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3D PRINTING TECHNOLOGY IN CONSTRUCTION INDUSTRY ON-SITE: ANALYSIS OF THE IMPLICATIONS

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ABSTRACT

Technology has accompanied human race since ancient times through tools that were invented to facilitate his life, which has changed his traditional lifestyles. Use of technology has become a fundamental requirement for all societies. In a world, its title is speed and its identity is progress, today humanity begins a new phase of change as it stands on the threshold of the Fourth Industrial Revolution, which was built on the basis of digital revolution but offers many new technologies related to the automation of the industry.

One of the important technologies that plays a major role in this revolution is 3D Printing (3DP), which is one of the most flexible manufacturing methods, and has seen significant development in recent years in many fields. Architecture also had a significant share, not only in design where 3DP was associated with architectural models, but also in the construction industry, where recent studies have been conducted to develop 3DP for manufacturing of buildings, where the site is considered a temporary factory in which the building is manufactured. I.e., its use has transformed into the construction industry, which is one of the vital pillars of development in any country for its benefits to society and the economy. However, little is known about the current role of this technology in the construction industry. Besides, this industry, with growing demand for buildings' construction at the local level, faces many challenges that negatively affect the economy, society and the environment, thus reducing its effective and pivotal role in the development process.

Within this context, this study seeks to analyze the impact of using 3DP technology on the various corners of the construction industry on-site, namely: the stage of preparing the architectural working drawings, building implementation phase, and the architectural output. Besides extracting what has changed from the general culture of the construction industry through this technology. By reviewing the stages of preparing architectural working drawings for the 3DP process, in addition to studying some international experiences of buildings constructed using 3DP. Then, the study proposes a methodological framework to apply 3D construction printing technology on the local scene. As such, the study concludes by presenting the most important research findings and proposed recommendations.

Keywords: 4^{th} industrial revolution, 3D printing technology, additive manufacturing, construction industry, 3D printed buildings.

1. Introduction

The term "printing" has been associated in minds with two-dimensional products, as printing on paper, but to be related to one of the forming ways, where the idea of three-dimensional printing was born in the 1980s, it was not familiar to workers in the industrial design field. 3D Printing (3DP) is the technology that emerged from the womb of technological progress, through which a model is built. It has become one of the fastest growing technologies at present, and has penetrated many industrial fields in daily life, beginning from consumer goods, health fields and even satellite manufacturing, until it has reached the field of construction and printing of buildings.

1.1. The Problem

The research's problem is represented in several axes:

First: Little is known about the role and impact of 3D construction printing and hence on the architectural product and its design. The lack of understanding of these potentials, limits the ability of architects to creativity in design and generation of global architectural product that keeps pace with global architecture.

Second: local architecture lacks the pursuit of the world in using technologies, especially 3D printing in the construction industry.

Third: At the level of local practice: with the increasing demand for construction of buildings, the construction processes in all its stages are facing many challenges that result in many problems and associated effects, which negatively affect the economy, society and the environment, and reduce the pivotal and effectiveness role of the construction sector in the development process. The most prominent of these challenges and negative effects:

A. The stage of preparing architectural working drawings: laborious process requiring a long period of work and a lot of effort to prepare plans, specifications and quantities needed for implementation. Resulting in an increase in the cost and time of the project.
B. Implementation phase: the bedrock of the building's life system, this stage is facing:
   a. Weak existing labor efficiency, which leads to poor implementation, low quality and architectural distortions [1].
   b. The hazardous work environment to which labor is exposed, poses a risk to their safety [2].
   c. Draining a lot of energy and natural resources, starting with manufacturing raw materials phase, then the transport phase of the site and internal transport operations, and finally the implementation phase. This contributes to the limited availability of energy and resources, in addition to the harmful impact on the environment by emitting various pollutants, including carbon dioxide, which negatively affecting human health and life [3].
   d. Rising and increasing energy prices that led to high prices of key building materials (including steel, cement, and other materials). This has caused a high cost of projects [1].
   e. High rate loss and growling in construction materials due to its injudicious use.
   f. Increasing percentage of waste generated by the construction process, which is estimated at about 60% of the total waste in Egypt, causes many environmental problems visually and healthily [4].
   g. The emergence of many unexpected factors, including design errors due to poor communication between the parties of the project, and weather factors such as rain, and others affecting the course of the project, and the length of the implementation period, which causes delay in the final delivery and increases the cost [5].

1.2. Hypothesis

The study is based on several hypotheses:

A. 3D printing technology application reshapes the construction industry.
B. Integration of 3D printing in the construction industry plays a key role in reaching a sustainable and more efficient construction compared to the traditional method.
C. The architect's knowledge with the approach and possibilities of design for 3D printing works to develop his creative abilities and prospects in the design commensurate with the capabilities of the 4th Industrial Revolution.

1.3. Objectives

This study presents a set of research questions associated with the problem, most notably:

- The main question: Will the 3D printing technology change the construction practice or conduct some improvements on it?
- In case of change, to what extent can 3D printing change the practice of building construction?
- Can 3D printing contribute to the sustainability of the construction industry and be environmentally friendly? And how?
- To what extent can 3D printing replace the conventional construction techniques at present?

In the framework of these questions, this study aims to:

First: exploring and discussing the impact of 3D printing technology on the various elements of the building construction process on the site, where it goes through with several stages since it begins with the idea until it ends up to the actual building, namely: **the stage of preparing the architectural construction documents** – **building implementation phase** –**architectural output**. Then extract and analyze what changed from the general culture of the construction industry on the site by this technology.

Second: proposing a methodological framework for the application of 3D construction printing technology on the local scene.

Achieve these goals, to bring about a trendy leap in the construction industry, new launching characterized by speed and efficiency, contribute in providing appropriate solutions to reach a sustainable building, and performance development of the architect and enabling him to creative in design, in line with the massive industrial development in the architecture.

1.4. Methodology

Proceeding from the research objectives, the study addresses three main stages as a methodological basis:

A. Theoretical framework – literature review: focuses on identifying what it the basic concepts of the study.
B. Deductive analytical framework: this framework is divided into two main sections:
   - First: study and analyze the basis and stages of the architectural working drawing preparation for the process of 3D printing.
   - Second: study and analyze a set of global projects for buildings that have been constructed using 3D printing technology.
C. Applied framework: conduct a SWOT analysis, and identify internal features (strengths and weaknesses) and external conditions (opportunities and threats) for the

3D construction printing to contribute to the development of a proposal for the application of technology in the local reality.

D. Research findings: in the light of the previous stages, the most important research findings are extracted, besides showing the proposed recommendations.

2. 3D printing

3D printing technology is one of emerging technological breakthroughs at present for the Fourth Industrial Revolution, has attracted much research attention in recent years. Before addressing to its definition, a brief overview of the role of that technology is given in this Revolution.

