Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/12351
DOI URL: http://dx.doi.org/10.21474/IJAR01/12351

RESEARCH ARTICLE

CONTAINER ARCHITECTURE IN THE CONTEXT OF SUSTAINABLE CONSTRUCTION OF RESIDENTIAL FACILITIES IN BOSNIA AND HERZEGOVINA

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Manuscript Info

Manuscript History
Received: 20 November 2020
Final Accepted: 24 December 2020
Published: January 2021

Key words:-
Prefabrication Collective Residential Facilities, Shipping Container Architecture, Prefab and Modular Containers, Sustainability

Abstract

The rapid urbanization of cities creates a need for construction of new collective residential buildings in all major cities of Bosnia and Herzegovina. However, residential facilities are often built without any analyses, creating unsustainable architectural structures with a very high market price. The traditional monolith construction of residential units does not allow for any transformation or adaptation of the system. This paper aims to explore the possibility of the application of alternative solutions for the construction of sustainable collective residential buildings using shipping and prefabricated modular containers. Analyzing Bosnia and Herzegovina's market, it was found that there are no empty shipping container storages, but there are a few companies which produce prefabricated modular containers which are currently not planned for residential use. These prefabricated units could be transformed and used for the construction of sustainable residential buildings with the application of simple interventions suggested in this paper. The usage of prefabricated modular containers offers the possibility of transformation of space, simple assembly and disassembly, placement on existing structures, and the lower price of living area.

Introduction:-

The traditional construction of rigid residential structures without the possibility of adaptation and transformation of the system is the most represented construction method in Bosnia and Herzegovina. The construction of these buildings is often not following urban plans and regulations,which means that these neighborhoods become dorms without any content required for normal living of young people who are most often the users of that space (Figure 1).

According to Smith (2010), more than 26%of the energy is consumed now compared to 20 years ago. The buildings are consuming 39% of total energy and producing 39% of carbon dioxide emissions.

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Figure 1:- New collective residential buildings in Sarajevo. Author of the photograph: Vedad Orahovac.

Depending on the selected construction style (prefabrication or traditional monolith construction), it is possible to reduce, not only the energy consumption, but also the amount of waste materials. Prefabrication is a construction method that provides reduction of the building expenses, labor force, as well as more eco-friendly working conditions. It represents more responsible construction method compared to the currently represented traditional monolith construction method. However, residential buildings constructed with prefabrication as a response to urbanization from the 70s were built as rigid structures without the possibility of additional transformation or adaption of the system (Figure 2). Prefabricated buildings constructed in that period do not represent sustainable solutions because different ways of reducing the expenses meant that no innovative materials or technologies are applied.

Figure 2:- The example of a prefabricated neighborhood in Sarajevo.

It is necessary to find new alternative methods of construction. In this paper the usage of shipping and prefabricated modular containers as building components is suggested. Comparison of shipping and prefabricated modular containers as building components is done with the aim of deciding which of the compared components is more suitable and cost-effective for use on the territory of Bosnia and Herzegovina

Responsible And Sustainable Construction:-

According to Smith (2010), there is a list of methods by which designers can plan the construction of environmentally responsible buildings (Figure 3).

DO	DO NOT
Use recycled materials	Use all new material
Use recyclable materials	Use single-life materials
Use a few materials and components	Use many different types of materials and components
Use natural and non-toxic materials	Use toxic and hazardous materials
Use easily separable materials	Use composites that are inseparable
Use mechanical or natural finishes	Use composites that are inseparable
Use mechanical or natural finishes	Use applied coatings and finishes
Provide permanent identification of material type	Use materials that end of life reuse is unknown
Use mechanical connections	Use chemical connections and adhesives
Use a changeable adaptable system	Use fixed unchangeable systems
Use modules, panels, or components	Use non-standard sizes or configuration systems
Use standard construction methods	Use highly proprietary systems
Separate building systems	Compress systems requiring one and all to be changed
Make materials able toe be handled	Make systems that require difficult labor sequencing
Provide a means for handling	Neglect construction sequence process during design
Provide realistic tolerances	Make building too tight
Use fewer connections	Use infinite fasteners and connectors
Design durable joints and connectors	Design one time assembly connections
Provide parallel sequencing disassembly	Detail construction process to accommodate linear path
Use a structural/assembly grid	Make every component and joint entirely unique
Use lightweight materials and components	Use heavy and cumbersome materials and components
Permanently identify points of disassembly	Make assembly and disassembly obscure
Provide spare parts and onsite storage	Make a proprietary system where there is just enough

Figure 3:- Recommendations for constructing environmentally responsible buildings, Source: (Smith, 2010).

