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Reshaping Future Architecture Approaches Using Shipping Containers: Student Housing as a Case Study

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ABSTRACT

Pandemic diseases spread globally causing psychological and physical destruction to people in the whole world. COVID-19 is one of these diseases that started in the twentieth century and affected different nations in terms of economical, educational, cultural, safety, health and other aspects. Residential spaces have become dramatically important to control these types of pandemics as it is considered an environment that meets the needs of the residents throughout the quarantine period. The paper aims at reshaping future architecture approaches that can be applied during the design concept, construction and operation phases of residential units. These approaches are concluded with regard to space design, building materials such as prefabricated shipping containers, thermal comfort and self-sufficiency. The researchers fetch the reasons of contrast between the spread of shipping containers from one side and its un-usage from the other side. Moreover, all future implementations will be reviewed to apply the most benefits of containers. The paper is an attempt to explore the uses of prefabricated shipping containers to create architectural spaces that has higher standards of safety towards diseases and it also serves several functions and human activities not only on the scale of an individual building but also on a larger scale (students housing). It presents a future solution for a building or a group of buildings which are structurally stable, healthy and environmentally friendly.

1. INTRODUCTION

Since the first months of 2020, the inhabitants of planet Earth have been subjected to conditions that have never been seen before such as: illness, fear, loneliness and total lack of control. The built environment has always been affected by pandemics and catastrophic events. Further, buildings have long reshaped the built environment and forced users to respond and learn from failure [1]. As a result, users adapted new ways in architecture to be concerned with a person's way of life, values, habits and new requirements.

Housing became more than just a living space, resulting in a huge rise in buildings' resource consumption (e.g. electricity and water). Therefore, even after the end of COVID-19 pandemic, the existing built environment needs to change and adapt in order to be more resilient to future diseases outbreaks and lockdowns introducing solutions for challenges that exist in residential buildings to adapt a new reality.

Architects and urban planners will become the new "treaters" because architectural practices are going to change because of the influences of the pandemic. Thus, reshaping future architecture approaches are believed to be an important tool for responding and even preventing infectious diseases in the built environment.

There are certainly places with material shortages, or situations where pre-fabricated housing might be acceptable, especially when an area is recovering from a disaster. In this situation, container buildings would be appropriate. This is because, it is temporary, it can be placed from one place to another, easy to be assembled and dissembled and can be reused in other project. In addition, reusing containers seems to be a low energy alternative solution and easiest sustainability formula.

The main problem of the study is that COVID-19 came as a surprise element around the world which negatively influenced the lives of millions of people. On the global scale, there are numerous numbers of containers that are stacked and sit in ports unused and virtually abandoned, accumulating in hundreds of thousands around the world. Some of these containers are suitable for one-time use, meaning they cannot be reused for shipping again. Also, transporting empty containers back to where they came from would cost loads and energy for no benefit [2]. So, it might be better to keep them and reuse them, if not for shipping, then for a living.

However, on the local scale, in Egypt, people at the time of pandemic faced two major problems. The first one was keeping themselves and their families safe from the Corona Virus infection. The second issue was that, as a result of the lock down, architectural projects stopped or got delayed causing a great loss of income. There were delayed decisions by clients and lack of money due to which many projects have stopped. In addition, there were cancellations of upcoming and future projects due to the risk of infection because workers spend a long time in the site as a result of using traditional building construction techniques which might increases the spread of the virus between workers.

To ensure being durable and sustainable, future buildings must be able to respond to questions under epidemic conditions, such as:

1) How to avoid effectively the spread of the disease?

2) How to reduce the building negative impacts on the environment?

3) How to sustain and enhance the comfort of people who spend most of their time inside buildings.

The paper assumes that shipping containers are the most efficient structures, according to the analysis of some examples and reviewing mega production structures that are used in slums upgrading and pandemics spreads [3]. The usage of shipping containers, as a new construction material, will help to construct buildings quickly and professionally without physical interaction between workers and without spending much time in the construction site. Accordingly, this will lead to the return of working in construction sites resulting in an increasing demand for new ideas, opportunities and flexibility in the design of architectural spaces.

2. RESEARCH METHODOLOGY

The paper is divided into three main parts. The first part is a literature review that discusses the evolution of COVID-19 disease and its negative impacts on building users and construction sites. Also, it presents the post-pandemic architecture through the use of prefabricated shipping containers that are characterized by modular construction to create flexible architectural spaces. Then, it analyzes different examples of student housing that used shipping containers in its construction and the different architectural approaches used during the design, construction and operation phases of buildings. Then, the paper shed light on the advantages and disadvantages of construction using shipping containers. The second part proposes new solutions and building technologies that use shipping containers through explaining the three phases in details, design phase of architectural spaces and construction phases that deals with construction elements, building foundations, building connections, stacking and the finally operation phase and how the building deals with HVAC systems, water management and thermal and acoustical insulation. Finally, the third part, apply solutions and future approaches on a proposed design for Students' Housing in New Alamain City (Alexandria, Egypt) to conclude the main strategies and technologies that can be applied in new buildings during the design, construction and operation stages and can face infectious diseases (Figure 1).

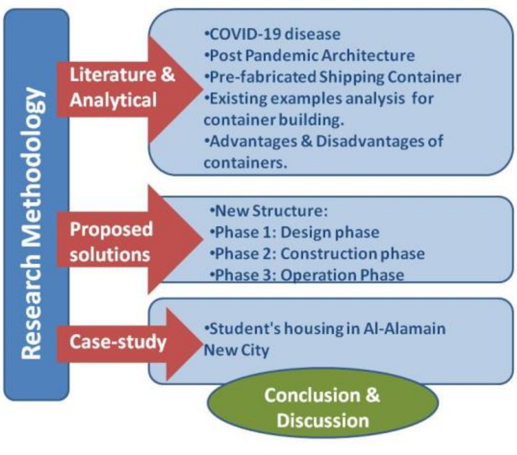

Figure 1. The methodology adopted in the study

The main aim of the paper is to find out new innovative solutions and future building technologies to be used through pandemic times that can facilitate the construction process using shipping containers.

3. POST PANDEMIC ARCHITECTURE

3.1 The evolution of COVID-19

Corona virus disease, also known as COVID-19, is an infectious illness caused by the corona virus2 that causes severe acute respiratory syndrome. The first case was discovered in Wuhan, China, in December 2019. Since then, the disease has spread worldwide, resulting in a pandemic [4].

Unfortunately, the impact of this mysterious illness is unclear and symptoms are not the same for all people. It might be moderate to mild respiratory disease that recover without treatment or it could be severe leading to millions of deaths throughout the world or leaving the survivors with long-term health issues and damaged organs [5].

Many scientists and specialists all over the world have undertaken many tests and researches to find treatment and medicine for the disease, but unfortunately, till now, there isn't a specific vaccine that has promising results for protecting and curing from COVID-19. Therefore, it is a necessity for architecture and human awareness to play their role effectively in deriving methods to decrease the spread of infection from one side and limit the symptoms from the other side.

