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The Effect of 3D Printing on Lightweight Structures. Case Study: Mansoura Public Transport Bus Stop

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KEYWORDS:
Lightweight structures, 3D printing technology, bus stop

***Abstract*— The traditional building approach in Egypt has several drawbacks. This is evidenced by the long completion time for projects, the large number of workers, and the high to average error rate. These issues lead to negative environmental impacts and a higher construction cost. These drawbacks can be efficiently remediated through the use of the emerging technology of three-dimensional printing (3DP). This study aims to showcase some of the current success stories of 3DP in lightweight structures. A comparative analysis was conducted between construction using 3DP and the conventional construction method. A SWOT analysis was also conducted for 3DP to determine its strengths and weaknesses, as well as to find out areas of opportunities and those of threats. Many of the advantages of this technology can be highlighted, including reductions in cost and time, providing safe working conditions at the designated location (less injuries and deaths), and less pollution. However, certain constraints still hinder the use of 3DP. This includes the production of firearms and medical devices that do not comply with set standards. An analytical study was conducted for certain lightweight structures, including a temporary exhibit and a bus stop. Finally, a study was conducted of the current situation of the study area and a proposal was prepared for its renovation using 3DP. A list of criteria was set that all public transport stops and stations need to abide by, as well as techniques to achieve them. The proposed design and implementation of the bus stop in the case study was found to comply with them and achieve the desired results.**

I. INTRODUCTION

MODERN architecture does not recognize isolation, introversion, and the search for roots. While searching for our architectural heritage, we must focus on the most important issue, i.e., keeping up with fast developing technologies, before the gap between architecture in the Middle East and the West widens. In light of the scientific changes of the third millennium, the digital revolution has extended to include construction and implementation processes to ensure the speed and accuracy of production. This includes the introduction of 3DP in the setup of facilities, where workers are substituted by a group of robots. These technologies have allowed the design process to continue during the construction stages, and this

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continuity goes beyond traditional boundaries. The result is a central role for the architect in the construction process. The research problem revolves around the lack of interest in designing and constructing public bus stops in Mansoura by the government. This process followed the traditional construction approach, including a large number of workers, a high error rate, and inaccuracy in the work produced.

Therefore, the research seeks to monitor the use of some lightweight structures, produced using 3DP and how to benefit from this technology through:

1- Learning about the concept of lightweight structures and 3DP and making a fourfold analysis to identify both strengths, weaknesses, opportunities, and threats

2- Presenting some examples of lightweight structures produced through the 3DP technology, to identify the timeframe, effort, cost, and flexibility in design, as well as design accuracy.

The research is based on the descriptive approach, which was conducted through the identification of both lightweight structures and the 3DP technology. It is also based on the analytical method, which depended on conducting an analytical study of some lightweight structures, produced through 3DP. Finally, the applied approach was employed for the proposed work on the bus stop in Mansoura, using the 3DP technology, in order to reduce time and cost and to increase accuracy and design flexibility.

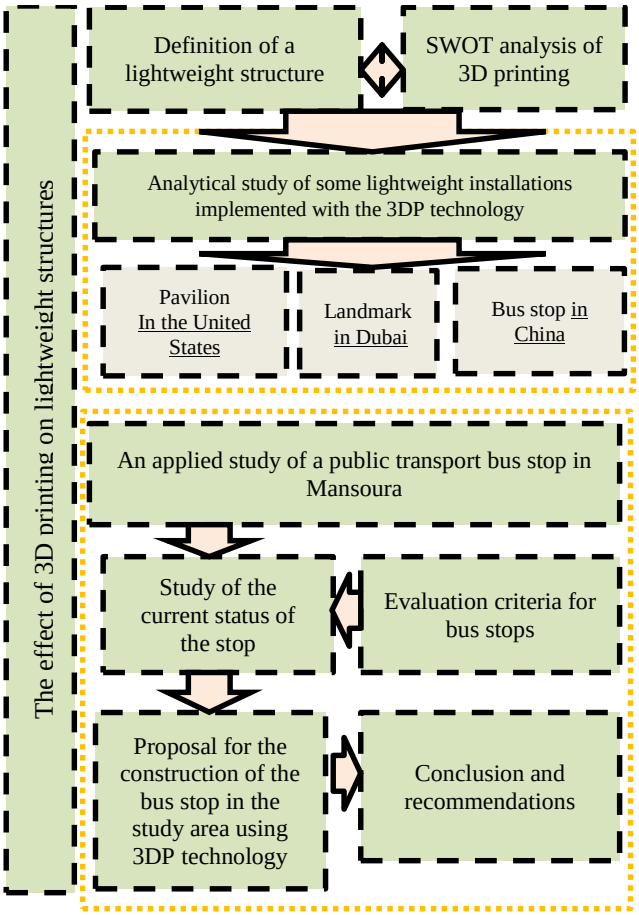


Fig.1 Steps of the research methodology

II. LIGHTWEIGHT STRUCTURE:

This section presents multiple definitions of light structures, provided by several engineers, especially architects; the most important of which are:

A. The first definition by Hani Issa Ahmed (1991)

A lightweight structure serves a specific purpose. It may be fixed or mobile. For example, a temporary structure is implemented in case of an emergency shelter. Thus, it is used as an urgent solution to accommodate individuals. This takes place in case of disasters caused by nature, such as floods or man-made disasters, such as fire and the collapse of a building. These types of structures can be quickly constructed to accommodate affected individuals.[1]

B. Second definition by Margit Pfeiffer-Rudy (2007)

The idea of building facilities out of lightweight materials began in traditional cultures around the world, where straw and reeds were efficiently used as building materials, along with earth and timber to create shelter for thousands of years. In Asia, Latin America, and Africa, some homes, bridges, and buildings were often constructed using bamboo. In many places, steel, concrete, and glass have replaced bamboo as building materials. Any intelligently designed facility aspires to be as light as possible.[2]

C. The definition of a light structure from the researcher's point of view:

The whole world is striving to make facilities lighter, to ensure lower consumption. A light structure depends on lightweight building materials. With the development in the world of building technologies, we can take advantage of efforts to make concrete and iron lighter, while maintaining their strength and tensile strength. This is done with the help of wood — bamboo — and recycled building materials, in order to reduce the amount of materials used in construction. This also results in ease of disassembly, installation, and transportation.

III. 3DP TECHNOLOGY

3DP is sometimes referred to as additive manufacturing (AM), which is the computer-controlled sequential layering of materials to create three-dimensional (3D) shapes. It is particularly useful for manufacture and for prototyping geometrically complex components.

AM is defined by the American Society for Testing and Materials as "the process of joining materials to make objects from 3D model data, usually layer upon layer".[3]

AM, often referred to as 3DP, is revolutionizing the way objects are created, manufactured, and serviced. AM provides on-demand production without the need for dedicated equipment or tooling. It unlocks digital design tools, has unrivalled flexibility across industries, and has a proven revolutionary performance.

3DP in engineering is a technique for creating physical buildings by layering construction materials. They are automatically produced by equipment in the construction sector, with a particular printing ink that meets building standards and has a practical function, according to pre-designed architectural drawing procedures. 3DP transforms the entire architectural system by bringing together design, construction, equipment, innovative materials, and applications in a single system.

IV. THE DIFFERENCE BETWEEN 3DP CONSTRUCTION AND TRADITIONAL CONSTRUCTION

It is our opinion that 3D printed building material can vastly outperform traditional construction methods. Traditional block and brick masonry is currently thought to be the most dangerous of construction systems. To begin with, Apis Cor and other companies print with a cement and sand mixture, so the printed building is identical to the concrete structure. The printer is nothing more than a device for arranging materials. The main difference is that the printer is a robot, which is an automated device that protects humans, while also lowering hazards.[4]

(a) (b)

Fig. 2. (a) traditional construction ، (b) 3D printed construction
https://medium.com/@Nik_chen/what-is-construction-3d-printing
(date 29/1/2018 11:05pm)

Blocks are first built in a factory, a process that includes people and manufacturing equipment, and then transported to the job site and unloaded with the use of manual labor and specific machinery. The building crew next spends around two months laying masonry on the walls, which is a time-consuming procedure.

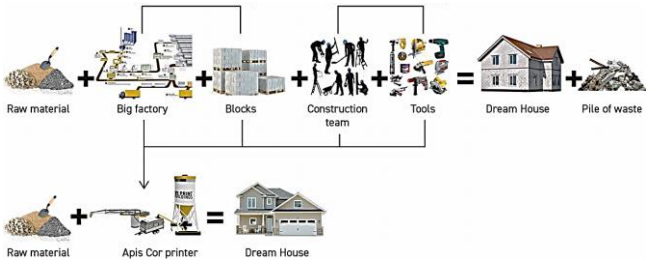


Fig. 3.The difference between traditional building and 3D printing
https://medium.com/@Nik_chen/what-is-construction-3d-printing (date 29/1/2018 11:05pm)

Since the supplies are already on hand, a printer can replace more than half of these activities, and the two-man-controlled printer can construct walls in a couple of days. By using 3DP equipment, money can be saved on logistics and human labor. Middlemen can be cut out from the supply chain, which is why 3DP in general cannot be more expensive than the cost of the printer. There are also additional benefits, including a decrease in waste, time savings, and new architectural possibilities.

Fig. 4.It shows the steps of traditional construction
https://medium.com/@Nik_chen/what-is-construction-3d-printing
(date 29/1/2018 11:05pm)

The brick and block industry in construction is a multibillion-dollar enterprise. Those who own shares in brick and block factories are advised to consider selling them now. It is our opinion that the next few years will bring on new changes within this field.

V. THE 3D PRINTING TECHNOLOGY AND MATERIALS INFORMATION

Printers can copy a variety of 3D objects in a layer-by-layer procedure. Since 3DP is a process in which various materials (liquid, powder, solid, or sheet) are strengthened layer by layer in succession by extrusion, sintering, bonding, or polymerization, certain details should be explained about the shapes that can be printed and the concept of printing itself.