The idea of using containers as a building material for construction of residential buildings originated in the 1970s. The starting cost of shipping containers as future building components is significantly lower compared to the cost of elements made according to the monolith building system. However, the total cost of the finished building depends on many factors, and we could not say that the price of the finished structureusing shipping containers is lower than the price using traditional building methods. According to (Kotnik, 2013) containers can adapt to numerous environmental characteristics which are necessary in buildings. Primarily, they can be recycled, used again, and they can reduce the amount of other usedbuilding materials. Analyses in the paper (De Garrido, 2015) have shown that it is possible to control climate conditions inside the building constructed of containers without additional technological devices.

The alternative approach to container buildings is the use of new exclusively produced prefabricated modular containers, because they have been made of materials used for the construction of residential buildings (Robison & Swindells, 2012). The problems of the insulation and application of non-toxic materials are solved in the phase of constructing the containers. The wall, floor, and roof structures represent elements which are easily replaced so that the long-term usage is possible.

Prefabricated modular containers also perfectly suit the representation of a building with the capacity of transformation (Figure 4) shown in (Durmišević, 2006), which means there are several advantages compared to buildings without the transformation capacity.

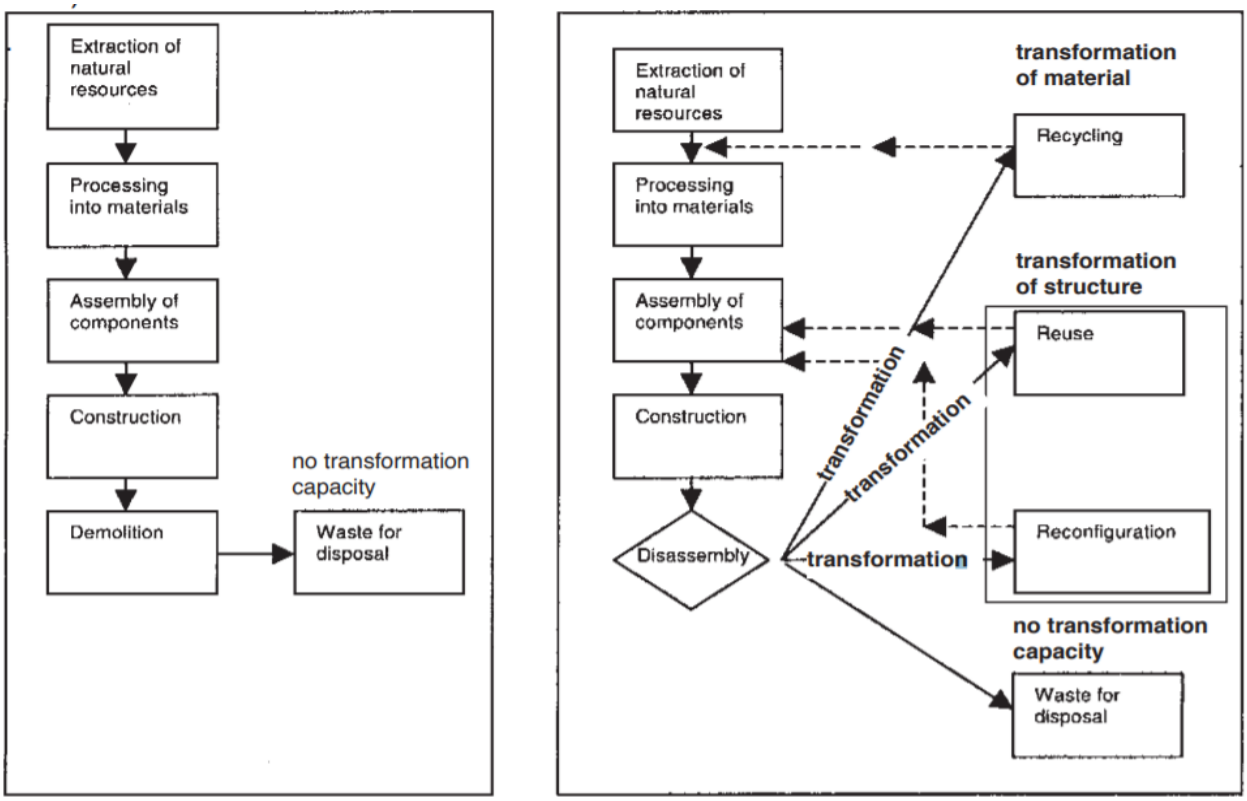


Figure 4:- Building life cycle: a) without transformation capacity b) with the transformation capacity, Source: (Durmišević, 2006)

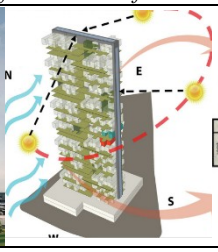
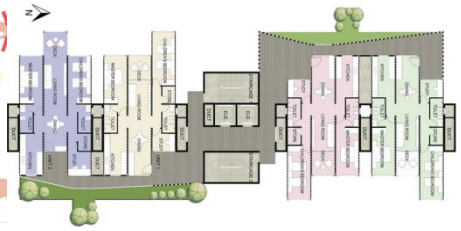
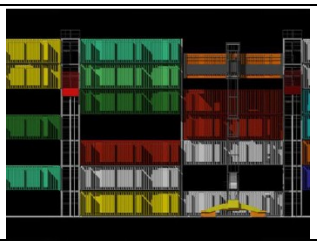
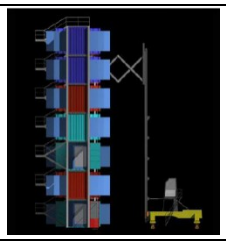
The use of shipping containers for the construction of residential units:

The idea to use box-like structures for the transport of goods originated at the end of the 18th century in England intending to improve carriage transport (Kotnik, 2013). It is not well known who exactly came up with the idea to turn shipping containers to houses, schools and entire buildings. However, the idea is not new because Philip C. Clarks recorded a US patent for his method of "converting one or more steel shipping containers into a habitable building" in the 1989.

Kotnik (2008) talks about architects noticing that stacked units in ports look like a built neighborhood and represent a kind of a complete building system. The container architecture is developed in the areas where they were necessary for sheltering people due to different environmental, or other devastating disasters. The main parts of shipping containers are the load-bearing steel structure, floor structure, facade panels, roof panels, and steel door structure. The shipping containers represent an easily available resource for building when cost efficiency and environmental acceptability are considered, and their modular form makes different ways of stacking units possible. Analyzing three Case studies (Table 1) that are shown below, three different concepts of the use of shipping containers are established.

Case study 1 shows how it is possible to add shipping containers as a new structure over the existing buildings, which is achieved by stacking the containers without the use of additional structure between them. The idea of a radical skyscraper made of containers (Case study 2) was proposed with the aim of providing temporary accommodation in Mumbai for many poor families. The third example shows a permanent steel structure with shipping containers placed as easily replaceable units. Analyzing these case studies, an important fact stands out, that the construction of up to ten levels in height is possible when using shipping containers, as well as higher heights when using additional construction.

Table 1:- Residential buildings made of shipping containers.

