3- DIMENSIONAL CONCRETE PRINTING TECHNOLOGY

الطباعة الخرسانية ثلاثية الابعادتقنية

by

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ABSTRACT

The structural engineers are always in a challenge between the responsibility for the people life and the development in the structural engineering sector, the long spans or the height of the buildings also the modern design that needs flexibility required from the structural engineer to discover new ideas and seek for a new solution to break the limitation of the traditionally used manufacturing processes of the concrete, and move to a new page which is a smart structure-based new technology, such as 3D concrete printing, that will help the structural engineer and the construction sector to be more creative.

Taking under consideration that every complex structure gives complex loads and dynamic nature, in addition to that it will increase time and cost which is very critical points in the construction stage. The present paper reviews all the properties, features, advantages, and disadvantages of 3D printing will be discussed with approval.

This dissertation or thesis is surveying research, the type of the survey is a questionnaire, it was done online by using SurveyMonkey or Google Forms, and the design of the question was developed and selected carefully which includes a critical point about 3D printing, the questions were distributed between engineers with different engineering background, like civil engineers, structural engineers, MSc. in structural engineering, PhD. in structural engineering, and researchers. And it was targeting engineers in different locations and in different fields.

This survey research includes questions that are divided into different sections. The types of the questions are closed-ended questions and that means quantitative research which provides numerical data that can be statistically analyzed to find correlation, trends, patterns. On the other hand, the result of the responses is static analysis, usually using computer programs like SPSS, Stata, or Excel. Knowing that survey results are organized and discussed in the conclusion.

الملخص

يواجه المهندسون الانشائيون داتما تحديا بين المسؤولية التي يحملونها اتجاه حياة الناس و التطور العمراني الحديث في الهندسة الانشائية، الامتدادات الطويلة و الارتفاعات الشاهقة للمباني تتطلب دائما من المهندس الانشائي اكتشاف مواد و افكار جديدة و البحث عن حلول جديدة لكسر الحدود التي تصنعها المواد التقليدية في البناء، والانتقال إلى صفحة جديدة وهي تقنية جديدة قائمة على الهيكل الذكي ، مثل الطباعة الخرسانية ثلاثية الأبعاد ، والتي ستساعد المهندس الإنشائي والبناء ليكون أكثر إبداعًا .

مع الاخذ بعين في عين الاعتبار ان كل هيكل انشائي معقد سيولد احمالا معقدة فيجب دراسة الطبيعة الديناميكية ايضا. بالإضافة إلى أنه سيزيد من الوقت والتكلفة وهي نقاط حرجة للغاية في مرحلة البناء. سوف تستعرض هذه الاطروحة جميع خصائص وميزات ومزايا وعيوب الطباعة ثلاثية الأبعاد و انواع الخرسانة المستخدمة في الطباعة الثلاثية وسيتم مناقشتها مع الدلائل.

هذه الرسالة أو الأطروحة عبارة عن استطلاع او استبيان للاراء، وقد تم إجراؤه عبر الإنترنت باستخدام بعض البرامج مثل SurveyMonkey أو Google Forms ، وتم تطوير و تصميم الاسائلة واختيارها بعناية و تتضمن النقاط الحرجة حول الطباعة ثلاثية الأبعاد، تم توزيع الأسئلة على أشخاص مختلفين بفئات هندسية مختلفة ، مثل المهندسين المدنيين ، والمهندسين الإنشائيين ، وماجستير. في الهندسة الإنشائية ، دكتوراه. في الهندسة الإنشائية والباحثين. وكان يستهدف المهندسين في مواقع مختلفة و في تخصصات مختلفة.

يتضمن هذا البحث الاستقصائي أسئلة مقسمة إلى أقسام مختلفة. أنواع الأسئلة هي أسئلة مغلقة ، وهذا يعني البحث الكمي الذي يوفر بيانات رقمية يمكن تحليلها إحصائيًا للعثور على الارتباط والاتجاهات والأنماط. من ناحية أخرى ، تكون نتيجة الردود عبارة عن تحليل ثابت ، عادةً باستخدام برامج الكمبيوتر مثل SPSS أو Stata أو Excel. مع العلم أن نتائج الاستطلاع ستكون منظمة و تتم مناقشتها في الخاتمة.

DEDICATION

Allah will exalt in degree those of you who believe, and those who have been granted knowledge.

And Allah is Well-Acquainted with what you do.

ACKNOWLEDGEMENT

Praise be to Allah that His grace is righteous, I was done with my thesis as a requirement for the graduation in the Master of Science degree in structural engineering. And I hope this thesis will be useful for community and for the student.

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Allah grants success...

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Singular	The Definition
Stress	It's a forced that applied to area per unit.
Strain	It's the displacements or the deflection that happened when stress imposed.
Strength	It's the measurement of any material under stress withstand.
Sustainability	It's the focuses of the people needs in the presents but without effect the future generation needs.
Compressive Strength	It's a physical property of different materials that can withstand when it's exposed to load compression and pressure.
Tensile Strength	It's a physical property of different material that can withstand when it's under tension load
Ductility	It's a physical property of the material to have its shape change due to some applied load without strength losing or breaking.
Brittle	It's a property of a material which is fracture when its subjected to load or stress but it has a very little tendency for deformation before rupture
Concrete	It's a construction material that made from a mixture of Portland cement, water, coarse aggregate and fine aggregate.
Reinforced Concrete (RC)	It's a construction composite material that composite of two substance which is the concrete and the rebar, and the rebar could be steel, fibers, etc.
Durability	It's the concrete ability to withstand the effect of surrounding environmental and other damages until it reaches the lowest performance level.

Singular	The Definition
Corrosion	It's a chemical attack that react with surrounding environment and that reaction will cause a damage and erosion in the material.
Modulus of Elasticity	It's the ratio of street corresponding the strain
Supplementary cementations materials (SCMs)	It's one of principal in the concrete mixture that usually helps with strengthening, the some of the properties of the concrete it reacts chemically with water.
Fibers	It's a substance that could be manmade or natural that is longer than its wide and its used to strengthening the engineering materials.
Pumpability	The ease and accuracy that the material can make through the delivery system.
Printability	The ease and accuracy of the material deposit through the deposition system.
Buildability	The resistance of the wet material that deposited to deform under load.
Open Time	The period where all the properties are consistent within allowance tolerance.
Plasticizers	chemical admixtures that can be added to concrete mixtures to improve workability. the strength of concrete is inversely proportional to the amount of water added or water-cement (w/c) ratio. In order to produce stronger concrete, less water is added, which makes the concrete mixture less workable and difficult to mix, necessitating the use of plasticizers or water reducers.
Fly Ash	It's significant to improve the performance of workability, durability, and strength of the concrete.
Silica Fume	Its significant to enhance mechanical properties and durability of the concrete

CHAPTER ONE

1. INTRODUCTION

1.1. Preliminary Consideration

The 3-Diamontonal Printing Technology sweeping the world now, and it is used in so many fields, every field has its own printing system so there are different printers and different materials. On the other hand, the 3D printing technology is very flexible, it allows to design and construction of complex elements, more than the traditional process which restricts the creativity of the design. Also, the 3D printing technology can manufacture many parts in a short period of time like hours, and the parts can be installed immediately. In other words, 3D printing is very efficient with time management it will reduce the duration of any project in any field which causes a reduction in cost also. (Anissimov, 2021)

The 3D printing technology is well known as additive manufacturing, which is creating three-dimensional objects with a method of layer–by–layer by using a created computer design, so it's a layer of materials that are built up to create 3D parts. This technology is the opposite of the subtractive manufacturing process, where the final design is cut from a huge section of material or a block, so that method causes wastage in the materials. So as a result, the 3D printing technology creates fewer materials wastage which considers a cost-saving also. The material type that is used in this technology is thermoplastic materials such as acrylonitrile butadiene styrene (ABS), metals (including powders), resins, and ceramics. (T.W.I, 2020) [2]

On the other hand, there are three main types of the 3D printing technology, it's as the followed:

1- Sintering: it's a type of the 3D printing technology where the material is heated but not reaching the melting point, to make a very high-resolution item. The metal powder used for the direct metal laser sintering, and the thermoplastic powder used for the selective laser sintering.

2- Melting: it's a type of the 3D printing technology, that includes the powder bed fusion, melting of electron beam and the deposition of direct energy, and these lasers method uses the electric arch, or electron beams to print the objects by putting the materials together and melt it in a very high temperature.

3- Stereolithography: it's a type of 3D printing technology which utilizes photopolymerization to make and produce parts, this type of technology uses the correct light source to react with material in a selective manner to solidify and cure the section of the object in very thin layers.

This technology it's like any other technology, it has its own advantages and disadvantages, both sides will be discussed briefly. Starting with the advantages side, the 3D printing is very effective in terms of cost especially when there is a complex geometry, the startup cost for any project will be less and affordable, it can be completely customizable, it's very suitable for rapid prototyping, and it can create different parts with different properties. On the other side, the disadvantages of this technology are, the parts or the elements might be lower strength is some cases, the large scale and high-volume projects parts might increase the cost, the accuracy of the printed parts or elements in some cases depends on the type of printer or the machine, and the requirements of post processing. (T.W.I, 2020) [2]

As it was mentioned earlier, the 3D printing technology is used in many fields or industries, and in each industry has its own application, some of these industries are:

- Engineering: architecture, industrial design.
- Automotive, aerospace.
- Dental and medical industries.
- Fashion, jewelry.
- Heavy industry.
- Robotic
- Construction industry etc.

And many other fields, that's why the 3D printing technology is very important now. (Markerbot, 2019)[3]

From the engineering point of view, the classical building manufacturing are no longer efficient like before and that's refer to the modern structural building that getting more complicated which required more smart systems and smart materials also. For example, the concrete is one of the most used and popular material in construction field due to its strength, but in the same time the concrete has many weaknesses that the structural engineer should take it under consideration in the designing stage, which can limit the designer whether the architectural engineer or the structural engineer form develop new structural codes or systems in construction sector. That's why the engineer always try to find new ways to move on with their engineering imagination. (Martin, Robert L., Bowsen, Nicholass, Marrill Chris, 2014) [4]

Hence, in the recent years the 3D printing is gaining popularity in engineering, especially in the civil engineering and in the construction industry and that refer to their unique in mechanical, strength, lightweight, and optical properties.
But how the 3D printing technology can help us in engineering field whether structural engineering, Architectural engineering or construction engineering field?
In order to answer this question, we should understand the concept and the definition of the 3D printing technology. As it was mentioned in the previous paragraph that the 3D printing can manufacture many parts in short period of time, it can also manufacture high strength and lightweight structural parts in different sizes and shapes, also it effects the cost in very positive way and many more other advantages that will be discussed one by one. (Martin, Robert L., Bowsen, Nicholass, Marrill Chris, 2014)[4]

The main idea of the 3D printing is the concrete mix which should be studied in terms of compression, flexural, tensile, and shear, and that's to identify the durability, extrudability, and workability. The superplasticizers add to the concrete mixture with percentage to enhance the strength, also fibers are used like polypropylene, PVA, GGBS, Steel also it helps to increase the strength. other than that, the printing machine have its own types and systems that will be covered later on. (N.N., 2016)[5]

1.2. Objective

The main objective of this research paper, listed as the followed:

1. To gain a good knowledge about the 3D printing technology and try to compare it with the traditional process to come out with a reason why the 3D printing technology is highly recommended and what is the positive effect on design areas, repair area, and maintenance of any construction project, also its important to know how it effect the environment and the green buildings.

2. To gain a good knowledge about the performance of the 3D printing technology, what is the types of the printers, and what the mechanism, how does it work and what is the types of materials used in this technology, especially in the engineering and construction sector.
3. To gain a good knowledge about the global market of this technology and study its sustainability.
4. To gain a good knowledge about what is the automation and how does the concrete get printed, what is the main application of the technology.
5. In-depth the research required identification the main problems of the 3D printing technology with solutions and summary the key factors.
6. The survey that was done in this research paper clarify a very critical points about the technology of 3D printed Concrete, the discussion was done based on the analysis that was taken from the survey that was distrusted between engineers.