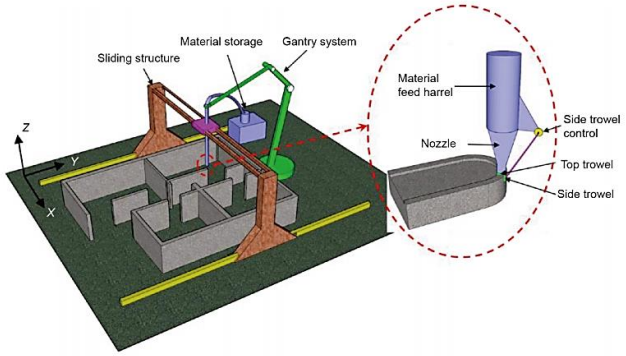


Fig. 5. Shows 3D printing during build construction
MA GuoWei1, WANG Li & JU Yang" State-of-the-art of 3D printing technology of cementations material—An emerging technique for construction"2017-scince china- Technological Sciences

- *Concrete Printing:*

Concrete printing (CP) is another large-scale 3D construction process. It is similar to Contour Crafting because the print head used for the cement mortar extrusion is also mounted on a top crane.[27] The printing nozzle moves along a

pre-programmed path and continuously extrudes the concrete material. Compared to Contour Crafting, the 3D CP method has less deposition resolution, which allows for better control of complex geometries.

○ *Contour crafting:*

As a major development in AM technologies and a breakthrough in 3DP, concrete,[26] polymers, ceramic paste, cement, and many other materials and mixtures have been used in the layered production method used to create large-volume items with a surface finish [27].

○ *D-Shape:*

It was created in 2004 claiming to be the world's first construction scale 3D printer. It consolidates crushed dolomitic limestone into a solid-stone material.[27] The aim of this step is to use locally available materials to form 3D printed structures.

(c) (a) (b)

Fig. 5. Shows 3D printing during build construction MA GuoWei1, WANG Li & JU Yang" State-of-the-art of 3D printing technology of cementations material—An emerging technique for construction"2017-scince china- Technological Sciences

VI. SWOT ANALYSIS OF AM (3D PRINTING)

A. Strength:

- Cost-free change of product design[5]
- Reduction in the design-to-manufacturing cycle
- Elimination of the need to screw and weld different parts of the end-product
- Use of new, lighter, stronger, and more durable materials
- Time Savings; Winsun's 3DP technology used for the construction of 10 residences and an office building in Dubai was estimated to allow for a 30% reduction in the project's time schedule compared to similar projects constructed using traditional methods
- Improvement in efficiency
- More flexible designs (complex shapes and structures)
- Elimination of tooling costs
- Elimination of the waste that accrues in traditional manufacturing
- Environmental benefits from reduced transportation requirements
- Increased flexibility in manufacturing
- Material savings when compared to traditional concrete placement; Winsun's 3D concrete printer's accuracy and precision result in 30%–60% less material waste (depending on the size of the printed components). Furthermore, 50% of the concrete utilized come from building leftovers

B. Weakness

- The high cost of construction equipment; since this is a new technology, there is also a need to plan device service.6
- Higher quality requirements, more testing, and conducting continuous monitoring of the printing of a building, due to the possibility of a faulty or defective feedstock. Careful planning of supply material, in order to obtain continuity in production
- The need for additional/complementary work. For example, the installation of windows and doors by teams of workers
- Building codes and regulations also represent a high barrier to 3DP in construction. Most building codes and procurement standards make no mention of this technology, making it difficult to legally implement 3DP components in large scale projects7

C. Threats

- The possibility of printing firearms and other military equipment
- Job losses in the disrupted industry
- Uncontrolled or unregulated production of body parts, medical equipment, etc.
- Difficulties/lack of supervision in construction and the possibility of illegal construction.

D. Opportunities

- Higher demand for designers, engineers, and IT specialists
- Printing infrastructure already available for space programs (landing pads on the moon and Mars)
- Production already in place for simple lab apparatuses
- Production already in place of complex parts in remote countries with lower input costs for electricity and labor
- Development of universal printing standards
- Birth of a new industry supplying printing materials
- Transportation cost savings
- Application of Building Information Modeling (BIM) integrated technologies8
- Production already in place for high-tech and manufacturing equipment
- Increased automation of processes on site.
- Increased safety on the construction site; fewer workers working physically leading to increased control over work[6]

VII. ANALYTICAL STUDY OF SOME LIGHT WEIGHT STRUCTURES IMPLEMENTED BY 3D PRINTING TECHNOLOGY

Table 1:
Description of work done in a pavilion constructed in Dubai (Example 1).

3d Printed Pavilion X MEAN

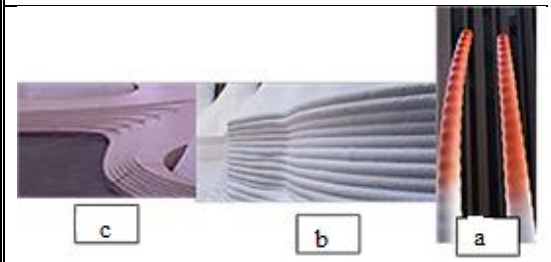
Location	**Dubai**
Dimensions	3.44 * 6.3 * 7.78 m (H*L*W)[9]
Year of implementation	2019
Architects	Middle East Architecture Network and Dubai International Financial Center
Technique used	3D printing, prefabricated buildings, BIM
Use	The Pavilion is considered a landmark for advances in sustainable building technologies
Materials used	Recycled water bottles

Description

The Pavilion is a stunning example of how 3D printing is not only a viable and affordable construction method in the future, but can also help reduce plastic waste.