Student housing in South Africa Source of pictures and decription:*http://inhabitat.com/eye-catching-shipping-containers-built-inside-two-former-silos-provide-student-housing-in-south-africa/mill-junction-container-housing6/?extend=1_*	
CASE STUDY 1	 
	The shipping containers are adapted for housing. The steel structure is kept as an outer facade and the interior is adapted according to the needs of residents. Mutual connection of containers in vertical and horizontal direction provides good insulation performance. The containers placed one next to the other provide sufficient widths of interior space and it reduces the energy losses. The roof of one container, together with the floor structure of the other, compose a double ceiling with good acoustic and thermal characteristics.
Skyscraper for Mumbai slum, Source of pictures and description: *http://www.archdaily.com/772414/ga-designs-radical-shipping-container-skyscraper-for-mumbai-slum/55db3f12e58ece585f000006-ga-designs-radical-shipping-container-skyscraper-for-mumbai-slum-image*	
CASE STUDY 2	   
	Since steel shipping containers can be stacked to up to 10 floors without any additional supports, GA won with the scheme of 100 metershigh skyscraper consisting of the array of individual shipping containers with steel load-bearing elements placed at every 8th floor. Because of the proximity of the harbor, where the empty container yard is located, this project is sustainable. Simple connections between the containers provide for a fast and simple assembly. Other systems of sustainable building, such as solar panels integrated into the building, as well as a micro wind turbine for energy generation, are applied here.
LOT-EK MDU Shipping Container House Source of pictures and description: *https://inhabitat.com/lot-ek-shipping-container-house/lot-ek-shipping-container-house-lot-ek-mdu-mobile-shipping-container-house-lot-ek-architecture-recycled-shipping-container-house-recycling-shipping-containers-reclaimed-design-sustainable-archi-5/*	
CASE STUDY 1	 
	Mobile homes are placed on a load-bearing structure with all necessary facilities for vertical and horizontal communication, as well as service facilities. The mobility of the building is enabled in a way that the load-bearing structure, or the frame, is found in all major cities which would provide the mobility of residential units and the constant transformation of created buildings.

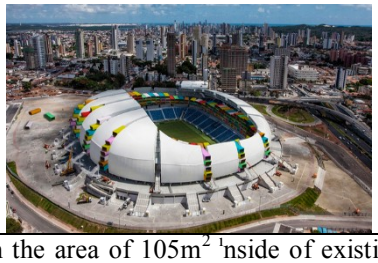
The use of prefabricated modular containers as residential units:

The idea of using prefabricated modular containers as building components for residential objects can be traced to the occurrence of Metabolists in Japan and their "Metabolism" movement. The idea was based on creating structures where the specific parts could be added or removed without disturbing the structure of a building. According to (Jenks & Dempsey, 2005) the Metabolists believed that the cities should be designed to grow and change, and it is only their fundamental structures that should remain constant. The other elements which are called city units should

be added over permanent structures like flowers and leaves are added to the branches. This concept was partially realized in Kurokawa's "Capsule Tower" in Tokyo in 1972.

The "Case futbol" is a new project proposed by architects Axel de Stampa and Sylvain Macaux. Architects suggested to place prefabricated units in existing structures of Brazilian stadiums (Table 2). The main idea is similar to the idea previously described. According to the mentioned Case study, it is concluded that the authors are using existing buildings which are not used sufficiently after hosting of the World Cup.

Table 2:- Residential facilities built using prefabricated modular containers.

Casa Futebol Source of pictures and description:*https://www.archdaily.com/526191/casa-futebol-proposes-a-different-olympic-legacy-for-brazil-s-stadiums*	
CASE STUDY 1	   It is proposed to insert prefabricated modular residential units with the area of 105m^2 inside of existing load-bearing structures. The proposed solutions are designed to be adapted to every stadium individually, so that they enable the continuation of the stadium initial purpose. The prefabricated modular units replace outer facade or a part of tribunes. Besides that, the stadium area gets a new dimension because it is adapted to the human scale.

The use of prefabricated modular containers for residential purposes dates to the earlier period compared to the use of shipping containers for constructing residential units. It is possible to transport 6-10 packets of containers on one shipping truck, depending on the available equipment. The transport method of prefabricated modular containers depends on many factors such as the proximity of the building site, the assembly cost, labor force cost and similar. In countries with the expensive labor force, the containers are shipped assembled. Prefabricated modular containers consist of a load-bearing structure and cladding elements with openings. With the advancement of technology and the modernization of the equipment to produce prefabricated modular containers, it is possible to use natural materials such as wood, bamboo, and similar, for container construction.

The comparison of the application of shipping and prefabricated containers for the construction of residential buildings in Bosnia and Herzegovina*:*
Analyzing the current state of the market in Bosnia and Herzegovina, it is found that the closest storages with abandoned shipping containers are located in Croatia. However, their purchase and transport to Bosnia and Herzegovina create huge expenses and additional air pollution due to the transport. The conclusion is that the use of shipping containers for constructing collective residential buildings in Bosnia and Herzegovina does not represent an environmentally responsible way of building.