2.1. 3D printing's role in Fourth industrial revolution

Today, the world stands on the threshold of a new revolution, where Klaus Schwab and the World Economic Forum in Davos, Switzerland declared the arrival of the Fourth Industrial Revolution, on January 2016. Davos participants described this revolution as a tsunami technological advance that would change in many details of human life. The concept of the Fourth Industrial Revolution is related to redraft the rules of the industrial sector and the automation of the industry [6, 7].

The 4th Industrial Revolution was built on the basis of the digital revolution, but it represents new ways, which are characterized by a fusion of technologies that blurs the lines between the physical, digital, and biological spheres [6]. One of the important novelties that play a major role in changing the path are developments in artificial intelligence, robotics, biotechnology, The Internet of things, 3D printing and other developments [8]. Despite the multiplicity of emerging technologies, but according to Dion Weisler, CEO of HP Inc. that the 4th Industrial Revolution, driven by 3D printing and digitalization. He confirms digitalization is already happening, with 3D printing, linking the physical world with the digital world and blending them in a unique way [9]. Through the 3D printing, "the digital" is turning into "the physical" with just a touch of a button.

Based on the previous review, the beginning of the fourth industrial revolution, which brings various technologies, was noted. 3D printing is one of the most important technologies that control the path of this revolution. So, in the next part, the concept of 3D printing will be recognized.

2.2. Conception of 3D printing

The term of "3D Printing" (3DP) is just one of the many new manufacturing techniques. In 2009, the American Society for Testing and Materials (ASTM) defined "3DP" as "the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology". While the simple definition of the term can be defined as: a process of producing a solid 3D physical object of virtually any shape from a computer-driven digital model. According to the Encyclopedia Britannica, this process is called with "printing" is due to the process is analogous to the fusing of ink or toner onto paper in a printer [10, 11, 12].

More precise definition defines 3D printing as additive manufacturing* technique (AM) where a 3D printed object is achieved using an additive process in which material is added

* The term "additive manufacturing" is defined by the American Society for Testing and Materials (ASTM) as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed

in a layer-by-layer fashion to build a 3D object. AM use a Cartesian plot (X, Y, and Z axes) where the print-head moves along the X and Y axis and the object being printed moves up on the Z axis, gradually creating a layered 3D shape. [10].

AM / 3DP is an umbrella term for a variety of printing technologies (processes used) covering a different range of materials used. Despite this diversification in both printing technologies and materials, all are based on the same principle to form a real object: a digital model is transformed into a solid 3D physical object by adding material layer by layer which result in manufacture very small to very large objects from all types of materials [13, 14].

According to the previous review, it is noted that:

1- 3D printing is one of the technologies that drives the Fourth Industrial Revolution associated with redraft the rules of the industrial sector and the automation of the industry, characterized by linking and integrating the physical and digital worlds together. It is an additive manufacturing process, by which turns digital models into physical objects, by depositing / forming materials using a layer-upon-layer printing approach based on a digital design file.
2- 3D printing processes require a diverse range of elements including: as in Fig.1.
   a. Digital designs that create by using software.
   b. Hardware (printer technologies) in which designs are sent to print, and
   c. Materials are placed in successive layers to build the desired object.

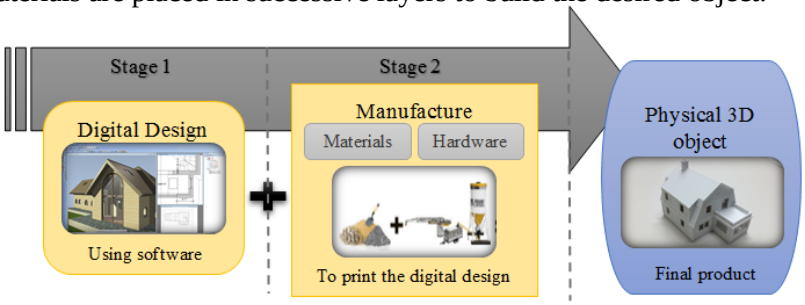

Fig.1. the requirements of 3D printing process. Source: the researcher.

3. 3D construction printing workflow

The building construction goes through many stages, from the beginning of the idea to its completion in the actual construction form on the ground, to perform its task. Therefore, in this section of the study, the impact of 3DP on the various aspects of the construction industry, which is the preparation phase of the architectural construction documents, phase of construction implementation, and the architectural output is explored and discussed.

3.1. 3D printing and preparation of architectural construction documents

Architectural construction documents are documents that transform the architect's imagination and his initial designs of any project into a set of executable drawings, specifications and quantities. Architectural working drawings represent one of the types of working drawings,

to subtractive manufacturing methodologies"[add con]. Additive manufacturing is used to encompass a range of technologies, including 3D printing, rapid prototyping and direct digital manufacturing, which are used to create three-dimensional objects through the process of layering material. Government Europa; (2018) "How 3D printing is revolutionising sustainable construction" available at" https://www.governmenteuropa.eu/3d-printing-sustainable-construction/88223/; (Accessed 26-7-2018)

the essential foundation upon which project implementation where it contain several plans, elevations and different sections, which includes many data and information.

However, through the above-mentioned study about 3DP conception, which requires the use of digital model to create 3D physical entity, some questions arise about pre-construction procedures: Does the 3DP change the stages and basis of preparing the architectural working drawings in the traditional way? If there is a change, will it be partial or total? How closely does the digital model relate to the stages of preparing the working drawings? By studying several various techniques for 3DP, a summary of the most common application of that process will be presented: as in Fig.2.

A. Step one – Create a design in a 3D digital model:

The essential purpose of a 3DP/ AM process is to transform an idea into a physical object. Therefore, in the case of building construction, the starting point is the embodiment of the design idea of building to be printed in a 3D digital model by using a variety of dedicated software programs for 3D modelling like 3D CAD, SketchUp, Revit, Maya, or others, or building information modelling (BIM) [15, 16].

B. Step two – Convert the building model into a printable model:

Because 3DP is a physical process contrary to screen rendering. Therefore, after the completion of 3D digital model file for building, it must be converted into a printable file format. That is, the design is ready to exist in the real world. So, this file is the single most important element in the 3DP workflow. In this step, the model tolerates specific features that will be crucial for 3D printing.

One of the most popular formats, which allows data transfer the 3D model from a computer screen to a 3D printer, called STL, it is the printable file extension, an abbreviation of the word "stereolithography" or an acronym for "Standard Tessellation Language" or "Standard Triangulation Language" [17, 18, 16].