Thus, the world needs to adapt quickly to such lifestyle changes. The experience of living under quarantine as a result of the COVID-19 pandemic continues to change people's perception of the environment in many ways especially dense areas which enhance virus transmission routes.

3.2 The use of prefabricated shipping containers

Following the coronavirus pandemic, architectural design was in a stage of "design for an independent building in case of emergencies". New buildings are most likely to be designed for energy and water self-sufficient.

Megahed and Ghoneim, identified several important changes in future architecture approaches, such as encouraging self-sufficient methods and concentrating on green spaces and low-rise buildings with improved indoor air quality which allow for a reduction in population density as well as the risks of being self-isolated for long periods of time [6].

Also, the COVID-19 pandemic experience has influenced building construction approaches. Modular construction gained more popularity, because it enables a rapid and low-cost construction of various building types [7]. Standardized prefabricated components of modular construction strategy (such as shipping containers) allow structures to adjust and satisfy buildings' needs throughout quarantine periods. Future buildings will allow for efficient, flexible solutions and a variety of uses and rapid transformation of buildings to meet specific demands (residential units, hospitals, healthcare facilities, universities, hotels, commercial use, … etc.). That is to say that, light weight and flexible structures have advantages such as construction speed and mobility. Also, post-pandemic architecture may include hygienic building treatments which make sanitization simple.

The utilization of modular and prefabricated elements in architecture is becoming increasingly widespread. The modular design of container building as well as the enormous quantities of low-cost containers are thus driving its popularity. This is due to that, shipping containers are stackable construction elements, that minimize the time of construction and reduce costs and wastes [8].

The shipping container is a steel-frame structure that is generally cuboid in shape and has a sufficient strength to support large cargo transits and storage. These are made of steel, which has a high-embodied energy in both manufacturing and recycling. There are various types of containers, varying from refillable to universally standardized.

Despite the fact that containers are designed to be reused, a great number of them are abandoned because their owners have considerably more containers than demand, or due to other economic reasons. This has led to great number of neglected and unforgotten containers in various ports across the world. According to research, over twenty million containers remain unused around the globe, with over one million having no purpose other than taking valuable space [9].

On one hand, containers have an active life of 8-10 years when used for shipping. After these years, they are discarded for transportation purposes. On the other hand, operational life is longer and if properly maintained, they may last for 20 to 25 years [10]. These containers are abandoned at port yards if they are not used posing significant recycling and disposal loads on the environment. Shipping containers are considered as a future temporary solution that can be implemented rapidly for disasters which appear suddenly. Furthermore, shipping containers can be maintained regularly to have a maximum life cycle.

Due to its numerous advantages, reusing these containers into living spaces has been used for more than a decade. Firstly, it is ready to be used as a shell that can be modified for architectural purposes. Secondly, it is a structurally flexible system that is capable of accommodating a large number of habitable spaces. Other advantages include earthquake stability, modularity and transportability after use. In container architecture, most of the work is carried out off the site (up to 90% including interior works) which saves time involved and manpower on the construction site [11].

4. APPLICATIONS USING SHIPPING CONTAINERS

The use of containers as a building material has grown in popularity due to their strength, wide availability and relatively low cost. Buildings have also been built with containers because they are seen as more eco-friendly than traditional building materials such as brick and cement. Construction using shipping containers is a recent building system, with already many successful examples around the world. This system presents a huge potential in the field of sustainable construction provided by the recycling of used containers. This paper also presents the analysis of examples that used shipping containers to build students' housing.

4.1 Keetwonen student housing in Amsterdam (The Netherlands)

Keetwonen is a tremendous success and is now one of Amsterdam's main campuses. The project began at the end of 2005 and was completed in May 2006. The city faced a huge lack of student accommodation and also low rents students can afford which do not cover the high operating expenses and construction costs usually encountered [12]. Thus, temporary housing has built the world's first and largest container campus for students.

The success of Ketwonen displaced any previous concerns that container households would be either too noisy, small or cold. The containers proved to be highly cost-efficient, roomful and insulated against noise and effects of weather than other student housing schemes present in the city.

Additionally, Keetwonen provides services that were missing in other student housing societies. Each container came complete with its own kitchen, bathroom, gallery, study and bedroom with featured upsized glass windows to facilitate daylight entering the unit and ventilation system (Figure 2 and Figure 3).

The project is based on the needs of students who wanted a private study space without the necessity to share showers and bathrooms within individuals to whom they are unfamiliar.

Furthermore, the campus offers plenty of opportunities to facilitate student convenience, for instance, the interior area features a cordoned area to facilitate bike parking [10].

Figure 2. The student housing unit in Keetwonen

Figure 3. Traditional containers are durable structures

4.2 EBA15 student housing in Berlin (Germany)

EBA15 is a student housing development that was built in 2014. It is made of almost two parallel bar-shaped multi-container units that when fully completed, stretch back from the road across the 10.000 m^2 site with a third unit extending alongside them at a slight angle (Figure 4).

The students' dormitory is made up of three long volumes composed of 420 container modules that are stacked on top of one another. The Corten steel shipping containers provide a characteristic architecture and a space for a dynamic and vibrant new form of cooperative living.

The 40' High Cube Containers are prefabricated as modular systems. The units may be linked together to form primary single, double and double mini units (Figure 5).

The center of the campus is made up of open spaces and access galleries connecting buildings. The communicative in-between zone is a gathering and exchange space that also functions as a shared balcony. The compact central building is divided into two open spaces of different character. Not only are there activity and sports area but also there is a green oasis of spacious lawn and trees [13].

Figure 4. Two parallel bar-shaped container units with a third one at a slight angle

Figure 5. The modular prefabricated containers

5. ADVANTAGES AND DISADVANTAGES OF SHIPPING CONTAINERS

Due to the presence of high numbers of shipping containers that are stored with no need, this caught the attention of many architects to re-use these containers as modular units to form strong and flexible structures that can be constructed perfectly and achieve the highest performance. The paper analyzes in (Table 1) the usage of shipping containers as structural building and benefits from the experiences of previous examples to form a scientific view on all advantages and disadvantages of shipping containers.

Observing the previous table, it is concluded that shipping containers have more advantages. Moreover, solutions for disadvantages will be introduced furtherly in the paper through the three phases of adopting shipping containers in architecture.

