shipping containers cannot be ignored.

Containers can be connected and placed in different configurations, either horizontally or vertically, which enables the construction of more complex buildings with multiple floors. The design takes advantage of modular architecture, utilizing shipping containers as building blocks to create highly efficient and adaptable structures [1]. Cost-effectiveness is another key advantage of "container" buildings, as they are popularly called. Reusing containers as building material not only reduces waste, but also reduces overall material costs.

Therefore, the idea of using old shipping containers for the construction of modular buildings has appeared primarily because of their high resistance, modularity, speed of construction, relatively low costs and ecological characteristics. Buildings constructed in this way have become an economically and environmentally sustainable option. In 1987, Phillip C. Clark obtained a patent for modifying shipping container boxes for habitable and productive buildings. Through this patent, shipping container architecture were established by attaching one or more container boxes on a foundation with all infrastructural elements such as inner side walls, roofs, ceilings, doors and windows [2].

2. EXAMPLES OF MULTY-STOREY CONTAINER BUILDINGS

"Container City 1" is the first multi-storey container building in the world. It was built from recycled shipping containers in 2001 in London, Fig. 1.(left) This building was originally high three-storeys. Now, it is a four-storey building that is used for residential and commercial purposes, including art studios and offices. Shortly after its construction, the "Container City 2" building was built in 2002, Fig. 1.(right), by the same company.

Figure 1.Container City 1 (left) [3], Container City 2 (right) [4]

This project has became the forerunner of many other innovative buildings made of containers around the world. To name only a few: "Container Building" in Santiago, Chile Fig. 2.(left), "The Stow-Away Hotel" in Waterloo, London, England, Fig. 2.(right), "Keetwonen" in Amsterdam, Netherlands, Fig. 3 .(left), "Cité A Docks" in Le Harve, France, Fig. 3 .(right), "Local Studio's IDA" on McKinley, Phoenix, the tallest container building in the USA, Fig. 4.(left).

Figure 2. Container Building (left) [5], Keetwonen (right) [6]

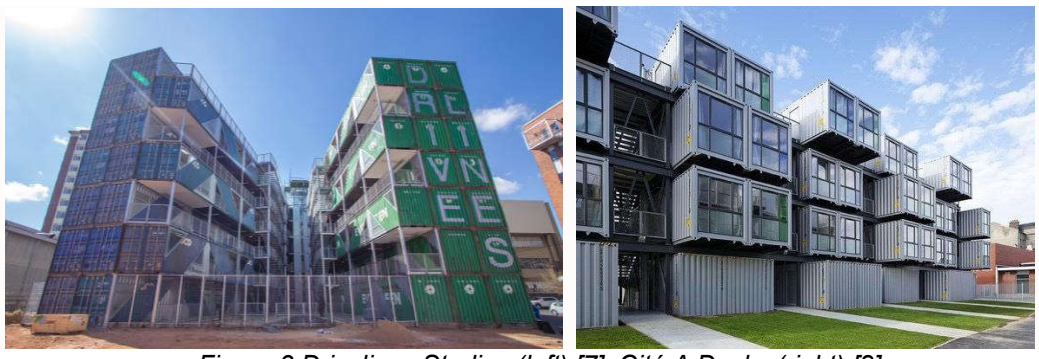

Figure 3.Drivelines Studios (left) [7], Cité A Docks (right) [8]

The world's tallest building made of shipping containers, called "118 VR", was planned to be built in London, Fig. 4.(right). Planning permission was obtained in 2019. This office building was supposed to be 26 m high (9 floors), and have a load bearing steel framework.

Figure 4. Local Studio's IDA (left) [9], 118 VR (right) [10]

There are also extreme examples of container architecture, such as the conceptual design of container skyscrapers. Two the most specific are the "Radical Shipping Container Skyscraper", and the "Containerscrapers", Fig. 5. Both examples are focused on providing temporary homes in Mumbai, India.

Figure 5. Radical Shipping Container Skyscraper, [11,] "Containerscrapers", [12]

3. ENVIRONMENTAL ASPECT

One of the major problems of environmental pollution is the accumulation of various types of waste, which is constantly increasing from year to year. Rapid economic development and intensive construction, primarily of residential buildings, significantly affect the environment. We must be aware that architecture and civil engineering are the areas that have a great impact on the environment, especially during the construction time, and therefore require the mandatory application of the principles of sustainable development. In addition to the application of clean and energy-efficient, green technologies, the world's modern trends in architecture and construction also include the use of ecological, non-polluting and recycled materials, renewable energy sources, reduction of construction waste, reduction of water and energy consumption, more rational use of construction land, application of modern technologies and construction systems, and improvement of living and working conditions in all buildings in general [13].