Compared to the shipping containers, which require a large amount of energy for conversion to the residential unit, additional labor force and work on site, the prefabricated modular containers provide significant advantages. However, there are limitations of the height of building constructed of these modules because the maximum height is up to three levels without the use of additional structure. Also, prefabricated modular containers currently produced in Bosnia and Herzegovina are not intended for residential use. The production of mentioned containers is mostly associated with temporary facilities, but it is possible to use these containers for constructing residential objects which will present energy and cost-efficient structures by applying simple interventions.

Architecture of prefabricated containers in Bosnia and Herzegovina:
There are factories in Bosnia and Herzegovina which produce prefabricated containers, but only 1% of them stay in Bosnia. The complete annual production assortment, more than 7000 containers are exported to various foreign countries. Analyses are conducted to verify their potential for constructing residential facilities, and the results state that existing containers cannot meet currently set sustainability standards. For this exact reason, the solutions for

improvement of the material and building principles are proposed to make future residential facility construction sustainable.

Figure 5:- Assembled and disassembled form of prefabricated modular container, Source of right image: http://www.alfe-mi.com/pogledaj.html; Source of left image: http://www.steelstructurewarehouse.com/sale-3310631-20ft-pu-sandwich-panel-container-modular-homes-for-bedrooms-prefab-container-house.html.

Prefabricated containers made in Bosnia and Herzegovina are adapted to ISO standards. The containers are made of a stable steel structure and interchanging wall elements. The interchanging of wall elements provides the possibility of merging containers and creating larger spaces for various uses.

	BM/SA/VC-Container [1/2/3] (standard load capacities in accordance with 1.5.1.)	Portable and sanitary cabins (optional load bearing capacity 1.5.2.)	Corridor cabin (optional load bearing capacity 1.5.3.)
Floor frame	from cold rolled, welded steel profiles, four container corners welded		
Longitudinal floor frame	3 mm	4 mm	
Short end floor frame	3 mm		
Floor cross beam	made of Omega profiles, s = 2.5 mm		
Fork lift pockets	two fork lift pockets on the long side (except type 30' containers)		
	inside clearance of fork lift pockets: 352 x 85 mm		
	fork lift pocket distance in centre: 2.055 mm [1/2/3] optional: 1,660 mm* / 950 mm* / without fork lift pockets		
Corner posts	made from cold-rolled, welded steel profiles bolted to a floor and roof frame		
	4 mm	5 mm	
C column [3]	3 mm	--	3 mm
Roof frame	from cold rolled, welded steel profiles, four container corners welded		
Longitudinal roof frame	3 mm	4 mm	
Short end roof frame	2.5 or 3 mm		
Roof cross members made of wood	---		
Cover	galvanised steel plate with double rabbet, thickness 0.6 mm		

Figure 6:- The materialization of prefabricated modular containers available in Bosnia and Herzegovina, Source: http://catalog.containex.com/catalog/CONTAINEX/en/catalogs/Technische-Beschreibung-Sanitaer/pdf/Technische-Beschreibung-Sanitaer.pdf.

The frame construction of prefabricated modular containers made in Bosnia and Herzegovina is described in Figure 6. Facade walls are made using polyurethane panels of 60 and 110 mm thickness with bilateral steel sheet cover. Two finishing layers of floor structure are waterproof floor plywood of 22 mm thickness and floor linoleum PVC of 1,5 mm thickness.

The heat transfer coefficient U depends on the thickness and the type of insulation material. It is possible to reduce the U valuewith the selection of correct insulation material with suitable thickness (Figure 7).

The significantly lower U coefficient value is possible to achieve by the application of polyurethane instead of classic mineral wool with the same material thickness

Component	Insulating material	Thickness (mm)	U-value (W/m²K)*
Roof			
	MW [1/2/3]	100	0.36
	MW	140	0.23
	PU	100	0.20
	PU	140	0.15
Wall element			
	MW [1/3]	60	0.57
	MW	100	0.35
	PU [2]	60	0.38
	SW	60	0.65
	SW	110	0.35
	PIR	110	0.20
Floor			
	MW [1/2/3]	60	0.55
	MW	100	0.36
	PU	100	0.20

* The U-values apply to the stated insulation thickness in the space between the timber frames in a half-timbered construction (within the panel).