1.3. The Global Market Knowledge and Sustainability

The global knowledge of the 3D printing in the construction market is projected to grow at annual growth rate (CAGR) of 69.77% during the prediction period 2021-2027, according to report (published by Gen Consulting Company). (MarketDataForecast, 2019)[6]

The global market size for the 3D printing in construction was valued USD 7081.7 thousand in 2021, and the expectations it will more increase in the coming years. The increasing rate of uses the 3D printing in construction industry leads to perfect growth in the market. The 3D printing is widely used in construction for complex building structure, and that refer to its perfect characteristics in green construction sector. The application of this technology provides high accuracy, improve efficiency, reduce the number of labors which means lower labor cost, and faster construction. The increasing adoption of the 3D printers for prototyping and design in the construction sector, along with the final product achievement in accuracy, and lower manufacturing expanses leads to growth in the global market. (Grand, 2021)[7]

The green building is now widely used because it's one of the main factors in global market growth. Now, most of the construction companies heading to 3D printing technology and green building construction methods, to reduce the energy consume and cost, and that's happen by using sustainable construction process as well as sustainable materials, that have negligible environmental impact. According to WGB trends survey 2018, there are around 47% of the companies that was surveyed, 60% from their project was design based on green building system by 2021. (Grand, 2021)[7]

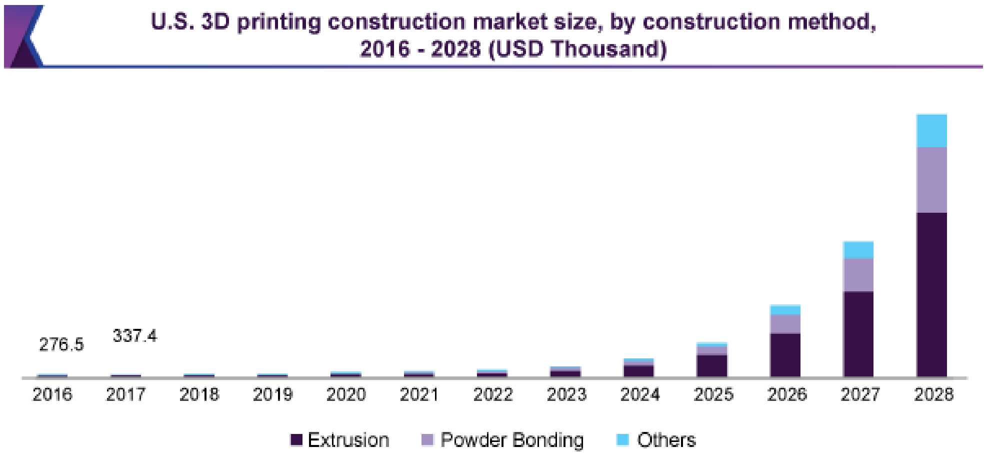


Figure 1 U.S. printing construction market size | Source (www.grandviewresearch.com, 2020)

The market growth is expected to increase by increasing the adoption of building information modeling (BIM). The BIM provides a source of information, knowledge and a collaboration stand for structural engineers, architecture engineers, construction professional, and also the stakeholders to successfully processed the design stage, planning stage, and the management stage of several construction decisions. Furthermore, it's expected that the growth in construction sector in the emerging countries, and the increase of focus on the environment friendly or eco-friendly construction practices, also the need of housing solutions with affordable range, are expected to lead the market growth in the coming period. (Grand, 2021)[7]

The government all over the world in different countries, a regional authority, are encouraging innovation in the top industries through the initiative, such as the National Competition, smart industry, the Expo innovation, etc. for example in United Arab Emirates, the government always enhance such an initiation and take courage in all industries sector for green environment. Furthermore, green building strategic in UAE was aligned in the

Municipality of Dubai and launched 2011. The Green Building Regulation and Specification (GBR&S), where to be applied under mandatory requirements for new construction building in the emirate so by 2014 the construction of any building followed the Green Building Regulation and Specification (GBR&S), all of these regulations were listed refer to sustainability development goals, the UAE reach the vision of 2021, to create a Green Economy to develop the sustainability in economics. Expo 2020 in one of the strongest example sustainability and green environment, it considered as an icon of the future. These initiatives aim strengthen the industries by encourage the usage of discovered new technologies in many fields, like 3D printing, nanotechnology, robotic technology, and so on. (Municipility, 2014) (EcoMEN, 2020)[8] [9]

In addition to that, the government also encourage the innovation through the development in the public infrastructures, which can also contribute with usage of the 3D printing technology. Therefore, the government efforts and encouragement in eco-friendly 3D printing technology are accentuating the market growth. (EcoMEN, 2020) [9]

However, the high investment correlating with 3D printing technology in construction is expected to prevent the market growth due to the materials used in the 3D printing technology are more expensive compared to the materials used in the traditional construction process. In addition to that, there are factors such as the material qualification, machinery limitation, and the concerns regarding the intellectual property, prevent the market growth in particular scope. Additionally, the shortage in skilled and professional labors is also a challenging factor that effect the market growth of 3D printing technology. [10]

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Preliminary Consideration

In all areas of study, it has always been necessary to create and study models whose creation was carried out by craftsmen and specialists who, using manual means and techniques, made models and three-dimensional drawings of them. After the industrial revolution that occurred in the 18th century, these artisan methods no longer have a place due to the short deadlines that currently exist, which has led to the investigation and development of rapid prototyping techniques (Paul et al., 2018). On the contrary, due to the limitations of the materials and the techniques used in the construction industry, this has not been possible, and the models made by hand have been maintained. It wasn't until the 1980s that research by people like Behrokh Khosnevis and Enrico Dini began to bring rapid prototyping techniques closer to the construction industry.

During the last century and especially during the last decades, the traditional vision of concrete, the material par excellence in the construction field, has changed due to new techniques and different technologies. The projection of concrete has supposed a great advance in the implementation of the material, evolving in a very significant way, due to the development of setting accelerators and superplasticizers and the improvement of the machinery necessary to carry out this technique (Kuzmenko et al., 2019)The union of different technologies in the same material and the incorporation of other materials, such as fibers, into concrete increase and improve certain properties. This is how different special composite materials arise, such as very high-performance concrete with fibers and concrete composed of alkali-resistant fiberglass-reinforced cement mortar. The union of several techniques and technologies has led the construction industry to advance significantly, until today, it is developing additive manufacturing techniques, such as 3D concrete printing. This new technique, which evolved in many other industries, is a novel technology in the construction field.

As mentioned in the previous chapter, 3D printing has now developed in many fields, but the scope of this chapter is to study the development of this technology in the engineering industry withier architectural, structural, and construction engineering. The study will cover the critical issues that affect the engineering and how the concrete 3D printing technology helps to improves these issues.

Despite the many benefits of concrete as a structural material, it also confronts a multitude of challenges which is becoming more well recognized. Because cement is manufactured by burning slag in a furnace, it is a tremendously energy-intensive process. As a result, concrete production contributes a large portion of world Emissions of CO2 the use of cement replacers such as fly ash (a by-product of the blast furnace) has lowered average concrete-related Emissions of co2, but it is still significant (Bos et al., 2016). Another main challenge is related to the physical labor involved, particularly in site-cast concrete. The manufacturing of molds and the application of reinforcement necessitate physically difficult work, especially when complicated geometries are required. This results in personal health issues of construction workers that should be avoided as much as possible, particularly with an aging workforce as in many developed countries. The US Department of Labor's Occupational Health and Safety Administration identifies the following as possible hazards for concrete workers: eye, skin, and respiratory tract irritation from cement dust exposure; inadequate safety security personnel on equipment; insufficient lockout systems on machinery; overexertion and awkward postures; slips, trips, and falls; and chemical burns from fresh concrete (Khoshnevis, 2004b).

2.2. Automation

Automation is the set of computer, mechanical and electromechanical elements or processes that operate with minimal or no human intervention used to optimize and improve a process.

2.2.1. Rapid Prototyping:

Rapid prototyping is an industrial process that allows an exact three-dimensional model of a product to be created using a CAD-type program. This model can be used at an aesthetic level to do market studies or serve in the design and manufacturing process to carry out functional tests before starting the final manufacture of the product. This technique consists of creating models created with CAD systems by adding material in different layers, instead of CNC systems that use drills to transform a solid block into a three-dimensional model by removing material. This technique is constantly evolving, which is why manufacturers continue to investigate the available materials (Sun et al., 2021). The main material is granular due to the theoretical possibility of generating any shape. However, Marchment and Sanjayan (2020) also find liquid materials with resins and solid materials in sheets and wires.

Rapid prototyping relies on printing as it is commonly known, but with the complexity of printing on a third axis, the Z-axis.

1. Creating a TL file: This is the phase before creating the prototype and consists of creating the model in an STL file. This file decomposes the model into a triangular mesh which leads to an error that can be minimized by modifying the size of the mesh (Marchment and Sanjayan, 2020). By increasing the density of triangles per unit area, the inherent error of this type of modeling can be reduced.

2. Transformation of the STL file into a printable model: After generating the STL file, check that it has no errors using specific software and then carry out the following actions. Orient the piece to optimize the printing of the piece and generate auxiliary supports for the correct printing of the piece (Hack and Kloft, 2020). It also generates the slicing of the piece, that is, creating the different layers in which the model will be printed. The final finish of the piece depends on this.

3. Prototype printing: The phase in which the final file is sent to the machine to begin the printing process in layers to make the final model (Panda and Tan, 2018). Depending on the size of the prototype, this process can take several hours, so the second phase is of great importance.

4. Final finishing treatments: After printing the prototype, we obtain a model whose finish is not perfect. In this phase, all the operations are carried out to eliminate the piece's supports and give the prototype the desired finish.

2.2.2. Types of Rapid Prototyping:

Rapid prototyping technology is highly evolved in today's industry and allows generating 3D models through a series of technologies such as:

- Stereolithography: It is a procedure in which a resin is solidified in a liquid state through an ultraviolet laser.

- Poly-Jet: It is a process that allows the creation of objects combining different materials and colors through the combination of inkjet technology and the use of photopolymers, two materials solidify on contact with ultraviolet light (Salet et al., 2017). This process does not need to create layers.

- Drop on demand: It is a process in which two inkjets are used to print viscous liquids: one deposits the material, and the other deposits the binder.

- Electron Beam Melting: It is a process in which the layers of metallic powder are fused with a beam of electrons, creating a completely dense piece (Kloft et al., 2020).

- Limited Object Manufacturing: It is a process in which part of sheets of solid material is cut using a laser and combined to create the final shape.

- Selective Laser Melting: It is a process in which a layer of metal powder is deposited on a heated tank where a high-power laser sinters the powder at certain points (Sanjayan, Nazari and Nematollahi, 2019).

- Multi-Jet Modeling: It is a process that consists of several injection heads of a photopolymer material deposited in the form of drops that solidify when exposed to UV light.

- Fused Deposition Modeling: It is a process that involves a head that melts the plastic filament and is deposited on a heated base (Lediga and Kruger, 2017). This deposited material is making layers; this process is repeated, making a model layer by layer.

2.3. Concrete

The concrete is the most ubiquitin substance after water, in such huge consumption demand required durability and long-term material, over the years many developments happened to the concrete starting from the concrete with low strength (15-20 MPa) in the 1960s to the ultra-high performance concrete to reach a strength of (100-120 MPa) that used nowadays in the construction industry, complex structural like skyscrapers all the development happened gradually to discover more efficient and advance concrete technique, like self-compacting concrete, fiber reinforced concrete, low-density structural concrete, etc. (Gjørv, 2011)

Concrete structure strengthening has evolved as key construction activity in response to revised design rules and strength requirements, as well as environmental degradation over time. Structures must withstand critical loads in adverse environmental circumstances such as high traffic density, explosions from terror attacks, debris flow impact, and extremely corrosive environments. As a result, reinforcement is usually necessary in reinforced concrete (RC) constructions in order to achieve appropriate strength requirements and extend service life. (Siddika et al., 2020) The Classic RC structure strengthening procedures may include the application of an exterior layer of a metallic plate, textile fiber sheet, steel mesh, post-tensioning, concrete or steel jacketing, and epoxy injection.

2.3.1. Evolution of High-Resistance Concrete:

In the construction industry, reinforced concrete has been used due to its formal, versatile, and economic advantages compared to other materials used in construction. The implementation of this concrete has always been done traditionally with phases that have hardly changed until now: rethinking of the elements, the placement of the formwork, the placement of the reinforcement, the concreting of the pieces, and the curing process and hardening of the pieces; and there has not been a great innovation in this technique. One of the most notable developments has been the shotcrete or shotcrete technique (Hack et al., 2020). This technique was created in 1907 by the American inventor Carl Ethan Akeley and originally consisted of applying dry materials pneumatically by applying water to the outlet. From the 1950s onwards, wet sprayed concrete began to be used, and in 1966 the ACI (American Concrete Institute) accepted the term shotcrete to refer to this technique, including the dry method of C. Ethan and the wet method (Lao, Li and Tjahjowidodo, 2021).