Fig. 6. the design flexibility and precision of the pavilion MEAN* Middle East Architecture Network (Date 24/2/2020 11:05pm)

It is made up of three different sustainable materials: birch flooring, a 3D printed concrete base, and a succession of 3D printed plastic polymers made from 30,000 recycled water bottles. It was installed without the use of heavy machinery, and each section is modular and primed. It was prepared ahead of time, while most of the materials were in their raw state. The Pavilion creates an S-shaped walkway between branches for guests to wander through. Given Dubai's emphasis on 3DP as a cutting-edge and long-term technology, robotic 3DP in plastic and concrete is the first step in attempting to examine the possibilities of use of this technology.[9]



demonstrates (a) 3D printed plastic polymers (b) 3D printed concrete base (c) birch wood flooring

3D PRINTED PAVILION X MEAN

Description

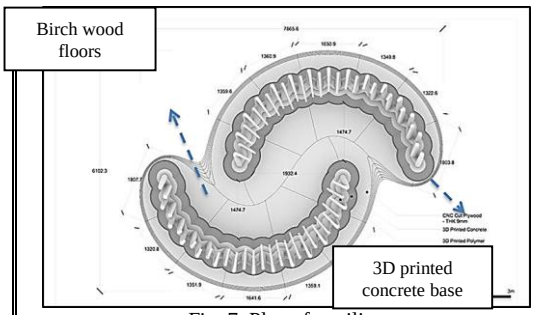


Fig. 7. Plan of pavilion

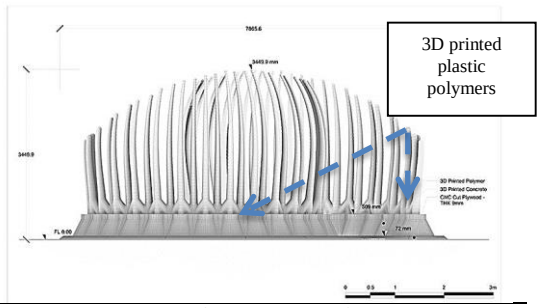


Fig. 8. back elevation of pavilion that it fits the human size, and when the visitor enters the wing, it suggests containment

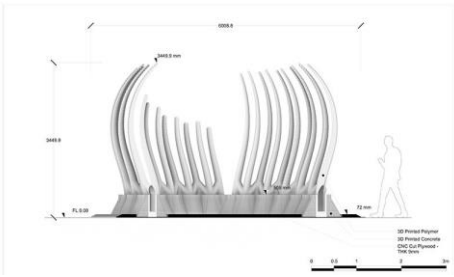


Fig. 9
front elevation of pavilion

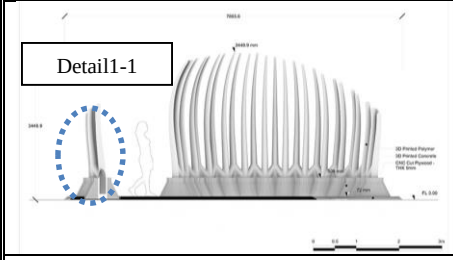


Fig. 10

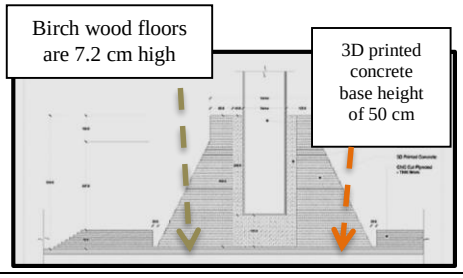


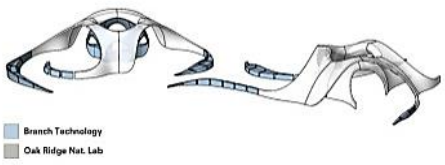
Fig. 11. Detail1-1
https://www.designboom.com/architecture/mean-3d-printed (date 24/2/2020 11:05pm)

(Continued on the next page)

TABLE 1: continued

	Conclusion	3D printing was used as an advanced and sustainable technology, where plastic and concrete were used to discover the possibilities provided by technology in terms of: ○ Reducing plastic waste, thus reducing the cost in materials used" This appeals to both sustainable design and developing countries as a means of providing affordable housing. Furthermore, by saving between 30 and 60% on raw materials, " ○ Provide implementation time as work is done throughout the day. ○ Accuracy in design and implementation. ○ Design flexibility "Because 3D printers can move in three dimensions (x, y, and z), they may be programmed to make irregular and exotic curves that are difficult and costly to achieve using traditional forms or moulds. This enables architects to create complicated components without incurring additional expenses ".

Table 2
Description of work done in a pavilion constructed in Miami, USA (Example 2).

3d Printed Pavilion X MEAN	**Location**	**Miami, the United States of America**
	Dimensions	3.22 * 6.3 m (H*W)[10]
	Year of implementation	2018
	Architects	Shop Architects
	Technique used	3D printing, prefabricated buildings
	Use	Pavilion
	Materials used	Biodegradable bamboo
	Description	The Pavilion represents a landscape that was transported from Miami Beach by the Art and Design Gallery, which aims to be a center of creative vision and technological discovery. Thus, it was executed using the 3DP technique.[10]  Fig. 12. Interior shot in pavilion https://www.archdaily.com/903710/flo-and-jet-shop-architects (date17/12/2020 9:37pm)  Fig. 13. the shape y before implementation https://www.archdaily.com/903710/flo-and-jet-shop-architects (date17/12/2020 9:37pm) Parts of the Pavilion were printed in the factory and transported to the site, as prefabricated entities. The transfer was completed within 24 hours.