Transferring model data via STL format requires constructing a mesh or series of triangles (polygons) that enclose all boundary surfaces of a 3D model to recreate its surface geometry. "Mesh" is the data that used to describe only the surface geometry of a 3D building model without generating non-relevant information for printing like texture or color. A typical model's mesh comprises hundreds of thousands of triangles; must be "water tight" so that the model is a solid, not just surfaces. This representation is a de facto industry standard [16, 18, 15, 17]

C. Step three – Slicing:

This is the process of converting the 3D printable File into a file readable by the 3D printer. In other words, into instructions telling the printer exactly what to do, how to print the building step by step, and control commands to position 3D printing head. This step needs a special software to do that, either installed locally or available in the cloud.

Slicing is a dividing or chopping the 3D model into hundreds or thousands of parallel horizontal cross-sections, or layers to obtain the 2D contour lines of each material layer. This step can be done with a constant layer thickness (uniform slicing) or with variable layer thickness (adaptive slicing).

After the files are sliced, a new file format is generated called G-code (the file extension .gcode.), it is a machine-level instructions file to control automated machine

tools like the axes, direction of travel, temperature of the hot end, and more, which mainly uses computer-aided manufacturing (CAM) software. Therefore, G-code is the most widely language of the machine that it is used to communicate with it. [19, 20, 15, 17].

With the completion of the third phase, the stage of preparing the architectural working drawings for the building is completed, which is followed by sending the print file to the 3D printer/AM machine. The printer uses its own software (firmware) to read the machine-level file and follow the automated G-code instructions to print the object one layer at a time [20].

As for the preparation of inventory tables of building quantities attached to the working drawings such as tables of openings and tables of finishes. These quantities are automatically defined with high accuracy using Building Information Modelling system (BIM) software used in creating the 3D design model.

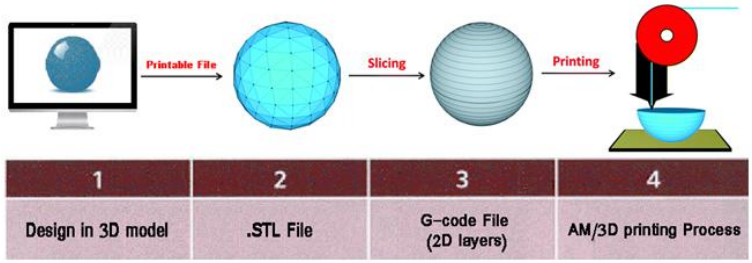

Fig. 2. the stages of preparing the working drawings in AM/ 3DP process. Source: [21].

After reviewing the workflow stages of preparing the architectural working drawings of the building for 3DP process, in the framework studying the impact of 3DP on the construction process. A comparison is made between the above studied and the preparation of working drawings in the traditional way to answer the research questions mentioned above. It notes through the comparison that there are some similarities as well as many differences between them. The comparison is illustrated in the following table.1:

Table 1.

A comparative analytical study between the preparation of architectural working drawings for both the 3DP technology and the traditional method. Source: researcher.

Aspect of comparison		The preparation of the working drawings for 3D printing	The preparation of the working drawings in the traditional way
Similarities		Both follow the design stage, which is a fundamental phase of the project's work, ends with the creation of the design in the form of a 3D digital model using 3D modelling software or building information modelling software (BIM).	
The differences	Basic requirements	A file that is read by the 3D printer.	Paper sheets that are read by the implementation team (contractor and supervisory authority).
	The scale required	Drawing inside the file in the real scale of building 1/1.	Scale of sheets, at least 1/100 or 1/50 for main projections.
	The necessary tools	A computer that includes many software to convert the 3D model into files necessary for 3DP, mainly computer-aided manufacturing software.	Computer + printer +sheets A computer includes 2D drawing software (CAD) or software that extracts 2D drawings (Revit) and then are printed on the sheets by the printer.
	Starting point of working drawings	Convert a 3D model file into a file changes the model to solid not surfaces	Transform the design into horizontal and vertical 2D projections.
	Stages and how to prepare	- Convert the building model into a printable model - Convert the 3D printable file into a file readable by the 3D printer (Slicing + instruction to control the printer tools + information about the step-wise assembly process)	-Draw different plans. - Draw architectural sections. - Draw external elevations. Include all information and data such as dimensions, levels, symbols, terminology and specifications of implementation materials and method

Based on the above table, the research questions related to this part of the study will be discussed:

1- As for the first question: Does the 3DP change the stages and basis of preparing the architectural working drawings in the traditional way? If there is a change, will it be partial or total?

Through both stages mentioned earlier and the aspects of comparison shown in the table, it is noted that in 3DP process, not only changed the stages and basis of architectural working drawings preparation. But were completely dispensed with traditional architectural working drawings. This is due to the entry of a new element in the construction process, which is the 3D printer, which sends to it directly the file that was created to construct.

2- As for the second question: how closely does the digital model relate to the stages of preparing the working drawings?

Through the previous review, it is clear that the digital model in the traditional way ends its role with the end of the design stage and has nothing to do with the preparation of working drawings. While in 3DP, the phase of preparing the execution drawings begins using the digital model then processed digitally.

3.2. 3D printing and construction of the building

Construction of buildings is one of the major industries that humans need to provide shelter and vital installations. The construction science includes familiarity with all building materials, their nature and characteristics, as well as familiarity with the different technologies of the construction process. In the framework of this knowledge, according to the purpose of the building, the architect's responsibility lies in identifying the materials used in construction very carefully where they greatly influence the selecting the most appropriate construction techniques.

Through the above discussion about the 3DP, which requires the use of printing hardware and techniques along with building materials for the construction, and in the context of examining of 3DP effect on the construction practice of the building, many questions emerged:

Are hardware and materials used in 3DP differ from those in the traditional way? If there is a difference, are these devices considered additional and assistance tools in the construction process? Or change the construction practice? In the case of change, what are the changes in the construction process? What distinguishes 3DP building materials? What is the return of the use of 3DP hardware and materials on both the process of the building construction and architectural output?

In the light of these questions, a set of the pioneering global projects that have been recently constructed using this technology are being studied and analyzed. By taking an overview of the building, then study the construction technology, and the impact of using 3DP technology.

3.2.1 Examples of 3D printed buildings

Even though 3DP only existed for a few years, there are a number of completed projects; it has been used to build houses, cabins, offices, bridges, pavilions, and many more. The techniques of implementation of these projects differed, some of which were built at the construction site directly, and others were printed as prefabricated elements and then assembled on site. The scope of this study focuses on the 3D constructed buildings in the construction site as it is the system used for the construction of most buildings in the

traditional way in the local environment, and thus it is easy to identify the changes in the construction process and the return of its use on that process.

3.2.1.1. Villa in China [22, 23, 24]

Overview of the building: In the first half of 2016, HuaShang Tengda, a Chinese construction company had designed and built a two-story villa, located in Tongzhou, a district of Beijing, China. It covers an area of 400 $m^{2,}$ and the height of each floor is 3 m.