In the 1970s, metallic fibers began to be used to improve the properties of concrete, a technique that led to the concretes being used in more traditional procedures. Concrete is a material with high compressive strength but whose tensile strength is quite low, which led as early as the 19th century to the use of embedded reinforcement to improve its tensile strength (Salet et al., 2017). During the last century, this material has been investigated and improved through metallic, inorganic and polymeric fibers. The addition of these fibers in the cementitious base has decreased the cost of construction and the possibility that the concrete acts structurally due to the improvement in the flexural strength, toughness and the control of the cracking that the fibers allow. According to EHE 08, fibers are classified according to their nature into steel fibers, inorganic fibers and polymeric fibers (Ji et al., 2019). These improvements of the concrete when adding the fibers depend mainly on various properties of these, such as their shape, their orientation, the number of fibers per unit volume and the type of fibers used.

2.3.2. GRC Concrete

GRC or Glassfibre reinforced Cement is a composite material formed by a matrix of Portland cement reinforced with alkali resistant glass fibers (Liu et al., 2021). This type of concrete emerged in Europe after studies in the 1960s to overcome the problems of micro cement that emerged in the early twentieth century, which were based on the health problems caused by the asbestos fibers used to reinforce concrete. At this time, this material began to be commercialized in GRC plates that had an internal metallic structure, the well-known skin + stud frame system is the system most used today in the creation of GRC facades.

2.3.2.1. Manufacture:

This system is based on low-weight, low-thickness panels. The manufacture of the panels consists of the use of molds where, using gun terminals, the GRC is projected, forming layers of an approximate thickness of 2-3mm that are compacted with rollers to form the total thickness of the piece (Yu, Du and Sanjayan, 2020). Depending on the desired finish, the first projected layer is made with concrete not reinforced by the fibers so that these are not observed on the surface of the pieces. Currently, these pieces can be obtained by the following methods:

- Simultaneous projection: in this method, a double nozzle gun is used that projects the mortar on the one hand and the fiber that the machine cuts on the other.
- Premix: in this method, the mortar and AR fiber are mixed in a low dosage of around 4% before placing it in the mold (Krause et al., 2018). This allows the mixture to be poured into the mold and subsequently vibrated or projected directly into the mold.
- Automatic projection: for certain elements, a robot composed of a projection gun attached to mechanized and automated equipment is used that performs a round-trip movement on the molds that circulate under the machine (Anton et al., 2021).
- Typologies: This type of product is mainly used in the creation of facades and enclosures. In the restoration of facades and thanks to its composition, it would be a possible candidate to be used in the printing of concrete pieces in 3D

Figure 2 Skin + Stud frame and Ribbed panel | Source (Classen Ungermann and Sharma, 2020)

Figure 3 Lattice and Simple plate | Source (Classen Ungermann and Sharma, 2020)

Figure 4 Sandwich panel and Single flanged plate | Source (Marchment and Sanjayan, 2020

2.4. Printed Concrete

The construction industry has been known to be one of the industries that have evolved the least on a technical and automation level. In the search for this technical evolution, the focus has been on rapid prototyping techniques applied in other industries. This automation present in other sectors has led to solving various problems focused on reducing costs and manufacturing time, giving great freedom when designing.

Moreover, many admixtures are used in the printed concrete in order to increase the strength like Fly Ash, Silica Fume, Geopolymer, these admixtures are the most probably used. Concrete 3D printing is a process of layer–by–layer printer that should not change the position. However, the printed concrete is a basic of two characteristics which is the workability and the extrudability, which defines the concrete printability flow, the flow of the concrete printing should not block the nozzle way and the concrete printed layer stiffness should not fall down or deform while the next layer in the printing process on the top of it. (Demyanenko et al., 2018)

2.4.1. Basic Properties:

To use concrete for 3D printing, it must meet a series of requirements:

1. To be able to be printed: The material must have sufficient fluidity to be extruded through the nozzle.

2. Be able to be pumped: The material must have sufficient consistency to circulate to the extrusion nozzle.
3. Short-term resistance: The material must have sufficient resistance to maintain its shape and support its weight and that of the upper material without deforming (Krause et al., 2018).
4. Working time: The material must maintain the previous characteristics for a certain time.

2.4.2. Setting of Concrete:

One of the most critical properties of concrete is the setting of concrete, a process during which, through chemical reactions between cement and water. Several factors directly affect the setting of concrete. Among these are the following:

1. Water and binder ratio: For the hydration and setting of the concrete to occur, a quantity of water is necessary to interact with the binder. Using low water/binder ratios allows for fast setting: you can supplement such low amounts of water using certain additives.

2. Cement fineness: To achieve a faster setting, a high specific surface is necessary, which is why, with finer cement, that is, concretes with smaller particles, we achieve a higher specific surface that reduces hydration and setting time.

3. Type of cement used: This depends on the composition and the amount of clinker, which is the main cement component. To achieve faster hydration, more clinker could be used since there would be more tricyclic aluminate that would react with the water. On the other hand, the regulations recommend the use of cement with more silicates than tricyclic aluminate.

4. Temperature: The setting speed varies according to the ambient temperature (Classen Ungermann and Sharma, 2020). With temperatures close to 30ºC, the setting is accelerated, and the setting time is decreased.

5. Use of additions: These materials can be both inorganic, with latent hydraulic or pozzolanic that can be added to concrete to reduce the amount of cement used and

improve some physical or chemical characteristics. Additions can be divided into two main groups: Active additions have pozzolanic activity and react chemically, modifying the hydration of the cement. Second is the inert additions; they do not react and serve to supply the finest sizes in the granulometric curve of the concrete.

6. Use of additives: These materials are added to the binder in precise proportions to permanently improve the conglomerate's properties (Rehman and Kim, 2021). Currently, there are various types of additives, among which are the following: plasticizers, superplasticizers, setting accelerators, setting retardants, air entrains, setting accelerators, mass water repellants and multifunctional.

2.5. Concrete 3D Printing Technologies

The 3-Dimensional Concrete Printing Technologies (3DCP) is a new technology that combines the digital technology and new premeditation from material technology, unlike the concrete conventional formwork casting., the 3D concrete printing allows a free building structures without any formwork or mold. 3D concrete printing is a new type of technology were the construction done by adding the concrete layer by layer.
There are two main process that currently leading the 3D concrete printing:

1- The Single Deposition Nozzle Concrete printer: which is similar to the fused deposition modeling, contour crafting is another technology that the concrete is eject against shovel.
2- The Power Deposition Process: it’s when the ink is deposited on a powder layer.

In addition to that there are main four significant characteristics of the fresh concrete that related directedly to 3D concrete printing and it was identified by Le Et Al (*)

1- Pumpability
2- Printability
3- Buildability
4- Open time

Additive manufacturing construction projects have been carried out in a variety of ways, including in situ printing of entire structures or building parts, or printing over existing elements, such as in façade repair or precasting. A 3D-printing system for concrete comprises three basic components, each with its own set of settings and variables: (Gosselin et al., 2016)

- Composition, aggregate size, additives, admixtures, and open time of printable concrete
- In a three-dimensional printer, pump pressure, flow, robot speed, acceleration, system length, system friction, nozzle geometry, temperature, and humidity are all measured.
- Print geometry includes the filament, overall form, size, curvatures, strength, and stiffness. It is critical in 3D printing concrete that the concrete keeps its form after extrusion. It should also be able to support succeeding layers without bending. Because of the material's setting time, slump, and flow characteristics, it is difficult to stack concrete layers

2.5.1. But what is the 3D concrete printing mechanism?

It’s basically a huge machine that include many different parts such as, controller board or mainboard which is the brain of the 3D printer. The controller board is responsible for the whole operation, its guidance the motion of the component depending on commands that sent from the computer and exegesis input from the sensors.

On other hand, there is a mixer or container for the dry mix that connected to a pipe where the water added to the dry mix, and under a certain pressure this material or the mix flows to the suspension system, at that point the 3D concrete printing start.

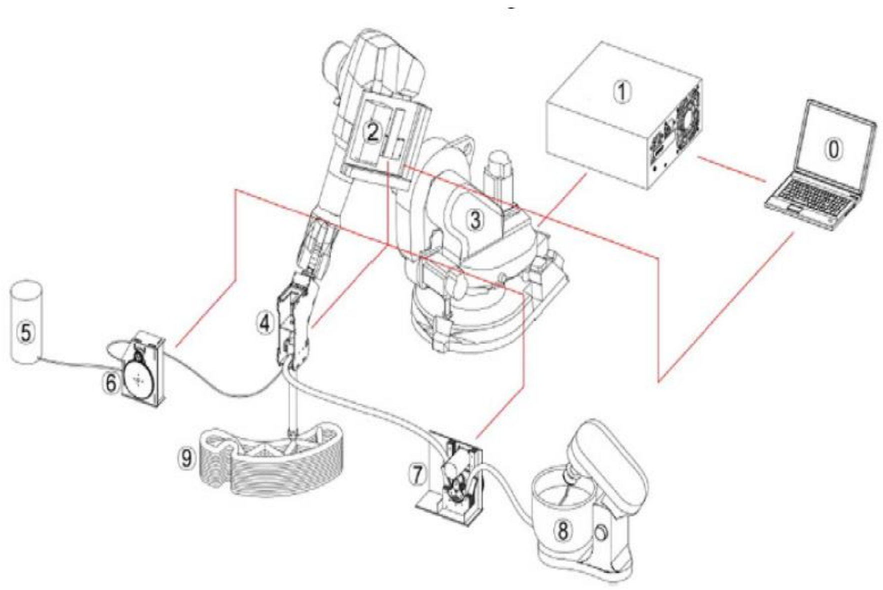


Figure 5 Schematic configuration of 3D printing| Source (A.R. Krishnaraja and K.V. Guru 2021)

The figure above shows the schematic order of the 3D printing system, that are as the follows by numbers:

0- The command device
1- The controller robot
2- The controller printing
3- The robotic arm
4- The printer heads
5- The agent accelerating
6- The peristatic accelerator pumps
7- The peristatic premix pumps
8- The mixer with premix
9- The printed 3D element

Figure 6 Robot machine of 3D concrete printing| Source (YouTube 2019)

Moving to the operation of a concrete 3D printer stages:

- Step 1 ⟹ Design stage.
- Step 2 ⟹ Test the path of the first layer to confirm the motion of the robot is correct based on the design.
- Step 3 ⟹ Filling the mixer or container with dry mix.
- Step 4 ⟹ Dialing in the mixer.
- Step 5 ⟹ Test the material consistency after the mix design.
- Step 6 ⟹ The moisture content measurement or test the water content.
- Step 7 ⟹ The back pressure, in this stage the concrete printer starts
- Step 8 ⟹ Monitoring the 3D concrete printer operation, to check if there is any problem in the mix deign like the moisture content that should be checked constantly, workability, and check every layer is in good condition, also control the speed of the robot.
- Step 9 ⟹ Addressing a clog, any clog happen in the robot pipe should be cured immediately.
- Step 10 ⟹ Install the reinforcement steel bars.
- Step 11 ⟹ Ending the print.
- Step 12 ⟹ Clean the machine and the robot immediately when the concrete fresh and wet, which make the cleaning stage easier.

Within the manufacturing processes in the industry, researchers find additive manufacturing. This technology is one in which automated machinery is used to generate three-dimensional models from a computerized model. This technology creates different layers by depositing a material that can be a solid, a liquid or a powder on a defined surface. Additive manufacturing emerged in the mid-1980s when Chuck Hill patented the system called stereolithography and founded his own company (Vaitkevičius, Šerelis and Kerševičius, 2018). It was not until the mid-90s when the first studies on the application of 3D printing in the construction industry began to emerge, where the incorporation of high-strength concretes was suggested. From this moment, the technologies that we find today in the market emerged. Additive manufacturing processes such as concrete printing follow very similar processes, although small differences are depending on the manufacturing method.