	Description	 (a)  (b)  (c) (a) the printing of parts of the exhibition at the site, (b) shows during the transportation of the units from the factory to the site, (c) shows the installation of the units at the site http://new.rushi.net/Home/Works/detail/id/216427.html (date17/12/2020 9:40pm)  Fig. 15 Plan of the pavilion https://www.archdaily.com/903710/flo-and-jet-shop-architects (date17/12/2020 9:40pm)  Fig. 16 the design flexibility and precision of the pavilion http://new.rushi.net/Home/Works/detail/id/216427.html (date17/12/2020 9:40pm)

(Continued on the next page)

TABLE 2: continued

3d Printed Pavilion X MEAN	*Conclusion*	Local and degradable materials, including bamboo, were used in 3DP, thus the following was accomplished: ○ Savings in implementation time, as parts for the exhibition were printed in the factory and transferred as prefabricated units. Although time and cost savings could be obtained in the future, there is a high upfront cost associated with purchasing the printer/equipment ○ Accuracy in design and durability; the type of layer manufacturing used in 3DP opens new possibilities for shaping materials and formwork-free structures ○ No trash on site; concerning material cost, the amount of raw materials required to fabricate objects can be well estimated before the printing process begins. Materials can be accurately deposited in the right place during printing, which results in a decrease in material consumption and an elimination of unnecessary material waste

Table 3
Description of work done in a bus stop constructed in Jinshan, China (Example 3).

bus stop china 3d printed	**Location**	**Jinshan, China**
	Dimensions	2.5 * 1.8 * 5 m (H*W*L)[11]
	Year of implementation	2018
	Architects	Winsun
	Technique used	3DP
	Use	Bus stop
	Materials used	Recycled building waste
	Description	The 3D printed bus stop is able to support more than 6 people at one time, who may be waiting for a bus or just using the stop as a shelter from the rain.[12]  Fig. 18 recycled concrete https://3dprintingindustry.com/news/world-3d-printed-bus-stop-produced-site-planned-community-126689/ (date20/12/2020 10:44pm) The gray-colored raw materials are environmentally friendly and can be recycled from demolished buildings. They were chosen to naturally match the style of the old town of Fengjing in Shanghai.

bus stop China 3d printed	*Description*	 Fig. 19 Front elevation http://www.winsun3d.com/En/Product/pro_inner_5/id/98 (date20/12/2020 10:17pm)
	Conclusion	Building material waste was used and recycled using 3DP. Thus, the final product was able to: ○ Promote technological and commercial innovation by using advanced technologies ○ Speed up execution; where 16 bus stops were printed within 24 hours[2] ○ Achieve environmentally friendly construction, which was accomplished through recycled materials, including cement, sand, and concrete residue ○ Achieve lower execution costs, as waste materials and recycling were used ○ Reduce the number of injuries and fatalities onsite, as the printers did most of the hazardous work

VIII. STOP EVALUATION CRITERIA

A conclusion section is required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

a- The design goals of the bus stop: are a collection of concepts that can be used to guide bus stop design decisions. Each goal is backed by research and illustrations. Safety, thermal comfort, auditory comfort, wind protection, visual comfort, accessibility, and integration are the seven objectives.

1- Safety:

Crime and accidents are reduced as a result of accessible design. It is preferable to install surveillance cameras throughout design.[14]

Fig. 20 Shows the station is not safe.
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

2- Thermal Comfort:

The most significant factor in deciding comfort is the temperature. To maintain a desired temperature range, passive and active controls can be used.[15]

Fig. 21 Shows it does not resistant to sun and rain
Source: http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

3- Acoustic Comfort:

Traffic noise negatively affects both riders and residents living in proximity to the stop. Elements should be arranged to best shield from or absorb noise.[16]

Fig. 22 Shows glass as a sound insulation
https://www.solairaheaters.com/commercial-comfort/transit-bus-shelter-heating/ (date29/12/2020 10:03pm)

4- Wind Protection:

Wind can have both mechanical and thermal effects on bus riders. Wind should be carefully controlled, since its cooling properties are desirable.[17]

Fig. 23 Shows it does not resistant to wind
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

5- Visual Comfort:

For safety reasons and for users to be able to undertake productive tasks at a bus stop, adequate illumination should be supplied. Glare and other forms of excessive light should be avoided.[18]

Fig. 24 shows it contains lights for safety
https://hu.pinterest.com/pin/514114113694086285/ (date29/12/2020 10:03pm)

6- Accessibility:

The bus stop should be conveniently accessible to people of all ages and physical abilities.[19]

Fig. 25 shows accessibility to any user
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

7- Integration:

Bus stops, as nodes within neighborhoods, should cater to the needs of the community.[20]

Fig. 26 shows it reflects the identity of the community
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

b- Bus stop design techniques: are a set of guidelines for designing various parts of a bus stop, in order to meet the objectives outlined in the previous section. Research and precedents are used to support each goal. Lighting, seating, shade, amenities, information, greenery, traffic control, pedestrian infrastructure, and cycling infrastructure represent the nine strategies.