Construction Technology: The Huashang Tengda used a giant 3D printer to print the villa, which has a forked extrusion nozzle. The company was erected first the villa frame including conventional steel reinforcements and plumbing pipes. Then, ordinary Class C30 concrete containing coarse aggregates was extruded over the frame and around the rebars by using the nozzle that simultaneously lays concrete on both sides of the rebars, swallowing it up and encasing it securely within the walls. This process quite different from other 3D printed construction techniques. The printed material, C30 concrete is an extremely tough, durable yet inexpensive; 20 tons of it were used to print the foundation and 25cm-thick walls. This technology, according to the company, is controlled by custom-designed software that consists of four "systems": an electronic ingredient formulating system, a concrete mixing system, a transmission system and a 3D printing system, as in Fig.3.

The impact of using 3DP technology: According to HuaShang Tenda, this villa highlights the advantages concrete 3D printing brings to construction. Not only is it very simple in use, but it is also quicker, more efficient and less costly than traditional construction techniques:

- The 3D printer greatly reduces production times. A conventionally made 400-m2 home would take about three months to build, whereas this villa was made in just 45 days.
- Especially material costs are kept as low as possible by using conventional materials and cutting waste almost completely. This not only reduces the project's total costs, but also eliminates the need for costly mold production.
- The 3D printer itself has already cut down on labor costs and increased efficiency. Whereby the labor force that brought only the steel insets to the site and assembled is needed for short periods, while technology specialists oversaw the process via computers.

The company also announced that the villa is very strong and durable. During seismic testing, experts estimated that it could withstand earthquakes up to level eight on the Richter scale – which destroys most other buildings.

Finally, a 3D printer also offers several obvious architectural advantages. Users can easily design structures featuring very complex facades and decorations, features that would otherwise be difficult and costly to manufacture with traditional building techniques.

The construction site of the two-story villa: the giant-type 3D concrete printer, the components that were installed before printing, the nozzle prints the walls over and around the rebar. Source: [25]

Fig. 3. The 3D Printed villa onsite. Source: [23]

3.2.1.2. The BOD building [26, 27]

In the spring of 2017, Danish 3D printing company 3D Printhuset, following its participation in the Danish government funded research project "3D Construction Printing", has embarked on 3DP a Building on Demand (BOD) in Copenhagen, Denmark. It is the first 3D printed building that fulfils the strict European norms and standards, and with attention to the environmental footprint

Overview of the building: The BOD building is a small office hotel of less than 50 m^2 located in Copenhagen Harbour. It contains a few workspaces that will be rented as an office hotel for companies and organizations that will work in and around the port in Nordhavn. Architect Ana Goidea designed the BOD with curved walls in addition to a ripple effect to make it more organic, while the only straight elements being the windows and doors. Construction began on site on September 11, 2017 and completed in the fall of the same year.

Construction Technology: The used 3D printer for the BOD is of the "gantry" type with servo motors adjusting the height, its dimensions are 8 x 8 x 6 meters, a print speed is 2,5 meters/minute and each layer is 20mm height with a width between 50-70 mm. It developed according to European norms. A tent has been erected above the construction site to work in safe environmental conditions. The printer was dedicated to print the upper part of the foundation that reached to 60 cm and the walls to 4.5 m. The used printed material is concrete containing a large amount of recycled tiles and sand, this concrete is very environmentally friendly, in addition, all walls of the BOD was insulated with recycled cellulose fiber from re-used building packaging, as in Fig.4.

The impact of using 3DP technology: Jakob Jørgensen, Technical Manager at 3D Printhuset A/S illustrated "Even if the BOD is less than a 50 sqm building, it is still large enough to illustrate some of the economic and architectural advantages of applying 3DP technology to constructions". Goidea explained this by saying: "The architecture of the building shows that the application of 3DP technologies frees the formal expression of the design". Jakob continued that 3DP of the building meant that "complex forms can be entered at no additional cost", as it "with traditional building techniques any shape that is organic or non-straight is a challenge, technically as well as with respect to costs".

The project also showed some environmental benefits. 3DP makes a more efficient use of materials and reduces the amount of waste generated compared to the traditional way. According to Michael Holm, Development Manager at 3D Printhuset, the BOD generates far less waste than the traditional way where only utilizing the designated material without producing waste.

In addition, automating the building processes further decrease any errors during construction and help lower on-site accidents.

The construction site of the BOD building:

Gantry-type 3D concrete printer, 3D printing curved wall & tent that covers the site.

Fig. 4. the organic design of BOD building –3D Printed BOD construction. Source: [28, 27]

3.2.1.3. YHNOVATM House [29, 30, 31]

In 2017, for several months, a team of researchers in France from University of Nantes, Nantes Métropole, Nantes Métropole Habitat , Ouest Valorisation, and their partners began work on a project using an industrial 3D printer and patented AM technology to build a YHNOVA house.

Overview of the building: It is a one level 95m^2 dwelling, located in a social housing neighborhood in the Bottière district, Nantes, France, designed by the French architectural firm TICA. This house includes 5 rooms, it's characterized by complex architectural shape, with curved walls, windows, doors and rounded angles. Construction of the Yhnova^{TM} began on site in September 2017 and was built in a few days.

Construction Technology: The automated, robotic 3D printing technique used to construct YHNOVA is called BatiPrint3D, was developed by two laboratories from the University of Nantes. A laser sensor, based on a digital model, guided the movements of the robot. A tent was protected the whole construction site so that the robots can work in safe environmental conditions. This technique has been dedicated to build the walls only that is composed of three layers: two layers of polyurethane foam that expanse and stiffen rapidly serving as formwork for a third layer of self-compacting concrete. At the end of the whole cast, the polyurethane is kept in place as the external and internal insulation of the building. At the end of the operation, the mobile robot comes out through an access point where the woodwork is scheduled to be implemented, as in Fig.5.

The impact of using 3DP technology: The project has helped demonstrate several important economic and environmental lessons. Since BatiPrint3D$_{TM}$ combines several

operations that were previously being implemented individually (3 layers) into a single construction process, and materials that adapt their new formulations to the new method of operating. One of the main advantages of this process lies in the speed of implementation and completion of a project that reduces construction time, and the operational costs of construction; in addition, improves thermal insulation. It is significant impacts of this process are reduction in the cost of CO2 in relation to logistics, reduction in grey energy (total energy consumption, for the production of a material throughout its life cycle, from its extraction, to its transformation, to its recycling) in comparison with traditional techniques, and a reduction in site waste, i.e., the project's ecological footprint was lowered. The project has also highlighted robotic 3DP technology needs far less human resources than conventional construction methods and it is crucial in reducing the arduous nature of the work and limiting high-risk positions or causes of MSD (Musculoskeletal Disorders). Among other features presented by the project, a much lower dependence on good weather conditions for a solid day of construction work.