1. Creation and transformation of an STL file: This phase before printing the model and generally consists of the STL file using a specific program such as Rhinoceros or CATIA. Once the researcher has the model, the researcher goes on to the process of converting the surfaces into a triangular point cloud (Vaitkevičius, Šerelis and Kerševičius, 2018). Depending on the density of this triangulation, people will have a greater amount of data and a greater weight of the file, leading to a longer printing time.

2. Printing the element: In this phase, the model is sent to a 3D printer so that the element can be printed. The printing characteristics and its final finish depend on the technology used, which will be explained later (Kuzmenko et al., 2019). Depending on the technology used, this may be the final step.

3. Treatment and final finish: In this phase, all the operations are carried out to eliminate the supports of the piece, give the desired surface finish, eliminate excesses and even improve the final properties of the piece.

2.5.2. Parameters that effect 3-D Concrete Printing

A variety of conditions influence the printing process, as seen in (Fig. 7). Computer-aided design, printing method, and material behavior are the three primary categories. These categories have a large impact on one another.

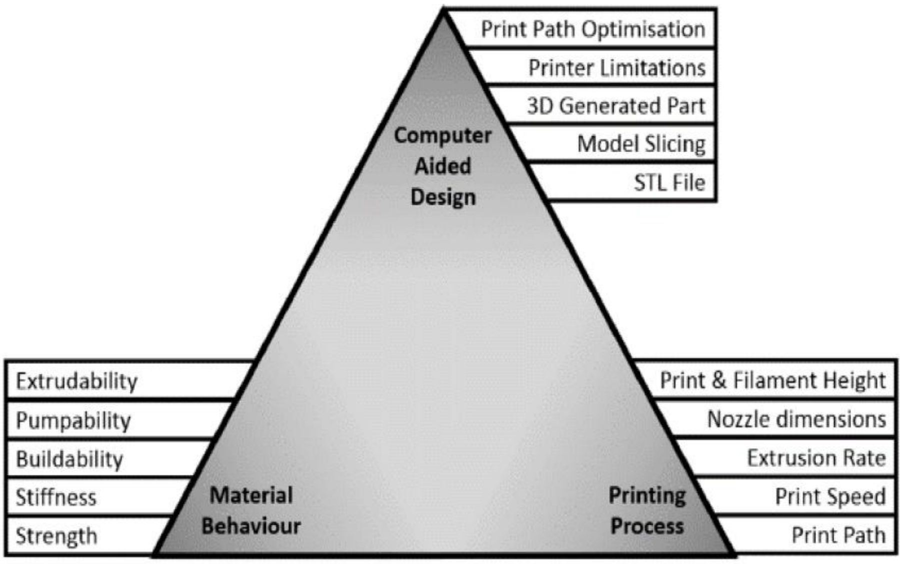


Figure 7 Parameters affecting concrete printing| Source (Ahmed Saleh /Engineering Research Journal 2019)

2.5.2.1. Computer-aided design for 3D printing:

As shown in the diagram, the usual workflow of concrete 3D printing begins with CAD modeling of the object to be made (Fig. 8). The CAD model is then converted to a standard 3D data format, often an STL file format. Before being fed into the printer, the STL file is sliced by software and transformed to a machine-readable language. The printer will next create the desired 3D item. It is critical to understand the physical process of 3D printing as well as its limits, which are not visible during the computer-aided design phase. For example, the design process should take into account the printer speed, nozzle size, layer thickness, material behavior, and the pump's extrusion capacity. (Hager et al., 2016)

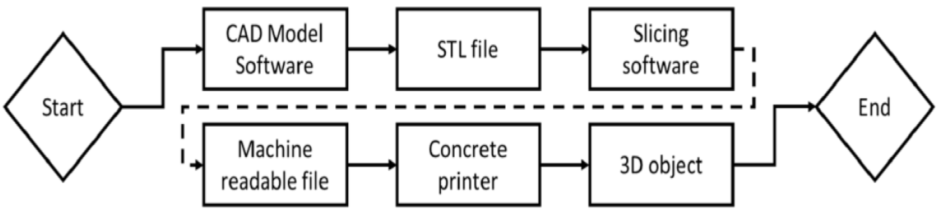


Figure 8 Modelling workflow of concrete 3D printing |Source (Ahmed Saleh /Engineering Research Journal 2019)

2.5.2.2. The printing processes:

A number of characteristics influence the physical printing process, including print speed, filament extrusion rate, nozzle size, printing route, filament height, and print height. The appropriate control of these factors has a strong correlation with the quality of the end product generated by the concrete printing process. (Wangler et al., 2016)

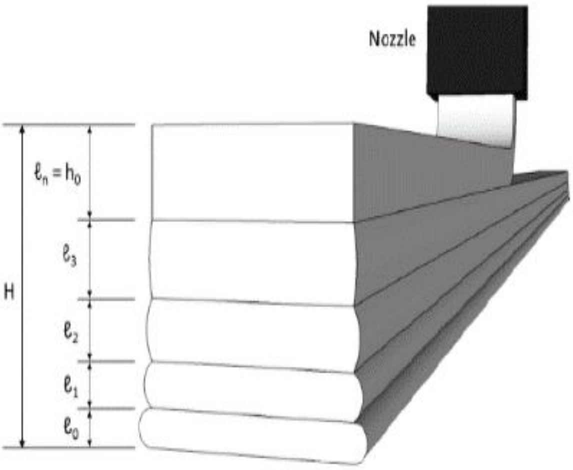


Figure 9 Filament height (h0), layer height (Ln) and print height (H)|Source (Ahmed Saleh /Engineering Research Journal 2019)

2.5.2.3. The material behavior:

The material behavior of printed concrete in its fresh condition affects its extrudability, buildability, pumpability, stiffness, and strength. (Fig. 11) depicts where these qualities are used throughout the concrete printing system. The behavior of fresh state materials is now a focus of concrete printing research. Several research report on a trial-and-error process for determining the best printed concrete mix composition. None, however, mention the usage of coarse aggregate in printed concrete. Particle sizes are typically confined to less than 2 mm. (Nithesh, n.d.)

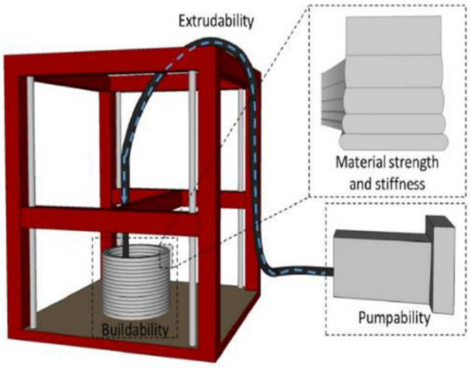


Figure 10 Material behavior affecting concrete printing |Source (Ahmed Saleh /Engineering Research Journal 2019)

2.6. Contour Crafting

This manufacturing technology is based on research by Manufacturing Engineering Graduate Program director and engineer Behrokh Khosnevis and its subsequent patent. These investigations tried to automate construction processes in the construction industry based on the rapid prototyping systems used in medicine (Sun et al., 2021). Contour crafting is based on "Layer by layer" manufacturing in layers to generate elements by computer and control their printing and manufacturing. This technology allows the creation of elements whose surface finishes can be flat or of any shape, while pallets can be designed to replicate it.

Figure 11 Offices in Dubai built by WinSun.

Figure 12 Housing built by WATG. Source: http://cort.as/-M59J

As it was mentioned earlier the contour crafting (CC) was introduced by Khoshnevis (1998), which eventually became an excellent way of producing 3D homes. CC is characterized as "an additive manufacturing process that combines computer control to harness toweling's excellent surface-forming power to generate smooth and precise planar and free-form surfaces." The concept of CC was to make a firm flat surface for exterior edges using two trowels. The extruded region can subsequently be filled with filler material, such as concrete. They demonstrated that CC may be used to construct structures such as the one seen in Figure 9, in which a nozzle is supported by a gantry system that travels in two parallel lanes. The nozzle has full 6-axis positioning capability and can extrude both sides and filler material. The CC nozzle may also be used to produce a paint-ready surface, to place reinforcement before pouring concrete, to plaster and tile, to plumbing, and to install electrical modules and communication line cabling. (Yossef & Chen, 2015)

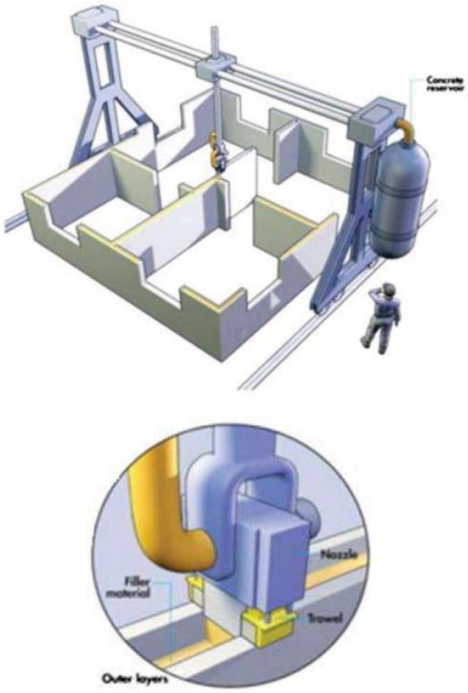
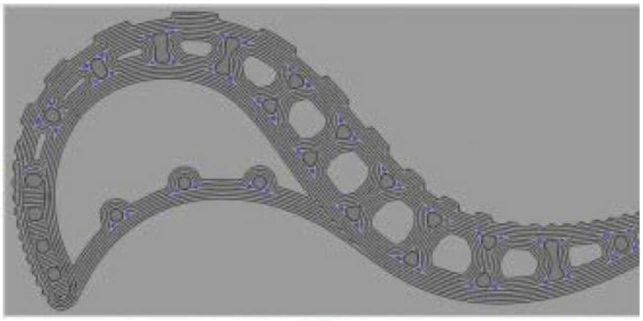


Figure 13 Schematic view of construction of conventional buildings using CC.| Source:Zhang and Khoshnevis 2013

Zhang and Khoshnevis (2013) created an optimal approach for CC machines to efficiently build complex large-scale structures. To minimize collisions between many nozzles, an extensive study was conducted. Path cycling, buffer zone path cycling, and auxiliary buffer zone were the three techniques that were compared. According to the data, path cycling and buffer zone cycling gave the best optimization. They determined that employing the CC

approach is substantially faster than traditional methods, and that climbing may be used to create multi-
story buildings, as illustrated in Figure 10 (A) the 3D model, (B) the model during printing. (Yossef & Chen, 2015)


(A)


(B)

Figure 14 Schematic view of construction of conventional buildings using CC.|Source: Yossef, Chen (2015)

2.6.1. Machinery:

The tool used for printing consists of an extrusion system complemented by two-directional blades that allow the creation of smooth surfaces on straight and curved elements (Salet et al., 2017). The complete system consists of the following elements: a hopper to store the material, an extruder nozzle, two pallets parallel to each other and computer to control the pallets.