1- Lighting

Even, white light with few shadows creates the optimum environment for activities while also improving safety. The character of the site is enhanced with pedestrian size lighting.[21]

Fig. 27 shows it contains night lighting
Miguel Saraiva & Paulo Pinho "A comprehensive and accessible approach to crime prevention in the planning and design of public spaces"2011-springer.

2- Seating and Surfaces:

Comfortable seating with a variety of microclimatic conditions is essential for riders' comfort and allows them to adapt their personal preferences. Pedestrian priority may be indicated by special paving.[22]

Fig. 28 Shows it Provides seats
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

3- Cover:

The principal weather protection from precipitation and excessive solar exposure is provided by the cover. Awnings or plants nearby might provide cover, where possible.[24]

Fig. 29 Shows it Provides covet to protect users
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

4- Amenities:

Public art, water fountains, and trash cans not only improve the bus rider's experience, but also help the community.[18]

Fig. 30 Shows it Provides Complementary Elements
http://www.milwaukeerenaissance.com/KinnickinnicAvenue/TheTSACAndTheArtStop (date 26/12/2020 9:57pm)

5-Information:

At a bus stop, providing transit information can considerably minimize rider anxiety. If the stop is in a high-traffic location, more space may be dedicated to presenting community information.[25]

Fig. 31 shows it Provides Station time
https://blog.metrolinx.com/2020/02/03/signs-of-our-time-new-transit-wayfinding-identifier-hits-the-streets/
(date26/12/2020 10:08pm)

6- Vegetation:

By providing shade, protection, and wind blockers, vegetation can help to control the microclimate of a stop. It can also be used to improve the location's appearance.[18]

Fig. 32 shows it contains for beautification and shading
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

7- Traffic Management:

The goal of traffic management tactics is to reduce vehicle speed around bus stops, while also making biking and walking in the vicinity safer and more enjoyable.[18]

Fig. 33 Shows determining pedestrian paths and providing ramps for the disabled
http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

8- Pedestrian Infrastructure:

The pedestrian network surrounding a transit stop is a continuation of the line of movement. As a result, high-quality walking environments are critical for attracting new riders.

Fig. 34 Shows Providing walking paths to motivate them to walk http://kjzhang.freehostia.com/BSUD_goals.html (date 25/12/2020 7:49pm)

9- Bicycle Infrastructure:

Many people would ride their bikes to bus stops, if this mode of transportation was made more convenient. Appropriate bike pathways and bike parking must be provided to encourage such behavior.

Fig. 35 shows it provides bicycle parking https://sk.pinterest.com/pin/84935142943594218/ (date 29/12/2020 10:12pm)

IX. Study Area

a. Current Status of the Case Study:

The study area was chosen in the City of Mansoura.

Table 4
Status of the current bus stop in Mansoura (the case study).

Location		Mansoura, Egypt
Reasons for choosing this location		Unsafe, no seats designated for people with needs, randomly designed
	Materials used	Iron Sheet  Fig. 36 shows users wait out station Source: Researchers
Bus station problems	*Assembly/ Disassembly*	Unavailable because design and implementation are random and the materials used are not suitable for disassembly and reinstallation.
	Lighting	No night lighting  Fig. 37 lighting at night no Source: Researchers
	Number of employees	No employees, people living in the area mostly do the work.
	Bicycle parking	Not available  Fig. 38 no parking spaces for bicycles Source: Researchers
	Dimensions	2.5 * 0.8 * 3 m (H*W*L)
	Packing (for prefabricated structures)	There is no packing
	Time of execution	The structure was executed in 2 to 4 days
	Resistance to weather conditions	Not resistant to wind, rain, and sun
	Accommodates all users	Does not accommodate people with special needs

b. Design proposal for the study area:

- Making a design in the shape of a butterfly, as an element from nature provides the necessary cover from natural elements (sun, rain, etc.)
- Providing parking spots for bicycles
- Using natural elements for shading (afforestation)
- Adding a map to the stop that shows the live location of the bus, along with the routes used by public transport.

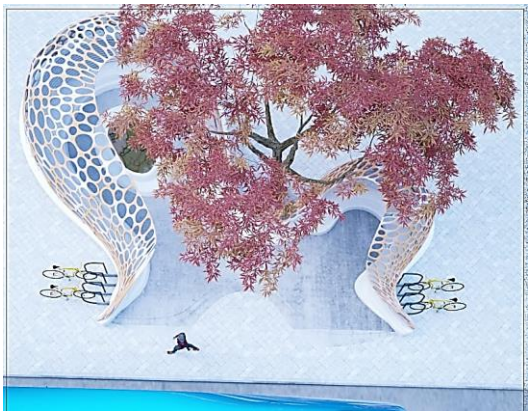


Fig. 39 Plan of bus stop station
Source: Researchers

The researchers' decision to leave the shape of the stacked layers of 3DP allows users to see how the structure was formed.