The construction site of Yhnova$^{TM:}$

Batiprint3D^{TM} deposits PU, three-layer wall & tent which covers the site. Source: [32, 33].

Fig. 5. Robotic 3D Printed YHNOVA House: plan of Yhnova^{TM}, different views. Source: [34, 35]

3.2.1.4. 3D Housing 05 [36, 37, 38]

In early 2018, CLS Architetti, in collaboration with the Italcementi Heidelberg Cement Group, Arup and Cybe for Milano Design Week 2018, presented a research project for a house on the possibilities offered by 3d printing in the field of sustainable architecture. The project has received the Best Sustainability Prize, Milano Design Award 2018 at the Salone del Mobile design festival.

Overview of the building: 3D HOUSING 05, one storey house, located in the grand Piazza Cesare Beccaria, Milan, Italy, covers 100 square meters; designed by the client CLS Architetti while Arup provided structural engineering and materials consulting services to project. The design and engineering process of the house started in February'18. It has double curved walls, is composed of a living area, a bedroom area, a kitchen, a bathroom and a terrace roof. The stratification of the walls into modules, generates a pattern, a surface on which climbing plants can grow spontaneously, reaching the roof that becomes an urban garden.

Construction Technology: A robot from Cybe Construction, mounted on a movable base for increased flexibility, was used to print the walls on-site. These walls were divided into 35 modules, each been printed in 60-90 minutes; the full house has been printed in just 48 hours effective time. These walls were molded with a special mixture of cementitious

powders, aggregate and binders that fully re-usable components, where in the future, it can be demolished, pulverized and reconstructed with the same material. The house was delivered in March ’18, as in Fig.6.

The impact of using 3DP technology: According to the CyBe & Arup websites, there are many advantages offered by 3DHOUSING05:

1- Creativity: freedom of design, where traditional constraints disappear, and allowing architects to generate more complex structures, where Arup said: “3DP technology has been key to create the double curved shape of the house”. As Guglielmo Carra, Europe Materials Consulting Lead at Arup, explained this by saying: “With this project we’ve shown that 3DP technology is now advanced enough to take on more complex structures”. Luca Stabile, Italy Building Practice Leader at Arup, confirmed that “Digital tools combined with new manufacturing technologies will enable the production of custom made shapes that cannot be produced otherwise”.
2- Sustainability: 3DP is a sustainable alternative to the traditional construction process, reducing material waste, according to Arup: "we've shown the ability to minimize the use of concrete and therefore reduce construction waste"; and allowing reconstructed the house with the same material or reused the materials at the end of the building’s life, rather than ending up in landfill. Guglielmo explained this “….. 3DP technology is critical to making buildings more sustainable and efficient. It creates less waste during construction and materials can be repurposed and reused at the end of their life.”
3- Accuracy: 3DP offers a direct transfer of information from the 3D design model into construction operations; therefore, it drastically reduces building inconsistencies and potential mistakes. Guglielmo confirmed that: “This technology is critical to helping our industry become far more accurate, ….”.
4- Affordability: 3DP is less expensive than traditional construction; where Arup explained that complex structures – such as double curved walls –produced at a lower cost. This due to the more efficient use of materials and to a more structured and faster building process where producing 100 square meters in one week.
5- Flexibility: the house can be easily expanded, raised, doubled even moved to a new location. It has been designed in such a way that is can be taken apart and reassembled in a permanent location after the festival, with zero impact thanks to the technology used.

Circular design of 3D printed house & general view of 3D Housing 05.

The construction site of 3D Housing 05: A portable robot prints the double curved wall & the site is covered with a tent.

Fig .6. 3D Housing 05 - 3D Printed house, Milan, Italy. Source: [38, 39, 40]

3.2.1.5. US Army Barracks [41, 42]

In August 2018, as part of a three-year program called Automated Construction of Expeditionary Structures (ACES), the US Army 3D printed a prototype barracks hut at an army base in Champaign, Illinois, the program is researching 3DP as a way to build semi-permanent structures out of concrete, made from locally available materials. It was built in collaboration between the ACES team, its project partner – Chicago-based architectural and engineering firm: Skidmore, Owings, and Merrill (SOM) – and Marines from the 1st Marine Expeditionary Force who ran the equipment.

Overview of the building: the 32-ft * 16-ft (512 ft2 – 46 m2) prototype barracks consists of two halves of the exterior walls of a 9.5-ft-height. The walls transition from a chevron pattern at the base to a straight wall at the top, forming "undulating" walls.

Construction Technology: the team used the world's largest concrete 3D printer consisting of a gantry crane with a hose, attached to the mixer, and a nozzle that extruded concrete sourced from local materials to construct a barracks room walls. The Army, NASA's Marshall Space Flight Center and Kennedy Space Center, and Caterpillar Inc. developed this technology. A tent did not cover the site, to invite journalists to see the live print, which led to was move the demonstration start time a few hours when the forecast showed rain because an issue with concrete is evaporation drying.

Rebar anchors were set in the foundation slab before printing. The anchors accept 18-in. long rebar dowels, installed after the first lift of the printed wall. For construction, at least three personnel are needed--one driving the concrete mixer, one supervising the pump and the third operating the mixer, with continuously printing executed in two or three shifts. The concrete walls were printed in 40 hours, this number does not denote a continuous job, but rather is the total number of print hours. The US Marines handled the finishing touches (windows and doors) manually, as in Fig.7.

The impact of using 3DP technology: this barracks highlights the advantages concrete 3DP brings to construction. Nadine M. said, according to team members that the ACES technology reduces the resources needed and logistics associated with material shipments for wood-framed barracks. Sarah Saunders added according to team members that the technology also lowers the cost of materials, decreases the amount of required personnel from eight to three or four, and reduces construction time per structure as building a wood barracks hut would normally take 10 Marines five days.

Additionally, the construction technology help keep U.S. military personnel safe, where said Matthew D. Friedell, 3DP officer for the U.S. Marine Corps said "We can bring forward better structures, houses and forward operating bases with less manpower and fewer Marines in harm's way." Finally, said S. Saunders that the concrete mixture can 3D print buildings with the necessary structural strength, as said Benton Johnson, an SOM associate director, that testing confirmed that the chevron walls are stronger than the International Building Code requirements.

Fig. 7. the construction site of US Army barracks, Champaign, Illinois. Source: [41, 43, 44]

Based on the previous review for a group of global projects constructed using 3DP technology, the research in this section aims to examine the impact of this technology on the construction building process on site. To achieve that, first, it is studied, what has changed from the general culture of the construction industry on-site by using this technology; as illustrated in the following Table 2:

Table 2.