According to the previous examples analysis from one side and data gathering corresponding prefabricated structures from the other side. The paper was directed to a conclusion that traditional structures consume much time, effort and resources which is not the best solution during the quick spread of pandemic diseases. On the contrary, the pre-fabricated structures like shipping containers and box units are seen to be from the best and quickest solutions in architectural projects for mega production in the least time [3]. Therefore, shipping containers can be used to face pandemic diseases due to the following:

- Availability of containers widely in Egypt, and particularly in Alexandria, Egypt.
- Numerous advantages and resolvable disadvantages of using containers in creating sustainable buildings and structures.
- Spread of previous experiences and examples of building using containers

Table 1. Advantages and disadvantages of using shipping containers as structural buildings

Advantages	1.	Durability and strength	Bear high loads and resist harsh weather conditions.
	2.	Modularity	Provide flexible design of architectural spaces.
	3.	Simple foundations	Simpler than traditional counter parts.
	4.	Short construction time	Minimize construction time by 40% to 60% as compared to others.
	5.	Availability	Presence of containers all over the world.
	6.	Employment	Low number needed.
	7.	Adaptation	Flexibility in adjustment
	8.	Pollution	Recycling containers decrease pollution
	9.	Economically	Feasible due to reusing existing containers.
Disadvantages	1.	Temperature and humidity	Require certain methods to thermally insulate structural elements and to protect against moisture.
	2.	Topography	Suitable for flat sites.
	3.	Acoustics	It is needed to control noise spread.
	4.	Unpopularity	Due to its appearance, it is important to increase aesthetic values.
	5.	Skilled labour	Professional labour with higher cost are needed.

6. METHODS: PROPOSED INNOVATIVE SOLUTIONS AND BUILDING TECHNOLOGIES USING SHIPPING CONTAINERS

The traditional container should undertake many development stages and changes to level up and be usable by people to live and practice different activities safely and efficiently. Therefore, the paper proposes three development phases concerning design, construction and operation to convert the containers to strong durable structures and spaces that can resist pandemic diseases and embrace the inhabitants and users while protecting them from infection from one side. On the other side, in case of infection, these spaces can isolate the infected users while providing maximum comfort and multifunctional activities in one space (Figure 6).

6.1 Design phase (shipping containers to create flexible architectural spaces)

By looking at any steel shipping container, the primary and fundamental characteristics of space emerge, with slight modifications. It can accommodate a variety of human activities and functions, thus creating not only functional spaces, but also interesting spaces for people to live, use and enjoy.

Figure 6. Transformation of shipping containers to durable structures

According to the tips on occupant's prevention and care, these components of the interior architecture that are in the field of physical health can be categorized into two dimensions include spatial organization, size, number and flexibility of spaces [14].

Several examples of structures existed in this way all around the world to create different projects with different functions and scales such as: emergency crisis shelters, emergency natural disaster shelters, school buildings, residential and commercial structures, studios, shops, museums, financial institutions, pharmacies, sleeping rooms, retail stores, public toilets, … etc. [10].

Nowadays, spaces are not only designed for a specific function, but also they should be flexible and multi-functional to handle different functions and allow users to undertake various activities achieving flexibility in use and in the distribution of furniture. Also, the plan should be studied in the very early stages of design. Moreover, by applying flexible spaces, more activities will be available and will offer the maximum utilization for users, thus increasing the efficiency of space [6].

Designers should also put into consideration, the possibility of isolating a member or more in one space due to infection. In conclusion, this will lead to a well-designed space that cooperates effectively with pandemic diseases by ensuring that common spaces are well ventilated (keep window open) [15]. natural ventilation through open windows and doors should be established on an individual basis, taking into consideration the characteristics of the room such as volume, size, purpose of openings, occupancy rates, activities taking place in the space, the climatic and weather conditions, as well as energy conservation and the comfort of the users [16].

In addition, adaptation of container is required to create openings for light, ventilation and access. Steel framing is necessary to frame out openings that are created inside panels [17].

6.2 Construction phase

A shipping container has a structural composition that allow different functions inside a building or even complete buildings to be easily constructed by reusing these containers, in addition to their uniform regular cuboid shape and its modular sizes [15].

Working with containers necessitates the employment of skilled labor to modify it for practical use. Cutting, welding, adding structural members, fixing-up services, fittings of doors and windows, insulation and finishes to corrugated metal sheet is indeed a skilled job. Training labor for this purpose is important because container architecture is rarely used.

6.2.1 Construction elements

Container materials consist of steel, aluminium, stainless steel and fiberglass. Both walls and ceilings of a shipping container are composed of corrugated metal sheets 2mm thick, in which each element is made of "corten" steel. The only exception is the floor, made of plywood.

As transportation units, containers are well processed in terms of rust, fire and mildew resistance and once warned out, they may be utilized for at least another five to ten years.

According to Alejo Andres and Palma Olivares research (2019), every time a 20-inch standard container is used, can save carbon dioxide emissions by 12 tons during the life cycle of concrete buildings [17].

Most shipping containers have uniform dimensions which are suitable for modular prefabricated construction projects. The most popular containers used as building components are 2.438m in width and 6.096m or 12.192m in length. For residential structures, several national rules have a minimum height limitation of 2.4m. Thereby, in this context, to meet the minimum clear ceiling height building, design only considers the high cube container with total height of 2.9m.

Meanwhile, the containers' internal dimensions differ from the external ones. In fact, internal walls have a variety of corrugations, each with a depth of 25mm. This reduces the container inner width by 50mm due to both a concave and convex corrugation.

The rear, the other side without the door, is also corrugated. The doors have a thickness of 50mm. The height of the inner dimension is less compared with the outer dimensions [19].

The following (Table 2) shows the standard dimensions, volumes and weights of shipping containers.

Table 2. Standard dimensions and weights of shipping containers [18]

Specifications	10 inch container	20 inch container	40 inch container
Inside cubic capacity	15.4 m^3	33.2 m^3	67 m^3
Max. gross weight	Non-payload	30.480 Kg	30.460 Kg
Tare weight	1.500 Kg	2.360 Kg	3.980 Kg

Most containers are designed to last at least a decade lifespan, with three decades being the most common lifespan goal. They are made to be extremely durable and secure in order to facilitate safe cargo transit over long distances [10].

6.2.2 Foundations

Speared footing, mat foundation and piles are the three most typical construction foundations. Speared footing is made of reinforced concrete blocks or cylinders that are placed under the container's corner post. In general, speared footings are best for small-to-medium sized structures on strong or medium-strong ground. Mat foundation can be utilized when the ground is extremely unstable and dangerous, or the ground water level is higher than the foundation [20].

Another alternative is to employ piles (long beams of concrete, metal and wood that run deep into the ground). This approach is obviously more expensive and it is only used when the ground's top layer is insufficient to support the load of the building [21]. The load can be transferred to the deeper load-bearing ground layers through the columns. For this reason, speared footings and mat foundations are more common under container buildings.

6.2.3 Connections

When stacking on the foundations, all containers need to be linked to each other or fixed to the foundation. Due to the lack of standards, the connection method should be developed separately according to each project. The connection has two ways: permanent welding or a temporary joint anchor bolt connection.

Temporary anchor bolt connections are normally composed of holes in the bottom and the upper corners which can be fastened together. In this way, twist and latch locks are the two basic options to attach the containers during stacking. These connections can take the horizontal and vertical loads from the shipping operations. For housing constructions, this joint can be sufficient depending on their intended purpose [8].