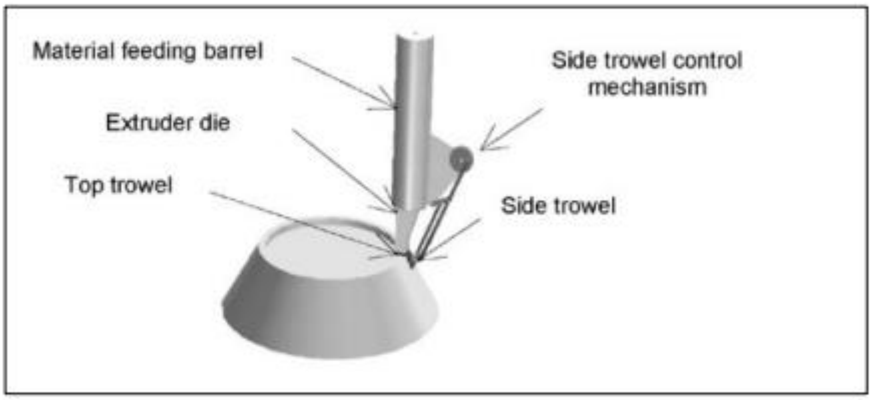


Figure 15 Scheme of the machine | Source: (Sun et al., 2021)

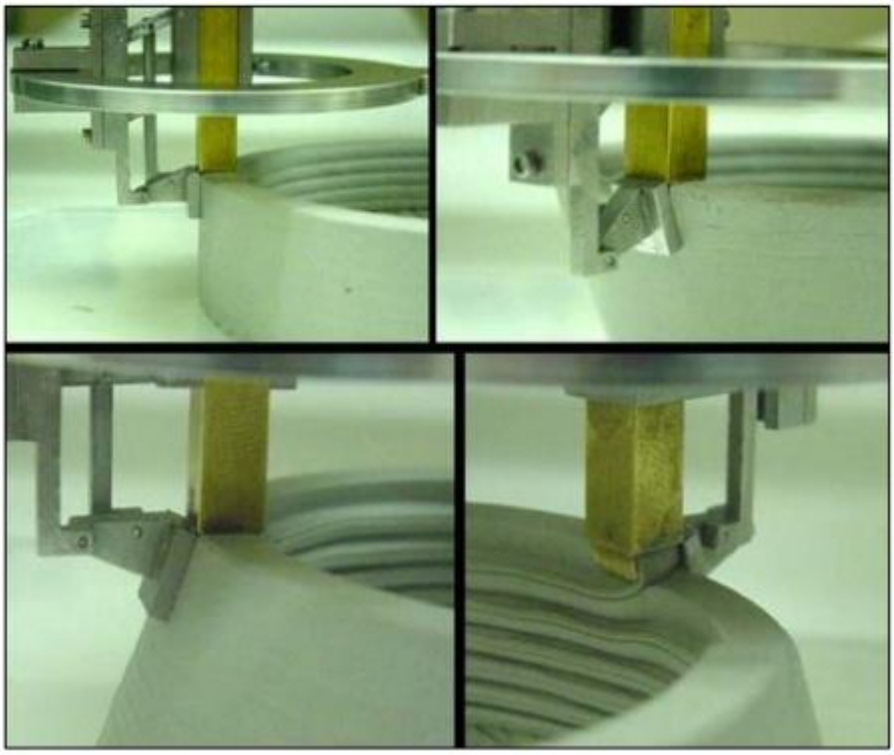


Figure 16 Detail images of the extrusion nozzle | Source: (Sun et al., 2021)

This configuration that is talked about is a scheme that can be adapted to the project's requirements (Nematollahi, Xia and Sanjayan, 2017). In large elements, the machinery can be coupled to a gantry system such as the one used by the Valencian company Bemore 3D. The gantry allows the extruder nozzle to move along the gantry while it is moving on rails.

Figure 17 Bemore3D printing system | Source: (Sun et al., 2021)

Another system used is based on the use of a nozzle hanging from a frame by cables. This type of system allows to increase the useful printing surface and at the same time facilitates the transport of the printer due to the lower weight of the system and a reduction in the cost of the printer.

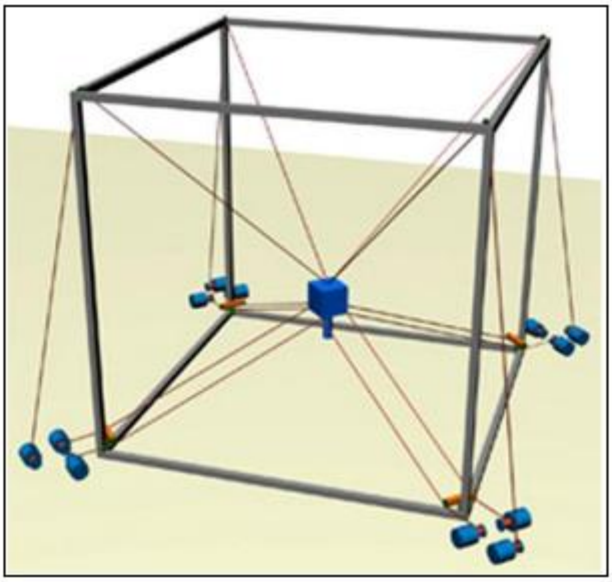


Figure 18 C^4 Robot | Source: (Sun et al., 2021)

For other needs, the machine can be incorporated into a telescopic arm that simulates the movements a human can perform thanks to the 6-axis system on which they are based. This type of machinery allows it to be relocated on the site where the building is being executed using a mobile crane such as the printer created by the Russian company Apis Cor House or it can be placed on caterpillars to increase the autonomy of the printer as it happens with the Cazza X1 robot (Lao, Li and Tjahjowidodo, 2021).

This approach to the use of robots that can move by themselves may lead to greater automation that would allow a greater number of teams that can simultaneously build the same project. One approach of this technology is the application in the creation of colonies on other planets due to creating structures without any auxiliary support and using materials located in the environment (Krause et al., 2018). Studies have demonstrated the viability of using synthesized regolith from the moon as a substitute for cement that allows the creation of buildings, as stated in the Space Solar Power organized by the USC. In 2019 NASA also organized a habitat challenge on Mars where the company AI Space Factory won the victory by printing a house with a basalt polymer found on Mars (Liu et al., 2021).

2.6.2. Process:

Contour crafting is a technology based on two independent processes that must come together.

1. Extrusion process: this consists of creating the outer edges of the building using the nozzle that had the two blades attached to it that help give a smooth finish (Ma, Wang and Ju, 2018). The orientation of these vanes allows the creation of sloped surfaces and even domes.

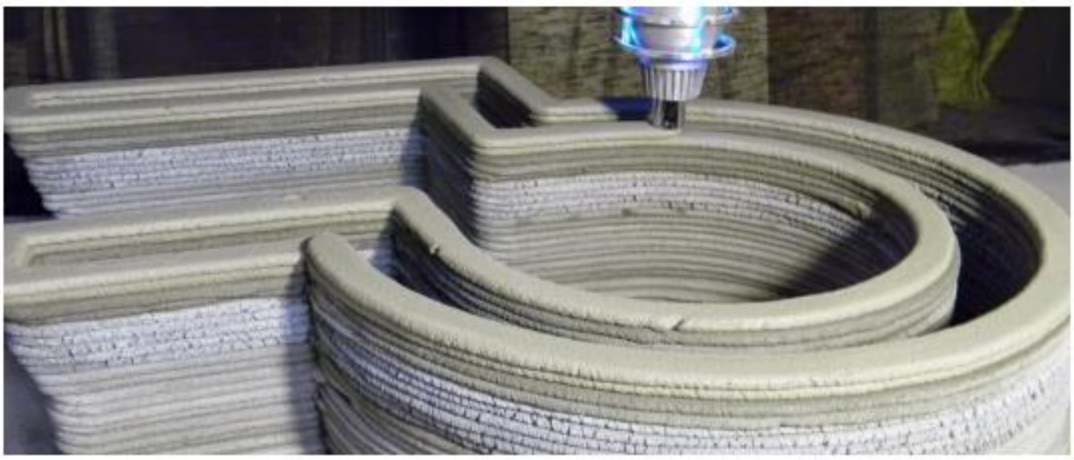


Figure 13 Extrusion of the outer edge of the wall | Source: (Sun et al., 2021)

2. Filling process: this consists of the creation of the core of the walls. This process is done after making each layer so that the material is poured into the edges. The fact that these are two independent processes allows them to be made of different materials, which can be

beneficial depending on the construction's climate (Yu, Du and Sanjayan, 2020). This is controlled by a computer that allows the dosage and quantity of concrete to be placed in each area to be varied.

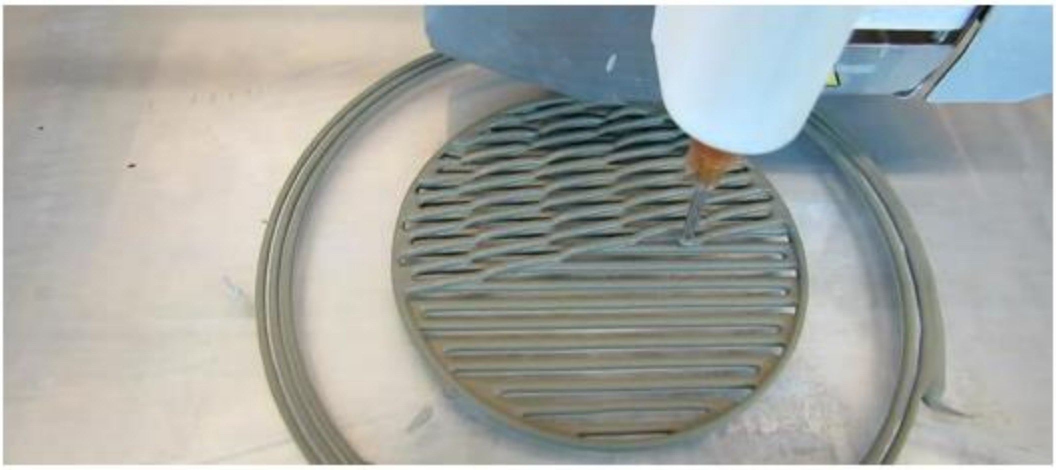


Figure 19 Element core filling | Source: (Sun et al., 2021)

2.6.2.1. Placement of Facilities:

The layer by layer system allows the automatic placement of installations within the wall itself. As for the electrical installation, modules of a non-conductive material are used that contain a conductive element. These modules have a tongue and groove system that allows a robot to position and join them. In addition, these modules can be created with a tongue and groove on one side to connect modules that have access from the walls, such as sockets or meters (Panda and Tan, 2018). In relation to plumbing installations, the way of acting is very similar to electrical installations; for each certain number of layers of concrete, a robotic system places a pipe next to another segment already installed. In the case of metal pipes, the robot that places the pipes has a ring attached that heats up, causing the pipe sections to be welded when activated, creating a watertight joint.

2.6.2.2. Construction of the Floors:

One of the current limitations is the creation of suspended horizontal elements, making it difficult to build flat floors and roofs. The proposed solution is based on collaborative sheet metal slabs (Lediga and Kruger, 2017). When creating a slab, the auxiliary machines on the construction site raise beams anchored by plates that serve as formwork. Once placed, a printer with a telescopic arm can pour the concrete and continue creating the plant.

2.6.2.3. Adhesion Between Layers:

One of the problems of this technology is based on its layer by layer construction since, a priori, it may seem that these layers cannot be joined, and the structure can collapse as a result. However, today there are two ways to deal with this problem. Reinforcement by using a robot, it is possible to place reinforcement between each layer. This method is based on a 3-piece modular system fed into the bottom layer, and then the printer places material on top (Rehman and Kim, 2021). This system also allows the creation of three-dimensional meshes to create thicker solid elements such as columns.

Reinforcement by fibers is the possibility of having nozzles of a relatively large size. During the printing of concrete, it can contain a greater quantity of fibers that allows the union of the different layers (Yu, Du and Sanjayan, 2020). The application of intermediate layers has been studied by researchers from the Swinburne University of Technology Taylor Marchment, Jay Sanjayan, and Ming Xia studied possible methods to reinforce the joints between layers using mortars (Rehman and Kim, 2021). The fundamental problem lies in one of the bases of stamped concrete, the rapid setting, which makes adhesion between the layers difficult. For the studies, a piston-driven extruder was used, and 50x30x30mm specimens were made, which were tested after seven days, obtaining a minimum value of mean compressive strength of 34MPa.

2.6.3. Applications:

Today, contour crafting technology allows a relatively simple application. There are several benefits to using contour crafting, such as reduced construction times and reduced material cost. It is these characteristics that have facilitated its use in these applications. Construction within a neighborhood in which there are different houses with different designs allows the automatic and continuous construction of the houses. Within this industry, contour crafting provides two advantages that make this technology be used optimally. Design flexibility is the process that allows architects to project unusual geometries that, with current techniques, would be very expensive and difficult to build (Rehman and Kim, 2021). Various materials can be used for both the external and internal parts, and this material can be printed, and a computer controls the quantity.

Low budget housing and public protection housing are currently the problem. The world population is growing at a very high rate, especially in underdeveloped countries where this growth cannot be financed. In these countries, the slums are the alternative to a population with very few resources (Anton et al., 2021). The construction speed of contour crafting would be a solution to allow this growth while maintaining healthy conditions. Emergency housing is the part of the population that suffers problems from wars and economic disasters, among others. In these cases, it is necessary to provide them with a home in the shortest possible period of time and contour crafting can provide good quality homes at a low cost.