The use of old shipping containers in the construction of buildings is just one way to contribute to sustainable development. All over the world, in various places, often inappropriate, and especially near major ports, there are piles of old shipping containers that have ended their long transportation life, which usually lasted from 7-15 years. However, many of these disused containers are a result of a recent, alarming trend toward single-use container shipping [14].

The reuse of shipping containers for other purposes, such as the construction of different types of multi-storey buildings, would significantly reduce the amount of waste as well as the need for the production of new construction materials. Shipping containers contain much more steel than is needed to build a house, for example. In addition, air pollution due to CO2 emissions during the steel recycling process in smelters would be reduced. Construction of buildings, especially residential ones, by reusing shipping containers is also an environmentally sustainable option. We give a new purpose to an old and worn-out thing and thereby contribute to the preservation of the environment [15].

4. ECONOMIC ASPECT

The use of old shipping containers as modular units in the construction of multi-storey buildings can, in certain cases, become an alternative solution, especially when it comes to the speed and cost of construction. It is well known that the two most significant advantages of modular construction are faster construction and cost savings. Construction time can even be shortened by half compared to conventional construction, and cost savings are directly related to time savings.

The shortening of the construction time is closely related to the preparation of the construction site itself and the foundation construction, while at the same time modifying of the modules takes place off-site. By using old shipping containers as modules, since the containers are already factory-made, the speed of construction is additionally increased because they are only modified in the workshop and require less construction work. In addition, the modules are quickly assembled on site and are functional in just a few weeks. Due to the increasing demands and innovations, construction processes are evolving. In recent decades, the construction industry has undergone significant industrialization and

adopted various methods of construction. As a result of this evolution, off-site construction has become an established practice as an alternative to traditional on-site construction [16].

Assembly on the construction site includes stacking the modules horizontally and vertically and connecting them to each other. If there is a supporting steel structure, the assembly includes inserting modules into that structure and connecting them to it. In addition, it is necessary to connect the previously assembled installation components on the construction site. Certainly, the whole process is much faster than the classic construction method. Also, there are no construction delays due to bad weather conditions at the site.

The cost of the containers themselves is low, while the conversion costs such as the assembly of insulation and installation and structural adjustments can increase the total cost. However, due to less need for the heavy equipment and faster construction, this is still a more affordable option compared to traditional buildings.

The use of all shipping containers is, therefore, a very economical option. In addition to faster construction and savings in construction time and costs, there is also a significant saving in material for the construction itself, considering that the containers are only modified.

5. STRUCTURAL ASPECT

Shipping containers are made of a special type of steel, called “corten” steel, which makes them very durable and resistant to weather conditions. Unpainted corten steel will form an outer layer of rust that reduces deeper rust spreading. Shipping container experts favor corten steel for its protective qualities. Corten steel structure is a key reason why we are confident that shipping containers will become a suitable and cost-effective building component for off-site construction [17]. Also, due to their very structure, they have great strength, so they can withstand heavy impacts and are often more resistant to seismic activity.

Structurally, each shipping container consists of four steel columns at the corners and beams that connect them longitudinally and transversely, at the base and at the top. There are also longitudinal and transverse wall panels and top and bottom plates. The floor structure as well as the walls between two adjacent modules or two adjacent modular assemblies are duplicated, which further contributes to the strength of this system.

Multi-storey modular container buildings belong to the cellular structural system. Considering that, they can be built by stacking containers (modules) directly one above the other without additional supporting elements, or by installing modules into a load bearing steel frame [18, 13]. Examples of the buildings built in these two ways are shown in Fig. 6.(left) (Stow Away Hotel, a building with directly stacked containers one above the other) and Fig. 6.(right) (City of the Sun, a building with load bearing steel framework). A combination of these two solutions is also possible. Modules or cells are usually prefabricated business or residential units consisting of only one or more connected containers that make up a modular assembly. It is important that their weight and dimensions do not exceed the allowed values for transport and assembly. In the phase of the conceptual design of the building it is also important to look at both possibilities and determine which solution is more profitable, taking into account all the advantages and disadvantages.

Figure 6.Stow Away Hotel (left) [19], City of the Sun (right) [20]

The main advantages of a solution where the containers are stacked directly on the top of each other without any additional supporting structure is that there is no need to insulate the containers on all six sides and the construction speed is higher. Therefore, this is a cheaper solution, since there are no costs for additional insulation and for construction of the supporting structure. On the other hand, the possible number of floors of these buildings is smaller, because the containers themselves carry all the loads, which limits the number of floors and resistance to external forces.