Analytical study of the most notable changes in the building construction phase as a result of the use of 3DP technology. Source: researcher.

The most notable changes in the building construction phase	Method of construction	Printing
	Who performs printing	The computer-controlled 3D printers / robots with different shapes and sizes to lay down the material. While human resources play a supportive role, which is competent to operate and monitor the computer, prepare and mix the materials, lay out supplies for printers and supervise the entire printing process.
	Components that are printed	Foundations of the building or parts of it, in addition to the entire building walls only, as the printers did not participate in printing the other components of the building.
	Materials that are printed	Multiple and sustainability: where varieties of new and innovative materials are used, which are extruded in successive layers based on a digital model, containing in its composition on the recycled materials or it is recyclable at the end of the building life.
	Construction conditions	Covering/protecting most construction sites a tent.

Based on the previous table, many results can be derived, the most importantly:

- Construction techniques and building materials used in 3DP technology differ from those in the traditional method, and this difference has led to a change the practice of construction greatly.
- With regard to the resulting changes in the construction industry, using 3DP technology helps to
  - Construction automation where the printer is able to accomplish most of the construction work, and use of new materials to suit to the printing concept.
  - Revolutionize in the world of materials and possibility of inventing and developing new building materials or improving properties of materials to use in construction in certain areas.
  - Use more sustainable, eco-friendly and cost-effective materials.
  - Reduce downtime due to weather conditions.

- Despite the changes mentioned in the previous table, however, 3DP is still in its infancy and beginning in the construction industry, where there are some limitations that require a lot of scientific researches and experiments, the most importantly:
  - Printing of horizontal structures as roofs, slabs and beams on-site are still technically difficult.
  - Most of the projects that have been printed on-site consist of one or two floors with small areas, therefore it is not clear how to use this technology to print structures higher than 2 floors with large areas, with regard to structural aspects and construction conditions (cover site).

In the context of examining the impact of 3D construction printing technology, and after identifying the most notable changes in the construction phase. Secondly, the impact of these changes on all levels associated with the construction industry is explored and discussed. The following table (3) illustrates this:

Table 3.

An analytical study of the most notable results and effects of changes in the building construction phase resulting from the use of 3DP technology. Source: researcher.

Direct results				Indirect results (implications)	
Construction automation	Human factor level	Reducing dependence on the human labor and less need for human intervention.		Reducing the arduous nature of work and the risk of accidents and injuries during the construction process.	Human factor level
	Performance level	Speed of execution of construction processes, and accelerate the completion and delivery of the project, where the printer is always operating at a constant and unrelenting rate.		Reduce costs, through: ▪ Low labor costs. ▪ Low construction costs. ▪ Provide cost to modify errors ▪ Reduce the cost of materials and reduce the cost of transportation (fuel).	Economic level
	Engineering performance level	Reducing potential errors during the construction process, due to the direct transfer of information from the 3D design model to the construction processes.		Save time greatly, through: ▪ Reduce construction periods. ▪ Save time to modify errors. ▪ Provide transportation time and making blocks.	Time frame
Using multiple and new materials	Environmental level	Environmentally friendly and more sustainable construction processes, through: ▪ The most efficient use of materials where the printer uses the exact amount of materials, thus reducing its waste. ▪ Reducing required resources and logistics associated with material shipments. Eliminating the need to produce building blocks.		Construction accuracy	Engineering performance level
				▪ Reducing consumption resources. ▪ Reducing total energy consumption to produce a material throughout its life cycle, from its extraction, to its transformation, to its recycling. ▪ Reduction of carbon dioxide emissions, thus reducing the rate of pollution and environmental damage.	Environmental level

Based on the previous table, many results can be derived, the most importantly:

- The most important effects of using 3D construction printing are saving a lot of time associated with the implementation of the building as well as reduce its costs.

- Using 3D construction printing:
  - Provide a solution to the lack of skilled labor.
  - Provide opportunities to accelerate delivery of the project and reduce the risk of delays, allowing contractors to move to build new projects quickly.
  - Allow the construction industry to be more sustainable, environmentally friendly, cost-effective and time-efficient.
  - Lead to the production of more sustainable with respect to building materials, low-cost and very quickly buildings.
- Finally, the results and effects of using 3D construction printing create many expectations and hopes towards a cleaner and brighter future.

To complete the analysis of 3DP effect on the various aspects of the construction process. Finally, the impact on the architectural output is derived and discussed, through identifying the most important characteristics that added by this technology to the building. As shown in table (4):

Table 4.

An analytical study of the most important characteristics added to the architectural output thanks to the use of 3DP technology. Source: researcher.

The most important characteristics that added by the 3DP to the building		The effect of 3DP technology on the architectural product	
	Formal properties	Freedom in the formation of the building - Flexibility in building design: 3DP allows the ability to create the structures with organic, irregular, atypical, or curved shapes that were seen as very complex and unachievable using conventional construction methods.	
		Reduce the complication related to curved walls and nonlinear forms that were very difficult and expensive by traditional ways: 3DP allows constructing the curved shapes without any additional cost or any technical constraints.	
	Structural properties	Durability and strength of the building structure The 3D printed concrete structures characterized by being more resistant to external conditions, withstand natural calamities and the possibility of moving the building without any impact on the structure, this was demonstrated by testing material (a concrete mixture) during the early stages of construction.	

Based on the previous table, many results can be derived, the most importantly:

- With regard to design, using 3DP technology:
  - Frees the architects' imagination to create what they want from designs without having to use traditional shapes to keep costs down.
  - Completely changed the design of the building form, where provided the ability to construct buildings with free or irregular shapes that cannot be produced by traditional methods, i.e. made the impossible possible.
- Concrete-based 3DP is the most convenient and widespread in architectural practice so far.
- With regard to the building durability, it may be partly due to the method of making the construction material and how they are assembled.

4. A proposed framework for the application of 3dp technology in the context of the local construction industry

3DP technology concept has emerged in the construction industry on the world's stage, as previously presented, as one of the options that offers a more sustainable and environmentally

friendly construction industry and has solved many of its problems. With the major and pivotal developments currently spreading such as sustainable and 3DP buildings, radical changes in architecture and construction are almost inevitable. Because the future is no longer a theoretical concept, but it is the expected tomorrow that is built on visibility, action and planning. This phase of study focuses on how to apply the 3DP technology in the context of the Egyptian construction industry, and aims to propose a simplified methodological framework to help the applicability on the local scene, which will place Egypt as one of the competitors in this field and strengthen its position in the region and the world.

Under this objective and based on previous analyses, a SWOT analysis is conducted, as it is the most convenient method that assists in making decisions and developing strategic plans on a logical basis. The study seeks to analyze the current situation and the main features of the3D construction printing by specifying its four elements. First: strengths or features that distinguish it from the traditional construction industry, Second: weaknesses or shortcomings that are present in it, third: opportunities and pros that come from outside and are exploited to apply and develop this industry, and finally threats or negatives that come from outside and hinder its application. These elements play an effective role in developing a methodological proposal for the application on the local scene. The table (5) shows an overview of the SWOT analysis of 3D construction Printing.