2.7. D-Shape

This technology was developed in the mid-90s by a civil and mechanical engineer, Enrico Dini, whose family was always connected to the mathematical world. This technology allows the creation of elements of any shape or size from one or more pieces without molds. The main difference with the other technologies resides in the material used in the printing, in contrast to the printing of a pre-mixed material; in this technology, a dry mixture obtained naturally from the seawater desalination process is used, on which it is injected an inorganic catalyst that is non-toxic and has high tensile strength (Marchment and Sanjayan, 2020). The possibility of creating any shape that this technology provides makes up for the deficiencies of the materials found in the construction industry. These high-cost materials increase the complexity of works with organic shapes, requiring special formwork and scaffolding.

2.7.1. Machinery:

The original machine, made of aluminum, consists of a frame system consisting of 6-meter metal beams supported on 3-meter-high pillars on wheels, which achieves a printable surface of 5x5m. Each column contains an electric motor that allows the nozzle to be raised and extended up to 6 meters to increase the printable height. On this structure, another 6m double beam supports the last beam that contains the injectors. These are placed perpendicular to this beam with a separation of 20mm so that with each pass, the entire surface is covered. In addition, an 1800-liter hopper is used that allows the printer to operate independently for 12 cycles (Sanjayan, Nazari and Nematollahi, 2019). The mixture will be sucked from this hopper using a series of pumps. Finally, the control of the machine is carried out from a platform where an operator controls the controls. The advantage of this machine is that it is a modular system; therefore, it can be disassembled and transported to another place with an ease that allows the machine to be used on any parcel that a van can access.

2.7.2. Process:

The D-shape consists of a series of processes based on printing, cleaning and final finishing and is described below:

First is the introduction of the mixture into the hopper is the dry mixture introduced inside the hopper so that it is then sent to the injectors. The second is depositing the mixture layer through the nozzles move along the printing surface and deposit the mixture forming a smooth and homogeneous surface. The third is compaction, where rollers are passed over the mixture to compact the surface and prepare it for applying the binder material. Fourth is printing the binder where the nozzles placed next to the injectors inject the binder automatically, closing and opening according to the shape to be achieved (Sun et al., 2021). Fifth is the elimination of unconsolidated mixture: using a filtering system located under the printing surface, the excess mixture is sucked and returned to the hopper to be reused. Sixth is the cleaning of parts, and this process can be done by hand or by robots. Seventh is the possible polishing; a specialized operator can carry out this process to achieve a smooth finish. Eight is the possible treatment; this process can be carried out to improve the piece or make it waterproof. Last is the possible pre-assembly and assembly on-site; this phase is the most complex since improper handling of the parts can cause cracks or breakage (Nematollahi, Xia and Sanjayan, 2017). For this reason, it is necessary to make a preliminary study of the assembly and assembly of the pieces.

2.7.3. Applications:

As is has been observed, this technology allows engineers to create free shapes simply and allows them to create elements of an unlimited a priori size with fewer workers and in less time. For all this, the possible applications of this technology are very extensive: Interior design can be small-sized elements such as furniture, sculptures, false ceilings, etc. can be created.

First is the urban design that can be produced from small urban furniture such as benches to large sculptures such as Radiolaria. Second is the residential construction; the possibility of creating large structures allows the creation of low environmental impact homes such as the one created by Marco Cerina in Sardinia (Vaitkevičius, Šerelis and Kerševičius, 2018). Last is the construction of public and industrial buildings; this technique allows the creation of large assemblable structures. To this day, there is interest in Monolite UK to carry out publicly funded research.

2.7.4. Problematic:

Although the technology is highly studied, it still has certain problems mainly related to the material itself. Fragility is the composition of the dry mix; the final product is comparable to a rock that can have a brittle break without too much difficulty. Adhesion of the layers is also related to the resulting product; when hardening at high speed, it is possible that the layers do not adhere completely, which could lead to delamination of the element. This is why this type of process must be carried out in a very exhaustive way (Paul et al., 2018). Assembly is necessary to carry out a preliminary study on the type of anchoring and the handling process of the pieces because incorrect handling can break the pieces due to fragility and possible delamination caused by improper handling.

2.8. Concrete 3D Printing Technology Applications

Contrast printing is another current concrete 3D printing technology developed by the English research group "Rapid Manufacturing Research Group" at Loughborough University (Ji et al., 2019). This technology consists of a technique similar to contour crafting, differing from it in the composition of the cementitious material used and in the absence of blades in the extruder nozzle.

2.8.1. Residential:

Currently, a large part of the building printed in 3D has been carried out in this type of buildings mainly to investigate this technology, obtaining homes at a lower cost than similar homes built with current techniques (Hack et al., 2020).

2.8.2. Ephemeral Architecture and Emergency Housing

Today, housing modules can be built without a foundation, which can help provide humanitarian aid in the event of a disaster in short periods (Lao, Li and Tjahjowidodo, 2021). An example of this is the barracks created by the UK Navy.

2.8.3. Rehabilitation and Reconstruction:

The existence of 3D scanners and 3D modelling tools allow a monument in danger or with a high degradation to be recreated on a computer and totally or partially printed as has happened with the Palmyra arch that, after being destroyed by ISIS, has been replicated and placed in New York (Marchment and Sanjayan, 2020).

2.8.4. Bridges:

Another line of research has been the creation of bridges due to the high speed of current 3D printers (Rehman and Kim, 2021). This line of research has provided us with projects such as the cycling bridge in the Netherlands and the bridge in the Castilla-La Mancha park in Alcobendas conceived by the IAAC.

2.9. Evolution

As seen in the previous sections, engineers can print parts to assemble a set and generate foundations and walls with current technology. However, this does not constitute the entire building, and today the rest of the elements must be done through other processes. Today, it is impossible to create a house printed in 3D in one day, which suggests that it would be necessary to investigate to approach the idea of a house printed in one day (Anton et al., 2021). Technical Code is the same way a section for fiber-reinforced concrete was created; studies should also be carried out on printed concrete and its inclusion in the CTE.

Printing of several materials with the same machinery, all 3D construction printers currently use a single material, concrete and the like. But we know that buildings are made of various materials. That is why the future printers should be able to print with the most common materials in construction sites (Yu, Du and Sanjayan, 2020). Simplifying the software is done to achieve all that is exposed in this work; specific software of great complexity is necessary. In the current works, engineers find personnel who does not have the knowledge to use this software and is an important part of the construction process. This is why the software of the future must be easy for these people to use. Specialized machinery and automation of the work can be used with current technology, and some processes must be done manually (Ma, Wang and Ju, 2018). The 3D printing process brings automation that should be increased, having robots that can install windows and windows in the future.

2.10. Metals (MX3D)

Currently, metal 3D printing is used in many industries such as automotive and aerospace due to the possibility of creating metal parts of high complexity at a lower price than parts created with traditional methods such as machining. In the 1970s, the fusion of metallic powders began to be used through an energy source. The most representative technology is the so-called Direct Metal Laser Sintering or DMLS, patented in 1990. At the same time, in the 1990s, hybrid technologies were developed that made machining and additive manufacturing compatible (Sanjayan, Nazari and Nematollahi, 2019). Its operation is very similar to that of rapid prototyping and starts with creating a computerized model in a file. STL, which is broken down into a series of layers with built-in stiffeners. These layers are created by a cutting process such as micro-milling or laser cutting to be assembled into the final shape.

2.10.1. Shotcrete or Shotcrete:

Shotcrete, also known as "Shotcrete", is, according to the British Standards, mortar or concrete pneumatically sprayed at high speed on a surface. Traditionally it is a mixture of cement, aggregates and water projected through a nozzle to produce a dense and homogeneous mass on surfaces of different nature (Yu, Du and Sanjayan, 2020). The British Standards classify the mixtures projected into shotcrete and shotcrete. According to this standard, sprayed concrete is that whose maximum aggregate size is greater than 8 mm. At the same time, the maximum size of the sprayed mortar (also called gunite) can reach up to 8 mm, both being applied with a machine is projected at high speed over a surface through a hose and nozzle. To consolidate the mix, the surface can be reinforced with a steel mesh to the later project or add fibers to the mixes, which is called fiber-sprayed concrete or SFC (Sprayed Fiber Concrete).

2.10.1.1. Historical Review:

The origin of the projection technique, also called gunite in its beginnings, dates back to the late 19th and early 20th centuries. The place where this technique was developed is located in the north of the United States, in Pennsylvania, specifically in Allentown. In 1907, Carl E. Akeley invented the first shotcrete or the gunite machine, introducing it in 1910 at “The Cement Show” and with it in the construction market, when the patent was registered by the “Cement Gun Company”, with the name of gunite in 1911 (Yu, Du and Sanjayan, 2020). But two facts motivate the inventor to develop this new technology.

First, in 1895, Carl E. Akeley (a sculptor and naturalist at the American Museum of Natural History, Chicago) was looking to create models of prehistoric animals by applying mixtures of clays plasters and cement mortars over skeleton matrices to form animal figures. Secondly, the great interest of the population at that time in using concrete and cement construction methods (Ji et al., 2019). This first machine allowed, using compressed air, to pulverize the mixture, transporting the dry mixture (cement and sand) from a tank through a hose that ended with a nozzle, in which the water was incorporated. This method was called the dry route, and it was the method used until the development of the wet route (approximately in the middle of the 20th century). Image 3 shows an example of a traditional machine typical of that time.

The technique was widely accepted and developed due to its advantages, having a global reach in 1922, thus reaching Europe, specifically Germany. During the following decades (1920, 1930 and 1940), the projection technique was used in hundreds of works worldwide; in 1950, there were around 5000 unite machines distributed by 120 countries. Between 1939 and 1945, the Second World War broke out, which represented a period of crisis in all areas of life that lasted until approximately 1955-1960 (Lao, Li and Tjahjowidodo, 2021). From this moment (1955-1960), a new method of projecting emerged, the so-called wet route, which had great development and is currently the most widespread method in the world, as shown below the table. During the following decades, 1970, 1980 and 1990, the incorporation of new materials to the mix such as fibers, additives, entrapped air, etc. as well as the quality and capacity of the equipment, have driven the development of shotcrete to this day (Marchment and Sanjayan, 2020).

Table 1 Trends in the use of dry and wet routes in the different countries | Source: (Sun et al., 2021)

Country/region	Dry %	Wet %	m³/year	Tendency
Australasia	0	100	> 50,000	wet
Italy	0	100	700,000	wet
Scandinavia	0	100	250,000	wet
France	10	90	250,000	wet
Japan	10	90	2-3M	wet
Switzerland	10	90	300,000	wet
UK	10	90	> 50,000	wet
Asia/Pacific	20	80	> 1M	wet
Brazil	20	80	400,000	wet
Germany	20	80	500,000 to 1M	wet very recently
India/Nepal	20	80	300,000	wet (large projects)
Spain	20	80	300,000	wet
Greece	30	70	200,000	wet
Hong Kong	30	70	100,000	wet
Colombia	40	60	200,000	wet
Rest of Latin America	40	60	> 300,000	wet
China	60	40	> 1M	wet (large projects)
USA	70	30	500,000	wet
Austria	80	20	250,000	wet – slow change

2.10.1.2. Methods:

As described in the historical development of the projection technique, concrete can be projected by two procedures or ways: the dry and wet ways. According to British Standards, the dry way consists of mixing all the shotcrete components, except the water, which is incorporated into the outlet nozzle before launching the mixture. The transport of the mixture, without water only with that provided by the humidity of the aggregates, is carried out through special hoses pneumatically to the nozzle (Nematollahi, Xia and Sanjayan, 2017). On the other hand, the wet route is the procedure by which all the components of the sprayed concrete, including water except for the setting accelerator additives incorporated in the nozzle, are previously mixed before being incorporated into the hose.

They are transported by pumping to the nozzle where compressed air is applied to project the concrete. Until the 1990s, the dry way was the predominant procedure in the projection of concrete. Still, this has changed from that moment and due to the advantages, that the wet route presents over the dry one (lower percentage of rebound, less wear on the equipment, etc.). As described by Nematollahi, Xia and Sanjayan (2017), which dates from 2001, a large number of countries use between 70-100% of the wet route for their projects, observing a clear trend in the countries that use the dry route (in high percentages), to develop the wet procedure in the coming years.