Window			U-value (W/m²K)*
	Standard insulation glazing with gas filling [1/2/3]	4/16/4 mm	1.10
	3 pane insulation glazing with gas filling	4/8/4/8/4 mm	0.70

* The U-values relate to the Ug value (U-value of the glass) of the specified glazing.

External door			U-value (W/m²K)*
1000	polystyrene	40 mm	1.80
875	polystyrene	40 mm	1.90

* The U-values relate to the Ud-value (U-value of the doors) of the specified construction width

Figure 7:- The possibilities of the materialization of elements and the display of U values, Source: http://catalog.containex.com/catalog/CONTAINEX/en/catalogs/Technische-Beschreibung-Sanitaer/pdf/Technische-Beschreibung-Sanitaer.pdf.

After analysis of prefabricated modular containers, it is concluded that the additional interventions are required to use these containers as building components of residential units. It is necessary to improve characteristics of the elements, as well as to adapt materialization of the containers to the future function of residential facilities (floors, ceilings and walls), and achieve the value of coefficient U under 0,3, to meet the correct standards and regulations for the sustainable construction.

Proposed interventions:
According to (Živković, 2011), by applying suitable insulating materials it is possible to reduce energy losses and improve the energy performance of the building.

Concrete interventions that should be performed on the prefabricated modular containers at the time of production in the factories are the following:

a) The application of modern ventilated panels :
Wall panels currently used to produce prefabricated modular containers in Bosnia and Herzegovina are made as polyurethane panels of 60 and 110 mm thickness with bilateral galvanized steel sheet cover d=0,55 mm, or as panels made with mineral wool as the filling between two galvanized steel sheets. The density of applied polyurethane foam is q= 35÷40 kg/m3. The panels with mineral wool insulation are not designed as ventilated panels. The disadvantages of non-ventilated panels are the following: mineral wool loses its characteristics, so that, the U value

weakens over time, the insulation shrinks, different signs of wear appear, and mold appears. It is recommended to use ventilated wall and roof panels with mineral wool insulation.

b) Using windows made of seven-chamber profiles with low emission low-e glazing:
The current windows used in prefabricated modular containers need to be replaced by seven-chamber PVC windows with triple glazing, from which two are low emission with argon layer – Low E. During the production of this glazing, the interior glass is glazed with a thin layer of precious metals, which have a role of reflecting the heat in the direction of the source. The applied coatings have the role of protecting the glass from the Sun radiation. In 4+16+4 option, this glass has the heat transmission coefficient k=1,2W/m2K, while with triple glazing the coefficient is significantly lower. It is necessary to assemble exterior blinds for the windows.

c) The application of modern materials and reflecting interior coatings:
The finishing layer of the floor structure is currently made of linoleum. It is suggested to use the finish of 1st class laminate in prefabricated modular containers. The wall finish is made of plywood boards in brown color. It is suggested to install gypsum boards. Different wood panels can also be applied to the walls.

Additionally, walls can be treated with reflecting interior coatings. According to (BUILD, 2015) reflecting interior coatings are maximizing the feeling of spaciousness and illumination because they reflect the light better than regular paints. The natural illumination is improved, and the consumption of artificial illumination is reduced. The experience of illumination is increased by 20% and these coatings can help with maintaining the heat produced by sun radiation during the winter months. Their application in prefabricated modular containers will significantly improve the quality of life.

d) The application of modern facade panels and highly reflecting exterior coatings:
The energy efficiency of the building could be improved with different facade covers added to the prefabricated modular container. If there is no possibility of installing the additional facade cover, then reflecting exterior coatings can be applied, which can save up to 15% of energy for the air conditioning. The expected life span of this technology is 12 to 15 years, depending on the climate. The expanses of these coatings are affordable and offer a reasonable increase of investment over time. The application of mentioned coatings on prefabricated modular containers is possible during the production in factories, so that the increase in investment is not significant.