For connection to the foundation, the container is generally welded to an additional steel base plate. The latter is identified by the presence of underneath reinforcing bars that are often inserted into wet concrete foundations. After hardening of the concrete, the steel base mat first and the container [20].

6.2.4 Stacking of containers

Stacking of containers horizontally and vertically is another architectural design and technical problem in the design of container structures. There are usually two techniques for connecting containers together. First, containers need to be stacked side by side along its length to increase the width of the living space. Second, a single unit design, if containers are stacked perpendicular to one another or along its width, it wastes a lot of spaces in pathways. There are no structural concerns in connecting containers horizontally. However, placing them horizontally has spatial consequences (interior layout and space making). Once the housing units are ready, there are several options for arranging them horizontally to create community public spaces.

Another problem is how to arrange them vertically. There seems to be conflict in the available literature as to how many containers can be stacked on top of each other. According to Karam, M., six units of fully loaded containers can be placed above each other. While during an interview with the designer Dhara Kabaria, it was found that usually five containers are stacked above each other in the dock yard.

Containers are stacked along the same axis while shipping. Although, there are no structural concerns of stability if containers are stacked one above the other along the same axis, it limits the innovation and creativity of building design.

Many case studies of housing containers show that containers may be stacked in variety of ways such as cross manner, however, it requires extensive and expensive engineering to take care of structural safety.

Containers allow wet areas (kitchen, utility and toilets) to be placed wherever they are needed inside one unit. However, when it comes to multi-unit housing, the design of the service core becomes crucial in order to reduce the cost of laying service lines. Thus, stacking plays a critical role in the design of service cores for container housing project [11].

6.3 Operation phase (healthy interior space indicators related to COVID-19)

To determine how the Coronavirus outbreak would influence people's future preferences in residential and housing spaces, it is necessary to identify the elements that affect interior design and the problems they cause for occupants. To this end, points have been selected relevant to the operation phase and interior of spaces have been selected. The preliminary findings on the COVID-19 virus, for example, show that according to the WHO study, it may remain on the surface for hours or even days. This can change depending on the surface type, the temperature and the humidity level in the air [22]. Therefore, the materials of finishing surfaces such as floors and walls as well as equipment surfaces, valves and fittings are all essential in avoiding and stopping the spread of the virus [15].

Operating a building in the era of viruses spread should not be handled in a traditional manner, as many actions should be considered concerning the residents and operators. Therefore, accordingly to the analysed study and understanding of a virus like COVID-19 formation and spread methods, building operation will be divided into two types; which are basics and specialized.

These basic precautions for building operation address people's culture about personal hygiene and methods for avoiding infections and diseases. The previous can be achieved through:

A. Maximize the frequency with which commonly touched surfaces are disinfected.
B. Increase the number of hand sanitizer dispensers to remind visitors to use them.
C. Prepare building with all alerting signage that conveys actions taken to protect public health. This signages should encourage and educate people on hygiene and cleaning.
D. Visualize recommended spacing by implementing floor/pavement markings (i.e. paint/tape) among occupants and delineate circulation and/or furniture location.

Once the basic precautions above are covered, the specialized operation phase ca be presented in five main sectors, which are:

6.3.1 Heating, ventilation and air-conditioning systems (HVAC)

Many health organizations like WHO and UNICEF have admitted that COVID-19, like many respiratory tract infections, spread and transmits effectively in closed spaces or those with poor ventilation system [23]. To prevent the spread of virus from sick people and transmission to others, direct airflow should be diverted away from groups of people. Mechanical ventilation should minimize the direction of airflow towards stationary persons.

According to ASHRAE, ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus.

The HVAC system (heating, ventilation and air-conditioning) is a group of systems used to allow human body to feel comfortable in closed spaces, concerning temperature, humidity and clean filtered air. Firstly, ventilation systems provide clean air by exchanging indoor and outdoor air, filtering air and increasing the time required for exposure to an infectious dose. Secondly, the three systems have a complementary role in decreasing transmission in closed indoor spaces by increasing the rate of air exchange, minimizing recirculation of air increasing the use of outdoor air and employing appropriate types of filters. However, there are HVAC filters, along with other strategies, that help to reduce virus transmission while removing other air contaminants that may have health effects.

Finally, depending on space occupancy HVAC systems, often reduce the air exchange just before and after the use of closed spaces and can even be switched off during certain periods [24].

A few actions related to HVAC systems are recommended, in case some spread of the virus can be affected:

- Increase outdoor air ventilation by reducing the number of people in the building, this increases the effective diffusion ventilation per person.
- Disable the demand-controlled ventilation system.
- Increase the minimum outdoor air dampers, to 100%, thereby preventing recirculation.
- Improve central air filtration to allow systems to function for longer periods of time.
- Consider using a filter-equipped portable room air cleaner.
- Provide equipment that promotes physical distancing and reduces disease transmission.
- Consider UVGI (ultraviolet germicidal irradiation), which protects occupants from radiation, particularly in high-risk spaces such as waiting rooms and highly populate zones [25].

6.3.2 Water usage (plumbing fixtures)

Water is a dual weapon as it has a great advantage in cleaning hands and swiping viruses away on one side. However, on the other side, it might be a reason for viruses to spread through plumbing fixtures, therefore many actions should be considered:

- Implementation of water management system for building operations.
- Usage of flush and potable water systems in buildings with extended enclosure.
- Replacement of flush valves and taps with hand-free devices.
- Addition of touch-less hand washing/hygiene stations throughout bathrooms and common spaces.

6.3.3 Appliances, equipment and accessories

There are many procedures taken concerning electrical, lighting and communication systems such as replacing light switches with motion sensor controls or phone-based application controls.

6.3.4 Flexibility of smart furniture

- Incorporation of physical barriers such as transparent plastic partitions or sneeze guards to keep people from sneezing.
- Separation of dining areas: usage of temporary partitions or tall booths and utilize, movable partitions to subdivide large spaces.
- The use of high-touch or difficult-to-clean finishes and equipment including door locks, elevator controls, carpets and others and encourage the use of touch-free equipment or mobile of phone-actuated.
- Prioritization of easy-to-clean materials when replacing furniture.
- Improve acoustic treatments for occupants who are wearing masks may hear and be heard.
- If a temperature check is to be used as part of the symptom screening process, non-touching temperature detection equipment should be used [26].

6.3.5 Thermal and acoustical insulation

Containers are not manufactured with the goal of being utilized for architectural purposes. All of its structural components are constructed of steel which is an excellent heat and sound conductor. Therefore, its acoustical and thermal characteristics do not meet the requirements of living space.

As mentioned by Ismail et. al, implementation of containers for architectural use in hot and humid climates are not usually applied due to various concerns and difficulties including a negative perception of its acceptability in these climatic conditions. However, he highlights that its advantages in terms of modularity, transportability and durability might overcome the drawbacks if the container building is properly installed and modified to create comfortable indoor environment [27].