Container buildings with an additional supporting steel structure are a more advanced version of shipping container buildings. Steel structure provides additional strength, flexibility and safety. This system has multiple advantages, especially when it comes to the loads acting on the building. Containers are placed inside the steel frames. The steel frames carry all the loads and increase the stability of the entire building when affected by wind, earthquakes and possibly other external forces. Considering that, in this way it is possible to build container buildings with more storeys than in a system without an additional structure in which the modules carry themselves. Precisely, in that case, the modules in the lower floors carry the entire weight of the building. Due to the greater load capacity and stability, it is possible to install additional equipment, such as solar panels or heavier loads on the roof, depending on the purpose of the building.

Also, the application of this system allows a greater flexibility in design as it facilitates the placement of larger windows, terraces or extensions that would weaken the containers themselves. In a system without additional structure, the containers are supported by their basic form, so the removal of walls is limited, as this could reduce their load-bearing capacity. Creative solutions such as consoles, open spaces or asymmetrical layouts are easier to implement. If additional bracings are needed to increase the stability for a higher number of storeys, they are easy to add. Buildings with additional steel structure are more suitable for larger, longer-term and more complex projects (residential buildings, business and public buildings) where a greater number of floors and larger spaces are required. Unlike them, container buildings without an additional steel structure are a good choice for smaller, temporary projects (work camps, temporary housing facilities, warehouses or summer cottages), where the budget is limited.

The main disadvantage of the solution with a supporting structure is that the modules (modular assemblies) must be completely waterproof and completely insulated on all six sides, which requires higher costs. The construction of the load-bearing steel structure increases the total cost of the building and the complexity of the project. Maintenance is also more expensive because steel requires regular corrosion protection.

When it comes to the construction of container buildings, the connections between the containers, and the connections between the containers and the steel structure are very important. The containers themselves have corner castings on the corners (Figure 7) which are used to connect the containers to each other by using twistlocks (Figure 8) or bridge clamps (Figure 9) to prevent the containers from overturning during ship transportation or storage of goods, when they are stacked on the top of each other in multiple levels. However, in the case of building construction, especially those that are not of a temporary nature, it is necessary to make bolt connections or welding.

All the rules for joints and connections defined by Eurocode 3 [21] must be applied, considering that this is a steel structure, both of the supporting structure and of the containers themselves.

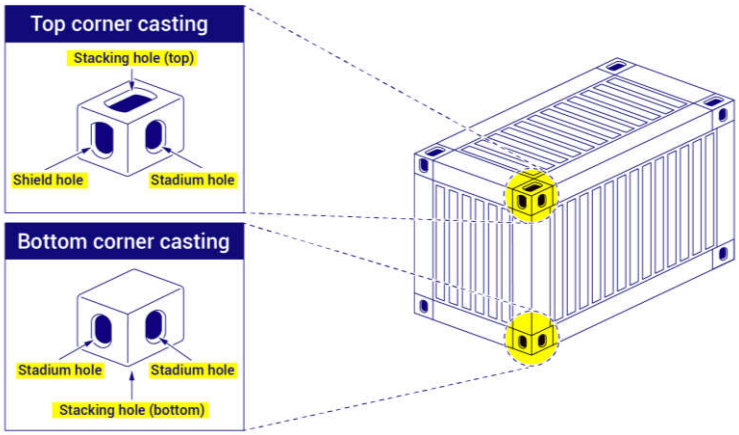

Figure 7. Corner castings, [22]

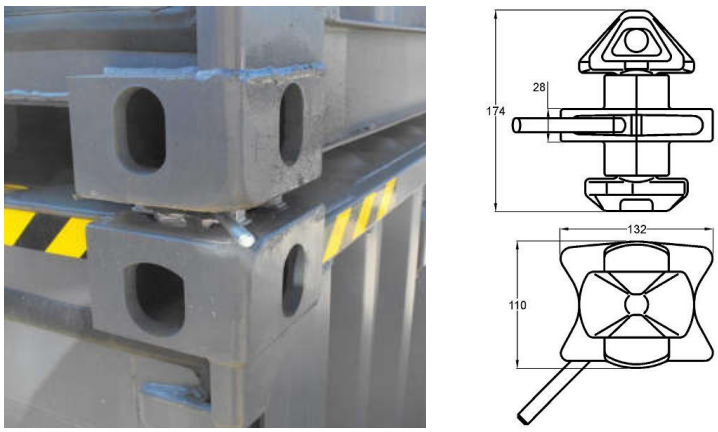

Figure 8. Corner castings and twist-lock, [23]

Figure 9. Bridge clumps, [24]

Connections between shipping containers and the supporting steel structure, which are made with bolts or welding, must be designed to ensure stability, safety and durability. For temporary buildings, it is necessary to make bolt connections for easier disassembly.