Fig. 40 design flexibility
Source: Researchers

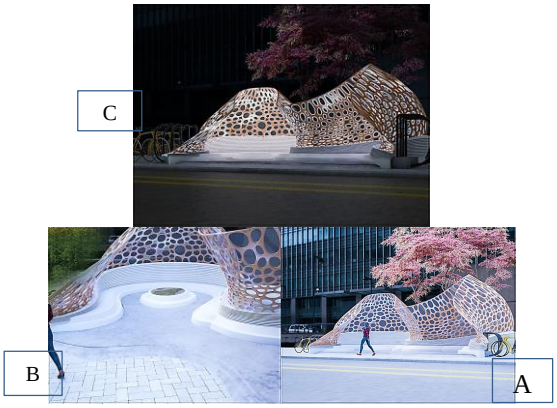


Fig. 42
(A) the station designed and implented with advanced technologies, (B) shows interior shot, (C) shows shot at night
Source: Researchers

TABLE 5
PROPOSAL FOR THE REDESIGN OF THE BUS STOP IN MANSOURA, USING 3DP STRUCTURES.

Location		**Mansoura, Egypt**
Reasons for choosing the case		The stop is the first structure visitors see in the city, leaving an important first impression on them. As such, it should reflect the technology employed by the community
Bus station problems	*Materials used*	Floors are made of recycled materials, seats are 3D printed recycled glass, the roof is made of plywood and glass  Fig. 43 shows recycled materials on station Source: Researchers
	Assembly/ Disassembly	3DP technology was used in the factory and the prefabricated units were transported to the site.
	Lighting	Contains night lighting  Fig. 44 lighting at nigh Source: Researchers
	Number of employees	No employees, people living in the area mostly do the work
	Bicycle parking	Available  Fig. 45 shows bicycles parking Source: Researchers

(Continued on the next page)

TABLE 2: CONTINUED

Location		Mansoura, Egypt
Bus station problems	*Dimensions*	3.5 * 4 * 10 m (H*W*L)
	Packing (for prefabricated structures)	Parts of the structure can be printed in the factory and transported to the site
	Time of execution	1 day for the design and 8 hours for execution
	Resistance to weather elements	Good resistance to wind, rain, and sun
	Accommodates all users	Accommodates people with special needs and children

- *Research and survey stage*

First, researchers were briefed on the current situation of the different public transport waiting areas in Mansoura, and the problems that appeared in their design, implementation, and efficiency. This is mainly due to the lack of a clear methodology of design and implementation. These problems include the lack of comfort for users, especially people with special needs. An information map was also absent, as well as parking spaces.

- *Design Stage*

From the above, the researchers concluded that when 3DP technology is employed, the final structure of the stops will be permanent. On the other hand, when using recycled materials, the lowest cost, less labor, fastest time and highest efficiency will be achieved, in addition to meeting the requirements of all users.

- *Implementation Stage*

Fig. 46 shows the power of solar radiation. In this Figure, the red color represents the areas of least solar radiation, while the blue color represents areas of highest solar radiation. Thus, solar panels can be placed in blue colored areas, and the electricity generated can be employed to light the station at night instead of using electricity provided by non-renewable sources.

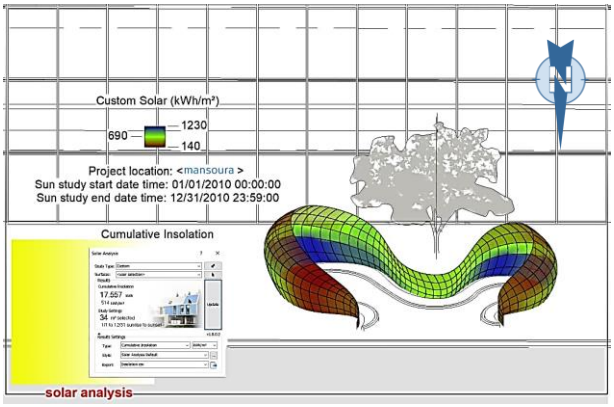


Fig. 46 shows the power of the solar radiation
Source: Researchers

X. Further Studies

3DP technology can be used as a quick and permanent solution, when natural disasters occur. Examples include the 1992 earthquake in Egypt and the 2020 explosion in Lebanon. These events destroyed many different facilities, which could be replaced by 3D printed structures. Another example is the outbreak of the emerging COVID-19 virus, when it was necessary to complete the construction of isolation health units. This technology can also be used in slums, as a solution to the complete but gradual replacement of different structures.

XI. Conclusion

In conclusion, 3DP can help to mitigate some of the key challenges faced by construction projects, such as construction planning and monitoring, effective communication, and safety and procurement. As implementation of 3DP has witnessed a surge, it is expected that labor involved in the production of construction material and its installation will be reduced. As such, there might be fewer opportunities available for employment in any given project unless traditional construction workers find a way to evolve with this new technology and remain relevant.

TABLE 7
EVALUATION CRITERIA TO MEASURE THE CURRENT AND PROPOSED SCENARIO OF THE BUS STOP IN MANSOURA.