Roof and side panels of containers need to be acoustically and thermally insulated to provide a comfortable indoor environment. Also, before installing the insulation and surface paneling, all electrical, plumbing and drainage services should be completed according to acoustical and thermal insulation regulations. Roof panels require false ceiling. Therefore, false ceiling cannot be comprised. On the other hand, floor can be finished with minimal thickness such as carpet or any type of floor tiles [28].

To conclude the above operation phases, several approaches should be taken into consideration to improve the building interior spaces such as effective ventilation, materials that are employed to create building interior spaces, smart systems that reduce hand and physical contact.

7. CASE STUDY: A PROPOSED DESIGN OF STUDENTS' HOUSING IN AL ALAMAIN NEW CITY (ALEXANDRIA, EGYPT)

Based on the previous studies and analysis, the methodology generated a proposal for building housing projects that can adapt pandemic disasters. Also, it is important to apply this sustainable agenda with its three phases: design, construction and technical applications to guarantee the effectiveness of the project.

Creating new settlements with a basic building block (shipping containers) limits diversity, therefore reducing time required to build and design. Individual base-types of equally sized modules are designed first. The next stage involves creating different combinations of these modules so that new settlements will not be lifeless. It is also important to take human scale into account and include Open and pleasant social spaces in future residential developments [29].

Therefore, the concluded future architecture approaches will be applied in the design of a Students' Housing in Alexandria city. This is due to the political governmental directions to invest and build new university campuses in the new settlements including their services like dorms.

The Students' Housing is a proposal designed and modeled by the authors as a solution for future construction problems. This design agenda resulted in a creation of a modified shipping container that presents an example for reshaping architecture in the era of pandemic diseases such as COVID-19.

7.1 Project location and climate

Al Alamein is one of the new cities located in Egypt. It was chosen as a site for its optimum location and its presence near many new universities such as, Al Alamain University at a distance of 121m. The area of the site is nearly about 30.287m^2 where two streets bound it. The main street is with width 100m and the secondary street 33.5m. The total built-up area is 14.100m^2 which is considered 46.5% of the overall area of the site (Figure 7).

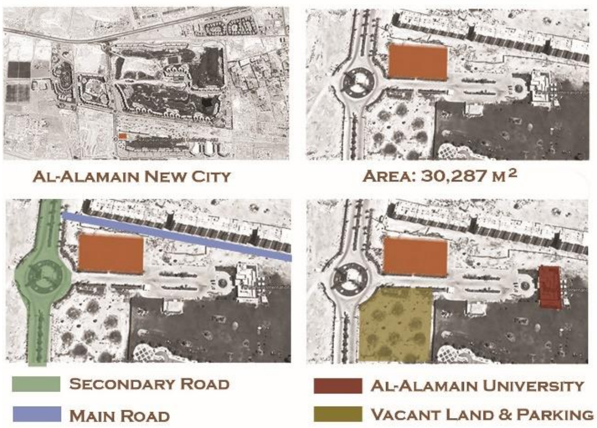

Figure 7. Project location in Al Alamain New City, Alexandria, Egypt

Since there are many climatic moderation processes to increase human thermal comfort, therefore the paper studies the weather conditions in Al Alamein New City, to select the suitable implementations according to the location's climate. The climate in Alexandria is characterized by being hot all summer days and warm in winter where the temperature varies between 26.1℃ and 12.9℃, with an average temperature for the year of 19.8℃.

7.2 Concept and project brief

The concept of the student housing project is to combine both technology and engineering to create the best architectural solution to face the problem of COVID-19 in such type of buildings that has high density of users. This took place by joining between new innovative technologies, (circuits of electricity, and new architectural structures like pre-fabricated shipping containers). Moreover, the technological circuits of electricity connect the whole site together as a grid that pumps life to the containers and control all important services such as the infrastructure and electricity wires, computerized temperature sensors for all containers, food, laundry and medicine shuttles. All these circuits are connected to a central control room in the main building.

The project consists of two main components. Firstly, the main administration building with an area of 426m^2. It is located in the middle of the site so that it is centered and accessible from all directions by the students. At the entrance, it is proposed to have isolation rooms, central control room, offices, dining area and other services.

Secondly, the presence of 175 separate accommodation units for 382 students, made of pre-fabricated shipping containers (single and double rooms with an area 14.4 m^2 each while triple rooms are with area 28.8 m^2 each). The proposed type of container used is 20-inch (Figure 8).

Figure 8. The concept of students' housing project

By applying the derived future architecture approaches on the project, it will undergo several phases to create innovative architecture that can resist the spread of COVID-19, minimize its negative effect, protect its users from infection and encourage them on increasing hygiene and sanitization standards while keeping social distance considerations. These three phases will be responsible for the formation of the project, followed by the application of environmental treatments.

7.2.1 Design and formation of flexible spaces

The single and double housing prototypes consist of one container (type 20-inch) which is designed with dimensions 2.40m * 6.00m * 3.00m height with an area of 14.4m^2 to achieve the smallest area although with the most comfortable proportions (Figure 9). In addition, there are triple housing units which consist of two containers (type 20-inch) stacked over each other with an internal stair. The lower level is designed for utility services like kitchen and bathroom and upper level is designed for sleeping and studying with a wide open terrace (Figure 10).

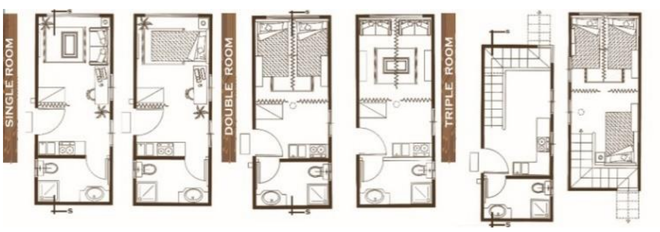

Figure 9. The proposed design of students' housing units using shipping containers (single, double and triple housing units)

Figure 10. Stacking the container units over each other

All room openings are proposed to be oriented with windows towards the north so that they can benefit from both natural ventilation and light. Furthermore, glazed windows are placed around the envelope to enable diffused light inside the container and to maximize the effective solar penetration into the living areas.

The container is supposed to mitigate the external climate and provide comfortable indoor environment. It consists of coating layers that provide thermal and sound insulation, reduce cooling, ventilation and electrical lighting requirements. Finally, the roof and façades are painted with light colour for the purpose of more heat reflection in summer time (Figure 11).