The connections must withstand all static and dynamic loads, including the weight of the structure, wind and earthquakes. All the basic components of the joints must be made of high-quality corrosion-resistant steel. At the connection spots, thermal and sound insulation must be installed properly, in order to prevent energy losses. Since the connections are exposed to weather conditions, it is necessary to use anti-rust coatings. The basic criteria for choosing the connection method are, first of all, the question whether the structure is temporary or permanent, then the size of the structure itself, the type and intensity of the load on the connections, the required resistance to external influences, the possible later need for expansion or disassembly, as well as the available budget.

Here, only basic notes are given on the ways of making connections in multi-storey container buildings. A more detailed analysis goes beyond the scope of this paper.

6. ARCHITECTURAL ASPECT

In architectural terms, buildings made of old shipping containers are challenging from several aspects. From the aesthetic aspect, container buildings can appear as industrial or unsightly without additional exterior finishing works. Architects around the world have enthusiastically embraced the idea of reusing shipping containers for construction, although it is still repulsive to some of the general public. Opinions are divided, both among experts and among ordinary people, but considering the rapid advancement of technology and architecture, it seems that more and more people are accepting this concept. Today we have a lot of multi-storey buildings built from old shipping containers that are far from what we can see by looking at the worn and scrapped containers, such as shown in Fig. 10.

Figure 10. Roundhouse Administration Building (left) [25], Clipper House (right) [26]

Therefore, the appearance of shipping containers can be a challenge, but with proper design and processing, they can become aesthetically appealing and modern. Containers can be painted or covered with different materials, such as wood panels, to achieve the desired look. Also, there are solutions with large glass surfaces and green roofs.

In addition to the reshaping of the external appearance, the finishing works also include the replacement of the original container floors with wooden or laminate floors and ceramic tiles and the installation of interior wall coverings, the installation of doors and windows in previously installed metal frames and the assembly of installations.

The modular characteristics of shipping containers enable the design of creative and functional spaces. Considering that the walls of the container can be cut, and the containers can be joined and stacked both horizontally and vertically, it is possible to form larger functional units with the necessary comfort. Their flexibility enables the design of various types of multi-storey buildings, most often residential, but there are also commercial buildings, business premises, public and industrial buildings.

From the energy efficiency aspect, metal containers are poor insulators due to the high thermal conductivity. In order to ensure the living comfort and reduce energy losses, it is necessary to provide the adequate thermal insulation. Polyurethane foam is most often used. It adheres to the walls of the container and prevents condensation, so using it solves two problems. Also, due to the metal construction of the container, good protection against the moisture and corrosion is required, as well as the provision of the adequate ventilation and air conditioning. Considering that they are made of metal, containers can be quite noisy, so it is necessary to provide adequate sound insulation, usually made of rubber, between adjacent units.

7. CONCLUSION

Shipping containers, originally designed for the transportation and storage of goods, after the end of their useful life end up in piles, most often near large ports, creating huge amounts of waste that is not acceptable for the environment. Besides the fact that they can be recycled in steel smelters, at the beginning of the 21st century, they began to be massively used for construction, firstly for one storey buildings of various purposes, and then increasingly for the construction of multi-storey buildings. Their reuse in architecture has emerged as a more sustainable solution.

The material they are made of, their structure and dimensions, make them ideal modules for construction of contemporary buildings. Due to the high speed of construction

and lower costs compared to conventional methods, as well as due to the environmental aspect, this innovative approach can in some cases be a good alternative solution. Although part of the public and the professionals do not accept them due to their unattractive, industrialized appearance, there are many realized projects in the world. Also, they often win prizes at competitions and contests for the conceptual design. The progress of architecture and technology today enables significant modification of containers so that their appearance becomes interesting and aesthetically acceptable. Shipping containers are inherently robust, designed to withstand the harsh conditions of global transit. This durability translates into resilient structural components for high-rise buildings. Their modular design allows for unparalleled flexibility in construction, enabling architects and builders to create multifaceted spaces that accommodate various needs [1]

Certainly, the most important aspect of the application of old shipping containers is their sustainability, but equally important are the structural and architectural aspects, especially when it comes to more complex projects of multi-storey buildings. This thoughtful approach to design embodies a vision of the future for urban architecture, presenting a sustainable and socially responsible model for future development.

The findings of this research can serve as a valuable foundation in the creation of public strategies that promote the principles of circular construction. Local authorities could support such an initiative through financial incentives, simplified legal procedures or strategic integration into social housing, emergency infrastructure or temporary facilities. With such strategies, this innovative approach to construction could promote greener and more adaptive cities. As such, it can offer, not only architectural and engineering innovation, but also a practical response to global challenges in housing, waste reduction and climate adaptation, creating a socially responsible path toward more sustainable cities.

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