With the application of proposed interventions and improvements, it is possible to significantly improve the energy efficiency of prefabricated modular containers currently available on Bosnia and Herzegovina's market. The proposed activities require a minimal investment of financial resources which will not make the production of prefabricated modular containers significantly more expensive. An example of an apartment constructed of three prefabricated modular containers is shown in Figure 8.

Figure 8:- The residential unit consisted of three prefabricated modular containers,
Source: www.conteinex.com.

The total price of an apartment made of three prefabricated containers without additional toilets is 10 500 euro. This price is not the final price, because we must add the price of toilets and the cost of proposed interventions (4500 euro). The total price of a 40 m^2 apartment is 15 000 euro.

However, the traditional understanding and the culture of living have shown that young people in Bosnia and Herzegovina do not want to live in residential buildings constructed of prefabricated modular containers. The survey was conducted on a sample of 200 young people. Only 20% said that they would like to live in a residential space constructed using prefabricated modular containers, which calls the application of residential units using this modular container into question.

Conclusion:-

The biggest problem of residential construction in Bosnia and Herzegovina is the construction of unsustainable architectural structures. The built structures are not affordable for younger generations because of high prices. The search for alternative solutions resulted with the conclusion that the use of prefabricated modular containers as building components compared to the use of shipping containers for construction of collective residential facilities in Bosnia and Herzegovina offers a more environment, economy, and energy-efficient construction. The analyses of prefabricated modular containers on Bosnia and Herzegovina's market are conducted from the aspects of materialization of structure and it is found that the existing containers could be adapted to the needs of residential space with minimal interventions.

The main advantages of using the prefabricated modular containers as building components of residential units are the possibility of the transformation of space and simple assembly and disassembly.Prefabricated modular containers can be placed on existing structures that have the capacity and possibility of upgrading in densely populated city zones, which makes it possible to form a larger number of cheap residential units because there is no need for additional costs for the placement of new structures.Maximum allowed height of the building using prefabricated modular containers without additional load-bearing structure is three levels. An additional steel or concrete structure with the function of a load-bearing element of higher levels, could be one of the solutions for this problem.Prefabricated modular containers could be interpolated in an existing structure which is partially used or damaged. Engineers should check if the construction has sufficient capacity for load-bearing before adding these units. In Bosnia and Herzegovina even today, there is a significant number of buildings damaged during the war from the 1990s. The advantage of using prefabricated modular containers for residential units is the possibility of creating different scenarios for space by removing or adding additional walls.

The improvements in the energy efficiency of the structures built from prefabricated modular containers are possible to achieve with an extra exterior cladding made of natural materials, such as wood or bamboo, by using ventilated panels, different interior and exterior reflecting coatings, by changing windows and placing additional protection such as aluminium blinds and similar. Energy efficiency of these buildings could be increased by adding solar panels and wind turbines.

Interventions and the application of modern principles and materials, directly in the factory on prefabricated modular containers refer to the currently available containers on Bosnia and Herzegovina's market analyzed in this paper. Application of these containers can create economical and environmentally efficient residential structures with a significantly lower price cost. However, it is necessary to provide more education for citizens about economic and environmentally sustainable structures.

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Source of pictures are from next websites:

1. http://inhabitat.com/eye-catching-shipping-containers-built-inside-two-former-silos-provide-student-housing-in-south-africa/mill-junction-container-housing6/?extend=1
2. http://www.archdaily.com/772414/ga-designs-radical-shipping-container-skyscraper-for-mumbai-slum/55db3f12e58ece585f000006-ga-designs-radical-shipping-container-skyscraper-for-mumbai-slum-image
3.https://inhabitat.com/lot-ek-shipping-container-house/lot-ek-shipping-container-house-lot-ek-mdu-mobile-shipping-container-house-lot-ek-architecture-recycled-shipping-container-house-recycling-shipping-containers-reclaimed-design-sustainable-archi-5/
4.http://www.alfe-mi.com/pogledaj.html
5.http://www.steelstructurewarehouse.com/sale-3310631-20ft-pu-sandwich-panel-container-modular-homes-for-bedrooms-prefab-container-house.html
6.http://catalog.containex.com/catalog/CONTAINEX/en/catalogs/Technische-Beschreibung-Sanitaer/pdf/Technische-Beschreibung-Sanitaer.pdf.
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