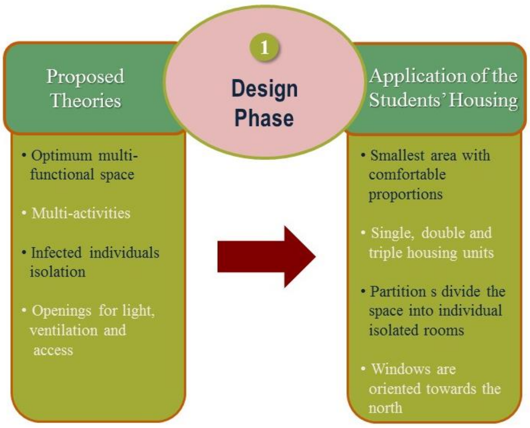

Figure 11. The application of proposed theories of design on the students' housing

7.2.2 Construction phase (constructional elements, foundations and connections)

Buildings with modular shipping containers is a form of architecture that uses steel frames as structural system. The pre-fabricated shipping containers were chosen as it will be fabricated in factories under precautionary measures, then rapidly installed in site, therefore decreasing labor and accordingly minimizing the possibility of infection between workers and control the construction period.

The use of containers as a building material has gained popularity in recent years due to their inherit durability, abundant availability and considerably low cost. In addition, they are considered to be more environmentally friendly than conventional construction materials such as cement and bricks.

The number of containers used is 228 containers stacked vertically over each other creating community spaces in between clusters. The containers materials are steel where walls and ceilings are composed of corrugated metal sheets (corten steel). It is proposed to use speared footing made of reinforced concrete cylinders placed under the corners of the container. The containers are connected permanently to each other by welding (Figure 12).

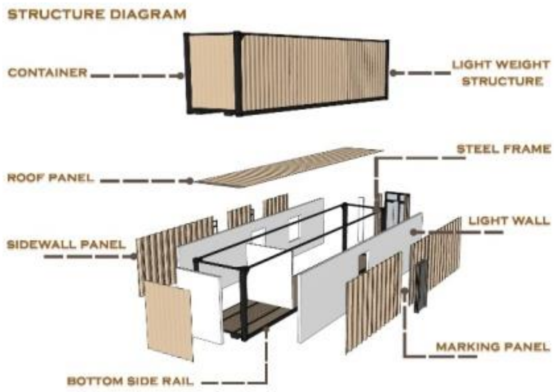

Figure 12. The constructional elements of pre-fabricated shipping containers

The proposed students' housing is designed to be a temporary building that is rapidly collected, assembled and built-up in site during the periods of disasters like COVID-19 disease. These types of structures are durable for 20-25 years and can be reassembled more than one time in different locations and various climates (Figure 13).

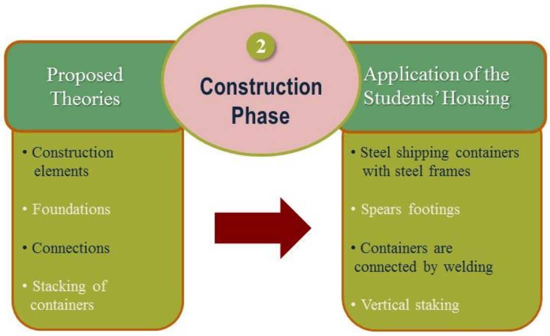

Figure 13. The application of proposed theories of construction on the students' housing

7.2.3 Operation and healthy interior spaces

All safety precautions were taken into consideration during the design of the main building. It was proposed to design sanitation areas at the entrance of the building, observation of students' body temperature, isolation areas for students housing units if a virus was detected.

More considerations are studied in the students' housing units, where they spend most of their time. There are many operational precautions taken to assist in pandemic disasters like:

Appliances, equipments and accessories

- Automatic entry door openers are present at each housing unit with automatic observation of students' temperatures.
- Shoes are one of the main reasons for viruses transfer, therefore, a take-off shoe area is present beside the door for automatic sanitization.
- There are separation areas such as installing temporary partitions inside the double, triple rooms for individual isolation in case of infection and in dining areas as a type of social distancing.
- There are clothes shuts for cleaning and food shuttles to provide food and medicine for the students, without direct contact between people.

In addition, there are several building fixtures that will be available as precautionary method like:

- Automatic entry door openers/proximity sensors or Bluetooth command.
- Post hygiene, cleaning, and sanitizing signage (Figure 14).

Figure 14. Operation phase considerations against the spread of COVID-19

Plumbing fixtures

- Hand-free flush valves and faucets.
- Toilets with flush and potable water systems, touch less hand washing.
- Touchless hand washing/hygiene stations in common spaces such as corridors, gathering spots and others.

Flexible furniture

To take advantage of this small area and fulfil the optimal utilization of the active area, a multi-function furniture was proposed to change the function of each space. Each unit is divided into 3 zones; the first zone is used as a bedroom and it can be closed and converted to a sofa to become a living area or a study area by using a desk for working. The second zone is an open kitchenette with a wall mounted dining table and finally the third zone is the bathroom (Figure 15).

Figure 15. Indoor multi-functional activity areas for each container using flexible furniture

Self-cleaning materials

Nano-science and technology are responsible of the creation of a new era of self-cleaning materials and nano-coatings [30]. In addition, they have many advantages being economical, especially when used as an exterior coating and also considered the best solution hygienically. It is proposed to use an anti-bacterial surface that continuously cleans itself from any harmful viruses without using any cancerous chemicals [31].

7.2.4 Environmental treatments and sustainability

There are different environmental treatments that are used in the project to improve the performance of the whole site such as:

Building arrangement with wind movement

According to the North-West wind direction in Al Alamain city, the containers are stacked with a shift over each other to allow open spaces between them, thus increasing air speed, wind direction and velocity. Besides adding opposite openings in containers to allow cross-ventilation within space. Also, cross ventilation will be allowed in spaces and will assist in controlling the spread of COVID-19 because fresh air will be always renewed inside spaces.

Green spaces and vegetation

Green roofs are used to cover the roofs of the units to multiply the clean green platforms for various activities and control thermal comfort inside the container. In addition, the presence of green belt in site acts as a wind shelter during winter and sunshade during summer (Figure 16 and Figure 17).

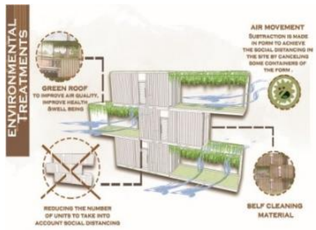

Figure 16. Improving performance of containers through green roof, air movement and self-cleaning materials

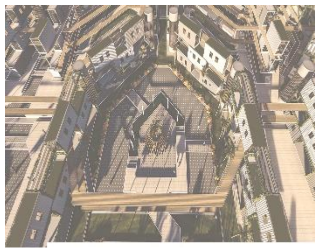

Figure 17. Green roof covering all containers

Shading

The containers are arranged above each other so that units can shade one another. In addition, there are to shaded gathering spots between the clusters, that can be used by students for different activities.