2.10.1.3. Composition of the Mixture:

For the design and subsequent projection of the mixture, it is essential to control the quality and dosages of the materials, the water/cement ratio, the working conditions and the equipment used to ensure correct installation and control the porosity and rebound. The characteristics of the composition will vary depending on the projection route used. Still, in general, some general properties indicated by the regulations can be highlighted, such as the main components are generally cement, aggregates, additions (micro-silica) and additives (superplasticizers and setting accelerators) (Marchment and Sanjayan, 2020). A high amount of cement is used, which can be replaced by additions, usually micro-silica (in the percentage of substitution between 5% and 20%) to improve the properties of the mixture due to its pozzolanic character and to reduce the amount of cement with the consequent reduction of carbon footprint and cost.

As for aggregates, sizes less than 8 mm will be used for sprayed mortars and sizes of 12 and 16 mm for sprayed concrete. It must be taken into account that the larger the maximum size, the greater the rebound and the finer, the more retraction (Sun et al., 2021). The additives normally used are setting accelerators, which will depend on the type of cement used, the amount of water and the ambient temperature, using liquid or powder accelerators. Superplasticizers are also used depending on the Water / Cement ratio used. As previously mentioned, steel or fiber webs can be incorporated to reduce cracking and costs and increase safety, durability and flexural strength.

2.10.1.4. Applications:

The large number of advantages presented by the material broadens the range of applications. Some of these advantages are the no need for formwork and, consequently, the associated cost reduction, mobility and adaptability to all types of surfaces (vertical, horizontal, irregular and curved) and compatibility with structural steel elements (Lediga and Kruger, 2017). Thus, when the placement of formwork is unavoidable and impracticable due to the difficulty of access to the work area or when works must be carried out on-site, it is a good alternative to a conventional installation. The main applications of the projection technique are: first is the underground works, tunnels and mining. Second is the rehabilitation works for structural repair. The third is the fire protection in metallic elements, and last are other structures, such as swimming pools, walls, vaults and laminar structures (Yu, Du and Sanjayan, 2020). The regulation classifies sprayed concretes according to the applications for which it is used and according to the function of said concretes.

For this reason, it is possible to differentiate between conventional, refractory, with fibers and special sprayed concrete according to the applications for which it is used and type I, II and III sprayed concrete according to the function for which it is used. Despite all the advantages and applications already mentioned, some of the disadvantages that have arisen since the beginning of the development of the technique must also be taken into account (Lao, Li and Tjahjowidodo, 2021). The lack of standardization in the international instructions, the deficient quality control and the structural responsibility that some of the applications imply have posed a problem for the development of the projection. During the progress of the technique, carrying out tests indiscriminately for conventional and projected concrete, knowing the differences in the implementation, caused some inconveniences.

2.11. Special Concretes

As is known, concrete has very good compressive strength but poor tensile behaviour, this being the main drawback of the material. This fact justifies the emergence and development of some special materials, the result of combining two or more materials to obtain improvements in the final properties, that is, mixing materials of different nature, which, individually, have inferior mechanical, physical or Chemicals of which the composite material as a whole present (Hack et al., 2020). As a traditional example, the adobe material for the construction of houses can be highlighted, being a material composed of mud and straw, which presents better properties when combined, then said materials separately. Reinforced concrete is also a composite material, born during the nineteenth century when William Wilkinson and Joseph-Louis Lambot included iron reinforcement in concrete to improve the resistance of homes (Lediga and Kruger, 2017).

From that moment, and experiencing great advances during the 20th and 21st centuries, special concretes (concrete with fibers, with recycled aggregates, self-compacting and light, etc.) in the construction field have been increasing (Lao, Li and Tjahjowidodo, 2021). The incorporation of fibers of different nature in concrete mixtures has been a great advance because these fiber-reinforced concretes have revolutionized the market by reducing costs and acting structurally since the addition of fibers improves the characteristics of toughness, crack control and flexural strength. There are different and very varied fibers, although the latest Structural Concrete Instruction classifies them according to their nature into steel fibers, polymeric fibers, and inorganic fibers (Ma, Wang and Ju, 2018). The improvement of certain characteristics in concrete when incorporating fibers depends on some properties such as the type of fibers used and their geometric characteristics (length, equivalent diameter and slenderness), the volume of the incorporated fiber (in percentage) and the orientation of the fibers in the matrix, among others.

2.11.1. Very High-Performance Concrete with Fibers:

Very high-performance fiber-reinforced concrete, also called UHPFRC (Ultra-High-Performance Fiber Reinforced Concrete), is, according to AFGC, a material with a cementitious matrix that presents a characteristic compressive strength at 28 days of more than 150 MPa, being able to reach up to 250 MPa, which has high flexural strength and very ductile behavior (Panda and Tan, 2018). It is a product that arises from the sum or combination of three recent technologies used for concrete: self-compatibility, fibers of different dimensions and characteristics (in this case metallic) and high strengths.

2.11.1.1. Historical Review:

UHPFRC is an advanced, practically new cementitious material that is being developed, after several decades of research and generation of patents, in many places such as North America, Japan and Western Europe (Kloft et al., 2020). From that moment on, numerous joint investigations were carried out worldwide by universities and some companies such as BSI / CERACEM, DUCTAL, BCV and CEMTECmultiscale, which presented numerous patents with this material on the market.

2.11.1.2. Composition of the Mixture:

Despite the large number of existing dosages to create concrete with these characteristics, all of them have common aspects that can be considered generalities of the mixtures. All the materials used for these mixtures require exclusive and very careful raw materials in regarding the geometry and nature of the compounds. The main components of the mixtures are first cement, and they must be selected carefully. The cement of intermediate resistant class, Sulfate Resistant, are usually used to increase workability, reduce shrinkage and allow the evolution of resistance over time (Liu et al., 2021). A large amount of cement is used, which can be reduced by adding coarse aggregate (between 5 and 8 mm) and other additions such as silica fume or quartz flour that can also reduce the amount of cement and consequently the carbon footprint.

Second is small in diameter aggregates, normally with a maximum aggregate size of less than 0.8 mm, all of which have high resistance. As already explained, coarse aggregates (between 5 and 8 mm) can also be used to reduce the amount of cement. The third is the additions such as silica fume and quartz flour to achieve maximum compactness by acting as a fine fraction of the composition, also reducing the amount of cement (Nematollahi, Xia and Sanjayan, 2017). Fourth is the metallic fibers to provide flexibility, reduce brittleness, and control cracking. The nature, size, slenderness, volume and other characteristics will depend on the type of response expected. Normally, to control the appearance of the first cracks, short and slender fibers are used, while long fibers are used to guarantee flexibility in the event of high deformations. Another important aspect is the water / cementing material ratio, which is usually low, between 0.15 and 0.25, to reduce the number of capillary pores and avoid the transport of gases and liquids that attack the concrete (Marchment and Sanjayan, 2020). Therefore, plasticizer additives can also be used to improve the workability of mixtures.

2.11.1.3. Applications:

The large number of advantages that the material presents, compared to some disadvantages that currently exist, have meant that since the 1990s, this type of composite material has been used for different applications. The main applications are developed in civil and structural engineering, as well as in the architectural and rehabilitation field, with the construction of elements such as walkways, beams, roofs, etc. The wide range of possibilities and applications that the material presents are due to its advantages (Krause et al., 2018). Advantages such as high compressive strength and good tensile strength provided fibers are incorporated, and their characteristics are studied during incorporation. The possibility of incorporating fibres to reduce brittleness and control cracking and the self-compacting capacity increases the durability of the structures, reducing costs associated with maintenance.

The fineness of the materials used, which reduces porosity and helps increase durability, is already mentioned, giving the element aesthetic value in the finishes. It also makes it possible to build slenderer structures, reducing the volume of concrete and associated costs. Incorporating some additions reduces the amount of cement, improving global sustainability

(Marchment and Sanjayan, 2020). But, despite all these advantages and benefits that it presents, it is a material that requires exclusive and high-quality raw materials (fibers with a high elastic limit, aggregates with high resistance, very specific superplasticizers, etc.), processes and non-conventional machinery, with very specific means of implementation and above all with very specific quality control. Furthermore, and as explained below, there are no unified normative criteria on the material.

2.12. 3D Concrete Printing in Architectural Engineering

The use of 3D printers to create architectural models has emerged as a viable option. The most common materials used to construct architectural models are cardboard, wood, and easily molded materials. Models are essential for architects while refining their concepts. In both architectural and interior design, it is frequently altered to get the desired effect. In the domestic, commercial, industrial, and public sectors, 3D printing on a building scale will have numerous uses. Faster construction, lower labour costs, improved complexity and the accuracy, greater function integration, and reduced waste are some of the potential benefits of these new technologies (Yu et al., 2020) Existing methods include building and construction component fabrication on-site and off-site, gantry systems, industrial robots, and self-tethered vehicles. For example, in situations where a human workforce would be unsuitable, such as those with special needs, it could make it possible to build without a human staff.

The architecture sector is frequently seen as a traditional one. One explanation is that most building tasks, such as bending steel, machining and nailing formwork, and pouring concrete, are done by hand. The majority of construction costs are made up of materials and labor. Labor costs approximately 25% to 35% of the total cost of a residential building project, with materials accounting for the remainder. Given that the profit on an architecture project ranges from 10% to 20% of the entire cost, the labor-intensive nature of the sector makes lowering construction costs difficult, hence lowering the profit margin. (Ko, 2021)

Construction is one of the most dangerous jobs, according to the Occupational Safety and Health Act (OSHA). Objects are created layer by layer in 3D printing. The additive technique (such as toolpath) and material parameters consequently have an impact on printing output (such as tensile strength and slump). Despite the fact that numerous researches have been conducted to enhance AMoC, the majority of them have concentrated on the manufacturing process. However, for AMoC to be used successfully in architecture, the potential limits and limitations of concrete 3D printing must be considered. So far, research on the possible problems of using AMoC in architecture from the standpoint of the construction lifecycle has been limited. The art and practice of planning and constructing structures might be characterized as architecture. The purpose of this study is to examine the limits and limitations that must be addressed while employing concrete 3D printing technology in structures. Buildings and building components are hence the focus of explanation and examples. The investigation is carried out using a descriptive research technique. AMoC is introduced first, followed by the challenges it may face. The strategies utilized to overcome the difficulties are outlined. Finally, the conclusions of the investigation and future research directions are reported. (Nerella et al., 2019)

3D printing architectural models has emerged as an intriguing alternative. Architectural models are often formed of cardboard, wood, or other moldable materials. Architects require models in order to explore many parts of their designs. It is frequently altered in both architectural design and interior design to get a flawless notion of their vision. (Saleh & Elfatah, 2019)

3DP is increasingly being employed in a variety of applications. Architectural modeling is one of the key areas where 3DP is used to create prototypes that aid in communication between the architect and the client. Architects may now print complicated buildings and color them for better representation. (Gibson, 2002)

2.12.1. printed interior design and structures:

No company manufactures entire houses because they are made up of numerous components like the foundation, walls, ceiling, windows and doors, and plumbing and electrical wiring. It's possible to print complete buildings from scratch using 3D printing in the construction business. Still, until now, the printer has only been used to print the walls of buildings, not participate in other processes. Researchers firmly believe that construction using 3D printing technology will substantially replace current methods (Krause et al., 2018). The most endangered building style is traditional stone construction using blocks and bricks. Cement and sand are also utilized in the printing process; therefore, a printed house is different from a concrete one. To lay down the material, the printer is all that is required. It's only a machine or robot now, an automated system that doesn't require human intervention (Classen Ungermann and Sharma, 2020). As a result, there's no reason to be concerned about printed houses losing their appearance over time.

Many architects and interior designers are turning to 3D printing and other cutting-edge technologies to create a truly modern and cosmopolitan ambience. Designers are no longer restricted by technological constraints for any object thanks to increased design flexibilities in 3D printing. They use salt polymer-based organic 3D-printed containers for the interior and polymer-printed blocks for the external cladding (Rehman and Kim, 2021). Through additive manufacturing, designers have the freedom to express their ideas in ways that were previously impossible using traditional manufacturing methods. Spain has the world's first 3D-printed pedestrian bridge. D-Shape produced the 3D printer utilized to construct the footbridge. The complexity of nature's forms is reflected in the 3D printed bridge.