Evaluation Criteria		*current situation*			*proposed situation*		
		Achieved	*Not achieved*	*Achieved to some extent*	*Achieved*	*Not achieved*	*Achieved to some extent*
Goals	*Safety*		√		√		
	Thermal comfort		√		√		
	Acoustic comfort		√		√		
	Wind protection		√		√		
	Visual comfort		√		√		
	Accessibility		√		√		
	Integration		√		√		

(Continued on the next page)

TABLE 7: continued

Evaluation Criteria		*current situation*			*proposed situation*		
		Achieved	*Not achieved*	*Achieved*	*Not achieved*	*Achieved*	*Not achieved*
Techniques	*Lighting*		√		√		
	Seating & surfaces			√	√		
	Cover			√	√		
	Amenities		√		√		
	Information		√		√		
	Vegetation		√		√		
	Traffic management		√		√		
	Pedestrian infrastructure		√		√		
	Bicycle infrastructure		√		√		

From Table 7, we were able to confirm that the proposal implemented through the use of the 3DP technology achieved all the criteria listed above. Additionally, this technology was able to reduce time and labor, eliminate building waste, and reduce the cost of materials used because it depends on recycled materials.

XII. RECOMMENDATIONS

Researchers recommend the use of advanced technologies in practical applications in general, and 3DP technology in particular. Thus, the following recommendations are presented to different parties:

A- Educational Entities:

- Developing academic systems for architectural education
- Encouraging students to learn about modern software and methods of development of the different design stages through the use of these software
- Taking advantage of the development brought about by building technology in design, such as BIM and virtual reality and also in implementation, such as the use of robots and 3DP

B- Governmental Entities:

- Paying attention to bus stops, as they represent the places that make the first impression on city visitors. As such, it is important to use the same design for all stops within a certain city, to give each city its own identity
- Creating Egyptian pavilions in various exhibitions to show the advanced technologies applied in Egyptian cities, in order to let people from other countries know the extent of the technology used in Egypt.
- Creating pavilions that simulate the advanced technologies in Egyptian cities in order to let people know to what extent technology has reached us.

(a)

(b)

Fig.47 (a) Bus stop station in front of the Delta Institute of Talkha
(b) Bus stop station in front of the Mansoura university
Source:researches

AUTHORS CONTRIBUTION

1) Design for work *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*
2) Data collection and tools *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*
3) Data analysis and interpretation *(**Asmaa Ahmed Abd El-Hay El-Taweel** 60%/ **Ahmed Al-Tantawy Al-Maadawy** 40%)*
4) Financing *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*
5) Methodology *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*
6) Software *(**Asmaa Ahmed Abd El-Hay El-Taweel** 60%/ **Ahmed Al-Tantawy Al-Maadawy** 40%)*
7) Supervision *(**Asmaa Ahmed Abd El-Hay El-Taweel** 60%/ **Ahmed Al-Tantawy Al-Maadawy** 40%)*
8) Drafting Article *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*
9) Critical review of the article. *(**Asmaa Ahmed Abd El-Hay El-Taweel** 50%/ **Ahmed Al-Tantawy Al-Maadawy** 50%)*

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TITLE ARABIC:

تأثير الطباعة ثلاثية الأبعاد بالمنشآت الخفيفة.
دراسة حالة: محطة إنتظار النقل العام بالمنصورة

ARABIC ABSTRACT:

نهج البناء التقليدي في مصـر له عدة عيوب. يتضـح هذا من خلال وقت الانتهاء الطويل للمشاريع، والعدد الكبير من العمال، ومعدل الخطأ المرتفع إلى المتوسط، تؤدي هذه المشكلات إلى تأثيرات بيئية سلبية وارتفاع تكلفة البناء، يمكن معالجة هذه العيوب بكفاءة من خلال اسـتخدام التكنولوجيا المتطورة للطباعة ثلاثية الأبعاد: تهدف هذه الدراسـة إلى عرض بعض الأمثلة الناجحة الحالية لـــتقنية الطباعة ثلاثية الأبعاد في الهياكل خفيفة الوزن. تم إجراء تحليل مقارن بين البناء باستخدام التقنية وطريقة البناء التقليدية. تم إجراء تحليل SWOT أيضًا لتحديد نقاط القوة والضعف، وكذلك لاكتشاف مجالات الفرص وتلك الخاصـة بالتهديدات. يمكن تسـليط الضـوء على العديد من مزايا هذه التقنية، بما في ذلك التخفيضـات في التكلفة والوقت، وتوفير ظروف عمل آمنة في الموقع المحدد (أقل الإصـابات والوفيات)، وتقليل التلوث. ومع ذلك، لا تزال هناك قيود معينة تعيق استخدام التقنية يتضمن ذلك إنتاج الأسلحة النارية والأجهزة الطبية التي لا تتوافق مع المعايير المحددة. تم إجراء دراسة تحليلية لبعض الهياكل خفيفة الوزن، بما في ذلك معرض مؤقت ومحطة للحافلات. أخيرًا، تم إجراء دراســة للوضــع الحالي لمنطقة الدراسـة وتم إعداد مقترح لتجديدها باسـتخدام التقنية تم وضـع قائمة بالمعايير التي يجب على جميع محطات ومحطات النقل العام الالتزام بها، بالإضــافة إلى التقنيات اللازمة لتحقيقها. وجد أن التصــميم والتنفيذ المقترحين لموقف الحافلات في دراســة الحالة يتوافقان معها ويحقق النتائج المرجوة.