Table 5.
The SWOT Matrix for 3DP technology at construction industry. Source: researcher.

S STRENGTHS	W WEAKNESSES	O OPPORTUNITIES	T THREATS
▪Reduction in the time of design-to-construction cycle. ▪A safer working environment. ▪Saving construction time. ▪Reducing construction costs. ▪Construction accuracy. ▪Using new, lighter, stronger and more durable materials. ▪Environmentally friendly and more sustainable construction processes. ▪Buildings with flexible designs without additional costs or waste time and materials. ▪Growing number of countries and companies that seek to apply technology. ▪Continuous and rapid changes and developments.	▪The upfront costs of the printers are high [45]. ▪Printing is limited to specific elements of the building (walls and foundations). ▪Inadequate of available techniques to print multi-story buildings. ▪Limited construction materials. ▪Many printers are limited to one type of material. ▪Printing devices constantly change. ▪Reduction of employment function. ▪Requires trained professionals to manage software and run the printing machines.	▪The citizen's ability to afford the building. ▪High demand for sustainable construction and buildings. ▪Various mental and research capabilities. ▪State plan for sustainable development. ▪Alliance between companies and institutions. ▪Competitiveness of institutions and companies. ▪Breakthrough ability of science and technology for different markets. ▪Marketing campaigns.	▪Economic constraints. ▪Barriers and restrictions of customs. ▪Aversion to new technology risks. ▪Resistance to change and keep up with technical developments. ▪Low level of interest and support from institutions and stakeholders. ▪Conflicts with the objectives and priorities of some institutions. ▪Human resources are not eligible for technological developments.
Internal factors		External factors	

Based on the analysis of key features and examine the different factors of SWOT analysis for 3D Construction Printing, a series of conclusions can be drawn:

- 3D construction printing has many noteworthy strengths that must be seized by stakeholders to achieve the expected benefits at all levels.
- There are many strong opportunities that are exploited when preparing the proposed framework.
- Despite of the fact that there is a list of strengths and opportunities that make this technology attractive, but there are still a number of weaknesses and threats that the study is attempting to minimize by transforming as much as possible into strengths and opportunities through actions that are taken in the methodological framework.

Based on the previous conclusions, a simplified methodological framework is proposed for how to apply 3D construction printing on the local scene, consisting of a series of stages contributing to guide the decision-making processes and develop implementation plans, and formulating as follows:

1- Organize a scientific forum

A research institution organizes a scientific forum (conference, seminar, workshop or other) and directing an open invitation, to:

- All researchers at the Egyptian research centers, institutions, and bodies to participate in the forum to conduct scientific research and discuss the latest in the 3D construction printing technology with various aspects in all engineering disciplines, in addition to the study of technology commensurate with the optimal use and application in local reality.
- The global construction industry leaders with expertise in this field to attend to take advantage of their research, experiences, and applications.
- Representatives of relevant government ministries and bodies, leaders of the construction industry, whether in government or private sectors, businessmen, and others, to attend the forum activities in order to familiarize them with technology and give them an overview about its role in improving and developing the construction industry into an eco-friendly and more sustainable industry, and its impact on various aspects of life (economic, environmental, human and other).

2- State support initiative for technology

In light of the State's Sustainable Development Strategy 'Egypt 2030', encouraging society to adopt more sustainable lifestyles, and in the context of rising demand for sustainable construction, the state is supporting the technology and launching the 3D construction printing initiative aims to serve its plan and strengthen its position in the region and the world. This initiative seeks to invite various stakeholders to invest in new 3D construction printing technology through its application to take advantage of its impact in the local reality as well as encouraging innovation to develop this technology. Through its initiative, the state also creates the appropriate environment, provides the necessary facilities and overcomes the obstacles facing the application.

3- Form a team to work on the applied project

Out of a deep understanding of the role of 3D construction printing and in response to the initiative, a partnership is formed between some governmental or private construction institutions, academic institutions and research centers to prepare a working team consisting of different disciplines to conduct accurate studies on the ambitious project to

apply technology and construct a 3D printed building on the local scene created by Egyptian minds. Work begins by specifying the site to print and then designing the building according to its function, but for the team to be able to print the building after design, several actions must be taken:

A. 3D printer availability: through the use of specialized outside expertise and printer designers in the global markets to obtain the printer, or by collaborating with and commissioning local creative experiences in engineering disciplines concerned with 3D printer design.
B. Preparation of printing material: due to limited printing materials, various external expertise is used that has designed the building materials that have been printed previously, to reach the ideal and eco-friendly specification for the material to be printed. Then the necessary tests are performed and the printing process of materials is carried out before the building is printed.
C. Training of human resources: due to the change of many necessary work skills for the site, training sessions are being prepared for human resources working in this industry, including:
   - Training the labour on a 3D Printer and how to assemble, operate, supervise the printing process, and maintain it, as well as to prepare, mix materials and other processes.
   - Training engineers to develop their skills in the use and management of 3D modeling software and applications to create a printable file and how to drive these programs during printing.

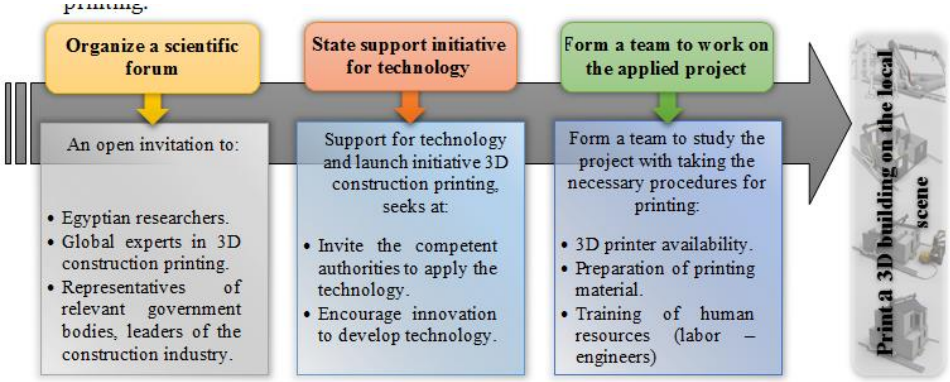

Fig. 8. the proposed methodological framework for application of 3D construction printing on the local scene. Source: the researcher.