Figure 18. Photovoltaic cells on the shades

Figure 19. LED light for pedestrian pathways

Energy Production

There are photovoltaic thin film cells (PV) integrated on the shades of the gathering spots to produce the energy needed for electric equipment in housing units of the project as a whole and to create an aesthetically attractive solution. In addition, it promotes the total energy performance of the site as a collaborative aspect of the design and having an architectural function. Moreover, the integration of PV modules as external solar shading devices is an efficient technique to manage the energy used in the project. Finally, LED lighted pedestrian paths are used in all site, using the clean energy generated from site, thus decreasing the negative impact on environment (Figure 18 and Figure 19).

Water surfaces

Water features have a great effect to cool the passing air and improve thermal comfort especially when directing building openings to capture wind with cooled air and allow them to enter spaces to assist in decreasing spaces temperature. Therefore, while designing the site, water features were added.

Water management

The application of grey water management through collecting water from washbasins and showers in bathrooms to a grey water tank, then treatment and filtration to be used once more in toilet flushing or in the irrigation of the site. In addition, collecting rainwater and recycling it and reusing it once more in different purposes (Figure 20).

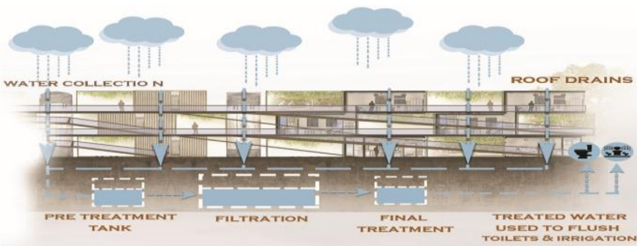

Figure 20. Re-use of grey water and rainwater in buildings

Cool reflective materials

Studies proved that using reflective materials can reflect incoming solar radiation and thus decreasing the unwanted high temperature and thermal effect [32]. In addition, white and light colored surfaces were used in the containers to guarantee thermal comfort (Figure 21).

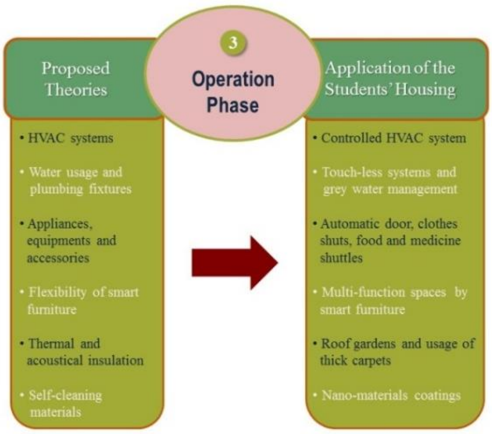

Figure 21. The application of proposed theories of operation on the students' housing

8. RESULTS AND DISCUSSION

The students' housing in Al Alamain New City is designed following the three main phases of creating a building that can survive through pandemic diseases and protect its inhabitants from viruses such as COVID-19. Other approaches were taken into consideration like vertical circulation presented in elevators, stairs and ramps. Besides horizontal circulation was presented in streets, pedestrian paths and bridges to ease the movement of students from one place to another safely. Moreover, the entrance of the main building was designed to be frontal for easy and remarkable entrance (Figure 22).

Entertainment areas for students were designed to maintain students' physical and psychological health in addition to allowing social interaction while applying COVID-19 precautions. The entertainment areas were divided into two types, the first one is "site group entertainment zone" with an area 332-1007m^2, that is included between the cluster of containers (Figure 23). These are considered as gathering spots where students can interact with each other as they contain seating areas, outdoor cinemas, open gym and many other useful functions. The second one is the "unit entertainment zone for each container", with an area 14.4 m^2. This area can be used for reading, relaxing, playing sports, yoga and others (Figure 24).

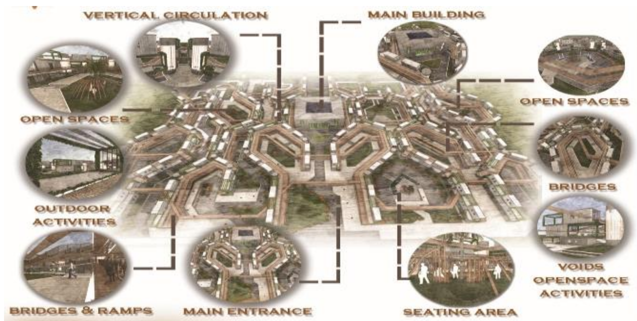

Figure 22. Vertical and horizontal circulation in site

Figure 23. Entertainment zones are included between shipping container units for different activities

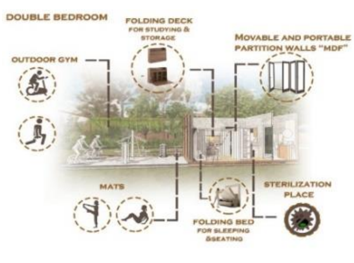

Figure 24. Entertainment areas in shipping container units

The design proposal provided several future solutions for the challenges imposed by COVID-19, through the design process starting from the design of spaces, the construction on site using prefabricated materials and the operation systems to achieve maximum health, social and physical distancing and safety for users. The design of the project took into consideration the environmental and economic problems through preserving natural lighting and natural ventilation, generating thermal comfort, enhancing energy and water.

9. CONCLUSION

The COVID-19 has inspired architects in predicting and imagining what post-pandemic architecture and urbanism could look-like. Although architects are not going to overhaul how to design buildings and cities before, based on the current circumstances and emergency measures, however, they should review new design approaches and strategies. They could recommend more effective use of health design ideas that can control pandemics and more sustainable architecture.

With the emergence of COVID-19 pandemic, questions undoubtedly arise, requiring the addition of security layers to up-date antivirus protection framework. This research does not provide answers, rather it identifies areas where more research is needed and suggests innovative solutions and technologies for reshaping architecture in the future.

The research presents a vision about the needed antivirus housing that may be adapted to stop the virus from spreading or minimizing its effects, based on the lessons learned during the crisis. Also, it presents post-pandemic housing that can be simply created through shipping containers and modular design. The current research analyzes the application of containers as the fundamental module for prefabricated housing projects. In addition, it explores the future potentials and prospects for modular architecture which is flexible and transportable in creating architectural spaces. It also examines how container buildings could lead to the development of a new housing style.

This is because container architecture has numerous advantages such as simplicity of assembly, short construction period to avoid long-time physical interaction between workers and low-cost.

The findings of the study which are presented in this research, suggested different ideas to answer the questions of the research and shed light on the appropriateness and difficulties surrounding shipping containers housing projects in post-disaster scenarios such as COVID-19. The reuse of containers as building materials to effectively avoid the spread of the disease and reduces the negative impacts on the environment through green building criteria. It contributes to the reduction of harbor waste amount. In addition, using reused container material, indirectly other green architectural principles are also applied to decrease air temperature in interior spaces. It makes users feel comfortable to sustain and enhance the comfort of people who spend most of their time inside buildings, for example, the application of cross ventilation and natural lighting and the use of environmentally friendly insulation materials.