5. Conclusion

Based on what was previously reviewed, several conclusions can be drawn, including:

- 3DP has changed the traditional and inherited rules of the construction industry and reshaped the various elements of the construction process on-site, leading to change:
  - Bases and stages of the architectural implementation documents preparation: which are conducted entirely through using digital design model and on the computers containing many programs needed to convert the 3D model file into a file that can be read by 3DP.
  - Scene of the construction on-site: in terms of automating the construction process and enabling 3D printers to print the entire building's walls and parts of its foundations, as well as using a variety of new and innovative building materials to fit the printing concept.

- The building's design and formation method: the new architectural approach of 3DP provides the architectural freedom and flexibility to create structures with organic, atypical, or curved shapes without additional cost.

- 3D printing contributes to access to a more sustainable and environmentally friendly construction industry. Where the study showed some important strategies that achieve the sustainability of the construction and the production of more sustainable buildings, including:
- Use of environmentally friendly materials containing recycled material or recyclable at the end of building life, the most efficient use of materials, reduction of waste during the construction process, reducing resource consumption, eliminating many logistics associated with material shipments, and reducing emissions that reduce pollution and environmental damage.
- In general, 3D Printing techniques can replace conventional construction techniques. Where it considers a much better alternative and a possible solution to many problems associated with traditional construction methods. The use of 3D construction printing, has generated many advantages, including:
- Increase: speed of execution and delivery of the building, productivity, accuracy and quality construction and sustainability.
- Reduce: time of architectural implementation documents preparation, implementation periods, production costs, errors during construction, depending on labor, the arduous nature of work, risk of accidents and injuries, waste of materials, logistics services, consumption of natural resources and energy, and co2 emissions.

All these advantages make 3D construction printing an attractive proposition to replace traditional techniques.

However, this proposal is difficult to imagine at present time because this technique is still at the beginning of its practice in the construction industry, and thus did not show their potential in full. Therefore, 3DP can be an additional and supportive tool in the construction industry on-site. It is likely in the next few years that both techniques will exist where traditional building methods continue to be used for multi-storey buildings, while 3DP will be the best for small-sized structures.

- 3DP in the construction industry is an emerging technology. Although there is a long list of strengths that make it attractive, there are still many weaknesses that need to be addressed continuously by optimal utilization of the opportunities, besides transforming threats into opportunities and push factors, both of which constitute the basis for the application and development of technology on the local scene.

6. Recommendations

- For decision makers in the state: support the national policy for 3D construction industry and provide the necessary facilities for the application of technology, making the local arena fertile ground where the 3D construction industry to grow and develop.
- For institutions of the construction industry: putting 3D construction printing within the scope of their priorities, the adoption of this technology and the trend towards constructing the project for applying the technology in the local realities. Besides providing the aid and financial support to researchers and continuous communication with them to apply their findings.

- For researchers: guiding and focusing future research efforts in the field of 3DP and its systems in the construction industry and 3D printed buildings, because of the small number of studies, and also because of its significant impact on improving many aspects of life.
- For construction industry human resource: the need to learn the new technology skills associated with a 3DP in order to update skills, thus qualifying for the requirements of the labor market, maintaining job security and expanding employment opportunities.
- For engineering and technical education institutions: the creation and adoption of new curricula integrate knowledge of 3D construction printing in various architectural programs and courses, in the various engineering departments and technical and vocational education. So that it is an important step in preparing and graduating cadres of technicians and young engineers in all their specialties, to suit future professions that require these skills.
- For architecture students: each student must be equipped with the largest number of architecture software for its ability and clear role affecting the creative process in the design as well as in the preparation of working drawings and the implementation of the building on-site. To develop his creative abilities and skills, becoming one of the foundations of evaluation for a job.

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تكنولوجيا الطباعة ثلاثية الابعاد في صناعة البناء في الموقع: تحليل للأثار الناجمة

الملخص العربى:

صاحبت التقنية الجنس البشري من قديم الزمن من خلال استخدام الأدوات التي تم اختراعها لتسهيل حياته، والتي غيرت أساليب حياته التقليدية. وأصبح استخدام التقنية مطلباً أساسياً تسعى إليه كافة المجتمعات. وفي ظل عالم عنوانه السرعة وهويته التقدم، تعيش البشرية اليوم بداية مرحلة جديدة من التغير حيث تقف على أعتاب الثورة الصناعية الرابعة، التي بنيت على أساس الثورة الرقمية ولكنها تقدم العديد من التقنيات الجديدة التي ترتبط بأتمته الصناعة.

أحد التقنيات الهامة التي تلعب دورا رئيسياً في هذه الثورة، هي الطباعة ثلاثية الأبعاد (3DP) وهي أحد وسائل التصنيع الأكثر مرونة، وقد شهدت تطورا كبيرا في السنوات الأخيرة في العديد من المجالات. وكان للعمارة أيضاً نصيباً عظيماً، ليس فقط في التصميم حيث ارتبطت الطباعة ثلاثية الابعاد بدراسة النماذج المعمارية، ولكن أيضاً في صناعة البناء حيث اتجهت الدراسات في الآونة الأخيرة لتطوير الطابعات الثلاثية الأبعاد لتصنيع المباني حيث يعتبر الموقع بمثابة مصنع مؤقت يتم فيه تصنيع المبنى. أي تحول استخدامها إلى صناعة البناء والتشييد أحد الركائز الحيوية للتنمية في أي دولة لفوائده للمجتمع والاقتصاد. وبالرغم من ذلك، فأنه لا يعرف سوى القليل عن الدور الذي تلعبه هذه التقنية حالياً في صناعة التشييد. إلى جانب ان هذه الصناعة مع الطلب المتزايدة على تشييد المباني على المستوى المحلي تواجه العديد من التحديات التي تؤثر بشكل سلبي على الاقتصاد والمجتمع والبيئة وبالتالي يقل دورها الفعال والمحوري في عملية التنمية.

وفي إطار هذا السياق، تسعى هذه الدراسة إلى تحليل تأثير استخدام تكنولوجيا الطباعة ثلاثية الابعاد على الأركان المختلفة لصناعة التشييد في موقع البناء، والتي تتمثل في: مرحلة إعداد رسومات تنفيذ المبنى المعمارية، مرحلة تنفيذ المبنى، والنتاج المعماري. إلى جانب استنباط ما تغيره هذه التقنية من الثقافة العامة لصناعة البناء والتشييد. وذلك من خلال استعراض مراحل إعداد رسومات التنفيذ المعمارية لعملية الطباعة ثلاثية الابعاد، بالإضافة لدراسة بعض التجارب العالمية للمباني التي شيدت باستخدام تقنية الطباعة ثلاثية الأبعاد. ثم تتوجه الدراسة إلى اقتراح إطار منهجي لتطبيق هذه التقنية في سياق صناعة البناء على الساحة المحلية. ومن ثم تختتم الدراسة بعرض أهم النتائج البحثية والتوصيات المقترحة.