It is concluded that there are three main phases that should be taken into consideration during the design of a project: design of flexible spaces, construction and operation. This study has revealed the limitations of how to control the built environment in terms of design, construction and operation.

In this context, the pandemic increased the need for policy makers, planners and architects to think outside the box, seeking to modify and reshape the physical spaces and restore the existing environment or create new concepts in order to combat the future virus attacks. The proposed solutions are considered as a call for immediate efforts to further investigate the built environment rather than waiting for another pandemic to serve as a reminder.

REFERENCES

[1] Dietz, L., Horve, P., Coil, D., Fretz, M. (2020). Novel coronavirus (COVID-19) pandemic: Built environment considerations to reduce transmissions. Msystems, 5(2). http://doi.org/10.1128/mSystems.00245-20

[2] Tokazhanov, G., Tleuken, A., Guney, M. (2020). How is COVID-19 Experience Transforming Sustainability Requirements of Residential Buildings? A Review. Sustainability, 12(20): 8732. http://doi.org/10.3390/su12208732

[3] Barakat, P.N. (2021). Remodeling informality into sustainable housing prototype, Alexandria Case, Egypt. Second Arab Land Conference. Cairo: UN-Habitat.

[4] WHO. (2020). Coronavirus disease (COVID-19). https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19, accessed on July 7, 2021.

[5] Lauren, M. (2021). What Is Coronavirus? Johns Hopkins Medicine. https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus, accessed on July 7, 2021.

[6] Megahed, N., Ghoneim, E. (2020). Antivirus-built environment: Lessons learned from COVID-19 pandemic. Sustainable Cities and Societies, 16: 102350. https://doi.org/10.1016/j.scs.2020.102350

[7] Smith, R. and Quale, J. (2017). Offsite Architecture: Constructing the Future. Taylor and Francis Group, Abingdon, United Kingdom.

[8] Shen, J.C., Copertaro, B., Zhang, X.X., Koke, J., Kaufmann, P., Krause, S. (2020). Exploring the potential of climate-adaptive container building design under future climates scenarios in three different climate zones. Sustainability, 12(1): 108. https://doi.org/10.3390/su12010108

[9] Levinson, M. (2016). The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger. Princeton University Press.

[10] Radwan, A. (2015). Containers architecture: Reusing shipping containers in making creative architectural spaces. International Journal of Scientific and Engineering Research, 6(11): 1562-1577. http://doi.org/10.14299/ijser.2015.11.012

[11] Anagal, V., Dhongde, S. (2020). Container housing-challenges and opportunities. First International Conference on Theory of Architectural Design: Global Practices Amid Local Milieu, pp. 175-181. http://ictoad.smvdu.ac.in/.

[12] Uittenbroe, C. and Macht, W. (2009). Sustainable containers: Cost-effective student hosuing. PSU Center for Real Estate, 53-54.

[13] Sottosanti, L. (Unknown). Smartbox: Reused container for a student dormitory in the city of Hamburg. Master Thesis. Politecnico di Torino, Italy.

[14] Bernardo, L., Oliveira, L., Nepomuceno, M., Andrade, J.

(2013). Use of refurbished shipping containers for the construction of housing buildings: Details for the structural project. Journal of Civil Engineering and Management, 1-19.
[15] Zarrabi, M., Yazdanfar, S., Hosseini, B. (2020). COVID-19 and healthy home preferences: The case of apartment residents in Tehran. Journal of Building Engineering, 35: 102021. http://doi.org/10.1016/j.jobe.2020.102021
[16] Container. (2019). Shipping Container Dimensions. http://www.containercontainer.com/shipping-container -dimensions, accessed on July 7, 2021.
[17] Yüksek, I., Tikansak, T. (2017). Energy-efficient building design in the context of building life cycle. In Energy Efficient Buildings. IntechOpen.
[18] ElRayies, G. (2017). Thermal Performance Assessment in Shipping Container Architecture in Hot and Humid Climates. International Journal of Advanced Science Engineering Information Technology, 7(4): 1114-1126. http://doi.org/10.18517/ijaseit.7.4.2235
[19] Islam, H., Zhang, G., Setunge, S. and Bhuiyan, M. (2016). Life-cycle assessment of shipping container home: A sustainable construction. Energy and Buildings, 128: 673-685. http://doi.org/10.1016/j.enbuild.2016.07.002
[20] Giriunas, K., Sezen, H., Dupaix, R. (2012). Evaluation, modeling, and analysis of shipping container building structures. Engineering Structures, 43: 48-57. http://doi.org/10.1016/j.engstruct.2012.05.001
[21] Weinan, W. (2011). Studies on the design strategies of contemporary shipping container architecture. Ph.D Thesis, South China University of Technology, Guangzhou, China.
[22] Doremalen, N., Bushmaker, T., Morris, D. (2020). Aerosol and surface stability of SARS-Cov-2 as compared with SARS-Cov-1. The New England Journal of Medicine, 382: 1564-1567.
[23] How to Protect Yourself & Others. (2021). Center for Disease Control and Prevention. https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html, accessed on July 7, 2021.
[24] ECDC. (2020). Heating, ventilation and air-conditioning systems in the context of COVID-19: first update. Stockholm: European Centre for Disease Prevention and Control.
[25] Larence, J., Schoen, P. (2020). Guidance for building operations during the COVID-19 Pandemic. ASHRAE Journal, 72-74.
[26] AIA. (2020). Re-occupancy Assessment Tool V3.0. New York: The American Institute of Architects.
[27] Ismail, M., Obaidi, K. and Malek A. (2015). Container architecture in the hot-humid tropics: Potential and constraints. Proceedings of the 4th ICERT2015: International Conference on Environmental Research and Technology: Exploring the Frontiers in Environmental Science and Technology Research, Malaysia.
[28] Morawska, L. Tang, J. and Bahnfleth, W. (September 2020). How can airborne transmission of COVID-19 indoors be minimized? Environment International, 142: 105832. https://doi.org/10.1016/j.envint.2020.105832
[29] Grebowski, K., Kaldunek, D. (2017). Using container structures in architecture and urban design. Materials and Science Engineering, 245(4). http://doi.org/10.1088/1757-899X/245/4/042087
[30] Daoud, W.A. (2013). Self-Cleaning Materials and Surfaces: A Nanotechnology Approach. John Wiley and Sons.
[31] Tipe. (2017). Advantages of Using a Nano Self-Cleaning Coating. Retrieved from Tipe Nanotechnology in life: https://titanpe.com/index.php/blog/post/3/advantages-of-using-a-nano-self-cleaning-coating, accessed on July 7, 2021.
[32] Faragallah, R.N. and Ragheb, R. (2022). Evaluation of thermal comfort and urban heat island through cool paving materials using ENVI-met. Ain Shams Engineering Journal, 13(3): 101609. https://doi.org/10.1016/j.asej.2021.10.004