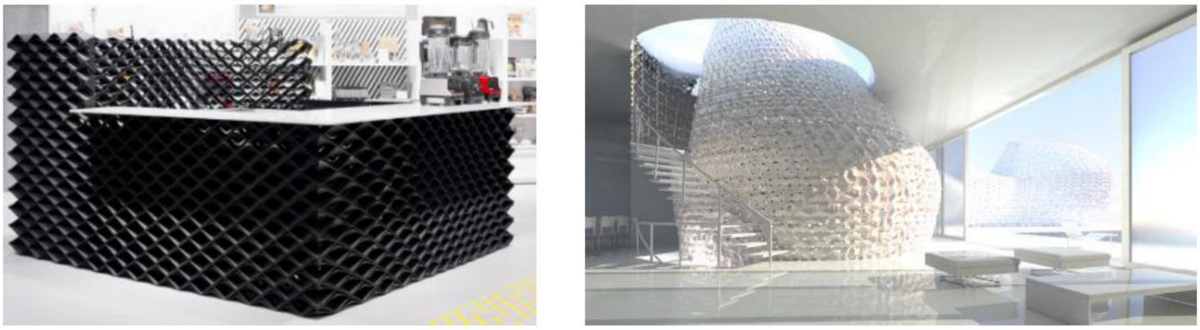


Figure 20 Interior space made of 3d printed mixture obtained by salt and glue | Source: (www.archdaily.com)

2.13. 3-D Concrete Printing in Structural Engineering

It is possible to manufacture efficient structural shapes for individual components by using 3D printing in construction, which helps to maximize the potential of a material, decrease waste, and save money in terms of both time and overall cost. Building information modelling (BIM) and 3D printing integration could greatly reduce the time needed to complete construction projects. Even while metal printing for small components has improved dramatically over the last ten years, the technology is still not ready for structural engineering projects of any kind (Serelis et al., 2018). Researchers believe that 3D printing cementitious materials, such as fiber reinforced concrete and reinforced concrete, presents new technological hurdles; major research is currently being conducted in this area. Using the Material Deposition Method (MDM) and cement-based paste against a trowel, contour crafting has lately been utilized to demonstrate a variety of fascinating projects. It is projected to be used for constructing real-scale buildings in the near future. By injecting liquid binder over a powder bed one layer at a time, binder jetting is another 3D printing method for cementitious materials. When the build chamber is finished, a thin layer of powder material is distributed on top of it, and a binder is ejected on top of it as droplets (Hou et al., 2021). During construction, any unglued raw materials are employed to support the next phase of construction. After printing, the unbound material can be vacuumed off the print bed and recycled or used again for another printing activity. Design gaps and overhanging elements are possible with this technique, enabling the printing of intricate shapes. Because of the short distance between layers and the high resolution, it produces a high-quality surface finish. Two companies are now using this technology to print large-scale components for the architectural and construction industries: Voxeljet and Monolite UK Ltd (D-Shape).

Robotics was the first form of automation used in the construction sector. According to(Bai et al., 2021), a survey of construction RM technologies led to creating a new construction method called Freeform Construction. Freeform Construction is a phrase used to describe processes that use additive manufacturing (AM) to create large-scale construction components without formworks (Hou et al., 2021). They concluded that Freeform Construction might save construction costs while still allowing for selecting desired geometries and providing greater performance than the old way. Low-income families may benefit from 3D printed houses because they are affordable and energy-efficient. The 3D-printed houses are made up of various printed components that are then put together to make the final structure. One house can be built in less than 24 hours and one of the primary problems with 3D printed houses has been solved because the buildings were fully compliant with key national regulations. 3DP can also be employed for constructions that aren't typically built that way (Weger et al., n.d.). DUS, an architectural firm in the Netherlands used 3DP to design solar-panel-integrated facades that could automatically adjust the solar panel's inclination for any given site.

As previously said, 3DP enables mass production while using less labour, speeding up the building, and generating less waste. In civil engineering, a layered structure, such as 3D printing, is nothing new. For the most part, the concrete masonry units (CMUs) are erected one at a time and then mortared together. Three-dimensionally printed structures have better structural stability than conventionally manufactured ones. Structures made with 3-D printing should be able to outperform those made with CMU milling machines. To now, the printer has only been able to print a 5-story residential complex as tall as it appears on the drawing. Multiple challenges have been identified by (Hanna et al., n.d.) as slowing the expansion of the construction automation business.

As previously said, 3DP enables for mass manufacturing, utilizes less labor, accelerates building, and generates less waste than traditional construction processes. 3D printed structures are layered structures, which are not uncommon in civil engineering. A Concrete Masonry Unit (CMU) structure is a typical layered construction in which the CMU units are put in sections and mortared together. The integrity of a 3D printed structure is superior to that of a CMU construction. As a result, 3D printed structures should be able to outperform CMU structures in terms of height. However, the highest building produced thus far was a 5-story residential complex. (Khoshnevis, 2004) and (Buswell et al., 2007) identified a number of challenges that impeded the expansion of the construction automation business. Which summarized as the following:

- Automated fabrication is frequently unsuitable for large-scale items, and traditional design processes are ineffective.
- In compared to other industries, there is a lower proportion of automated items.
- Automated machinery can only consume a certain amount of material.
- Expensive automated machines are usually economically impractical.
- management challenges, as well as rising environmental pressures on building materials in emerging nations. (Yossef & Chen, 2015)

Figure 21 A 3D concrete printed five-story apartment block| Source: Charron (2015)

Not to be outdone, Dubai launch the world's largest 3D printed structure, a 6,900 square-foot administrative facility for the Dubai Municipality, in early 2020. When it comes to building, Dubai has always been known to strive for the impossible. After all, Dubai is already home to the world's tallest structure, the Burj Khalifa, which rises over the desert terrain at more than half a mile in height. According to SingularityHub, Dubai partnered on the municipal construction project with Boston-based Apis Cor, the business recognized for producing a 3D printed house in Russia in less than 24 hours. The construction of the building is similar to that of a normal building in that it is composed of precast concrete and reinforced with rebar and concrete. After the building was completed, contractors were called in to add finishing touches like windows and a roof.

The city-state of Dubai has big aspirations for 3D printing technology. It hopes to use the approach to construct up to one-quarter of all new structures by 2030. According to SingularityHub, it is part of the government's effort to cut construction costs and time. (JOHN BIGGS, 2021)

Figure 22 Municipal Building, Dubai, United Arab Emirates| Source: Apis cor (2020)

2.14. 3-D Concrete Printing in Construction Engineering

The construction industry is one of the hugest industries that can control the global economies, the money spend in this industry is more than 10 trillion dollars globally, which is equal to 13% of the GDP (). Nevertheless, the construction has shown an uncommonly poor productivity gaining with comparative to other sectors. By taking these conditions into account, in the near future the global construction of infrastructure and housing structure will not meet the development of the global demand, and that refer to the time-lag.

Since the 19^{th} century, many of the scientists and researchers pursue to automate construction of the concrete, but many of these attempts and researches was not very successful. Thomas Edison's attempt to create a machine that build a concrete house with a single cast. And he has patented in 1917, but unfortunately, he faced many difficult challenges due to complexity of the concrete itself, so it was documented failure. It is said that, the great investor Thomas

Edison, hey spend much time with his concrete house project, but the complexity of the concrete at that time eluded him, as a construction material the concrete always shows it's a simple material but in fact and deeply there are many hidden challenges and difficulties. Although, many achievements were recorded in construction of the concrete, such as pumping technology, admixtures technology, transportation of the concrete, placing, compacting, vibration, and curing. All of these basic important techniques were discovered more than 100 years ago but still used today.

Figure 23 Thomas Edison with his single cured concrete house project | Source (3D concrete printing book 2019)

The concrete production and construction stages needs more labour work, costly, also highly accident-prone, the production of the concrete yearly is 30 billion tons nearly in the world wide, which makes it the most widely used material in the construction sector. Furthermore, the concrete itself plays a secondary role in the construction industry, and that's refer to formwork. The formwork represents around 35% to 65% of the concrete construction cost. But what is the formwork? It's basically a temporary mold that is made and customized for each and every structure and its usually made from timber, in that mold we can cure the concrete for each structure part, for example the beam and column and slabs all the different molds with different sizes and shapes, so this timber molds represent a significant source of waste because all these molds will be disposed sooner or later. And that's contribute the increasing of wastage amount from the construction industry worldwide.

According to one study that was done in 2011 () 80% from the total amount of waste globally is generated from the construction projects, and most of these wastes is the formwork, and the formwork waste it's a type of waste that cannot recycled easily, so it causes an environmental contamination. On top of that, in general the formwork can limit the creativity of the architecture engineers to build a various geometry that need an open space to think of it.

When a compression happens between the conventional construction process and the 3D concrete printing technology, a clear advantages 3DCP offers including:

1- A clear reduction in the construction cost because of eliminates formwork.
2- A clear reduction in the rate of labour dangerous work (working from heights), which increase the level of safety in the construction sites.
3- Creation of opportunities of high-end jobs that based on digital technology.
4- A clear reduction in the construction period by operating at the same constant rate
5- Decreases the chance of errors, that may cause a wastage of materials and time.
6- Increases sustainability by decreasing the wastage that cannot be recycled like formwork.
7- Increases the architectural freedom to enable more sophisticated designs.
8- Enable the multifunctional protentional of architectural and structural elements by utilizing complex geometry (47,48)

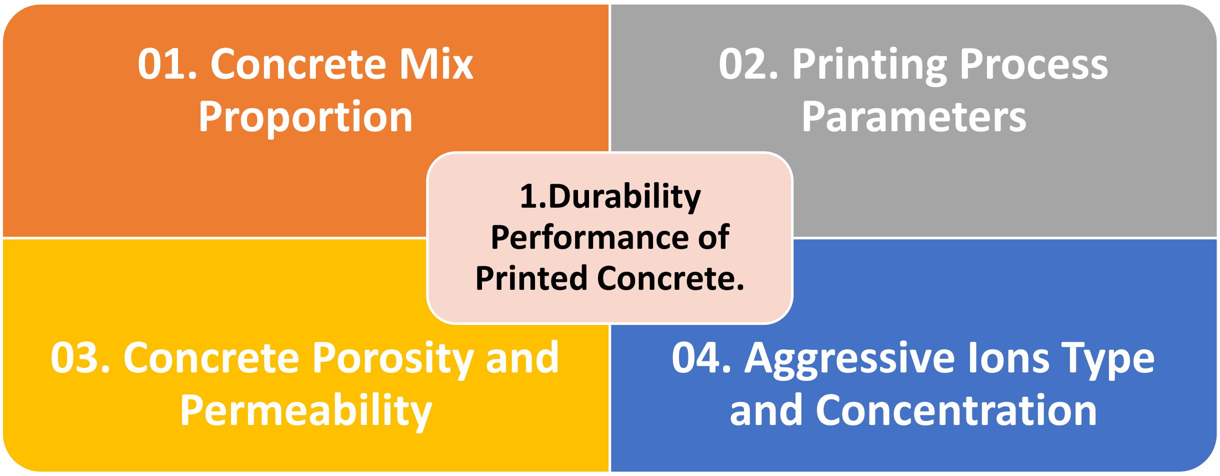
Using a layer-by-layer material deposition method, 3D printing can create various complicated shapes and geometries without the necessity of formwork. For now, 3D-printed construction can address issues and challenges; because of this, it can be employed in more sophisticated structural applications where strength and density are more important considerations (Hack et al., 2020). Three-dimensional printing has been called a game-changer by one study and disruptive technology by another because it outperforms traditional construction methods by order of magnitude. Several factors contribute to innovation failures, including a lack of stakeholder involvement and high initial innovation costs, a lack of risk finance, the natural conservatism of organizations, and the early non-profitability of new ideas. 3D printing and hybrid additive/subtractive manufacturing offer the construction sector many advantages, such as enhanced flexibility and lower operating costs due to their innovative nature (Salet et al., 2017). However, prior innovation experiences should be studied and used to boost the success potential of 3D printing in the building business and contour crafting is discussed in 2.9.

2.14.1. Drivers and barriers in construction for 3D printing:

The extensive customizing possibilities are one of the factors supporting the application of 3D printing in construction. Other intriguing possibilities include reducing waste and lowering one's carbon footprint. It is possible to save money by reducing the amount of labour required due to increased automation. The use of 3D printing and other forms of automation in difficult situations can lessen the risk to human workers (Ji et al., 2019). The capacity to quickly deploy 3D printers is another benefit. Uncertainty about the demand for mass customization and the availability of high-strength printing materials are potential hurdles. According to the research, it's also uncertain if 3D printing will lower or raise construction costs. A multi-story skyscraper cannot be printed in one go due to the current 3D printers' size restrictions. Rather than printing an entire structure, users can print individual structural components and combine them into a full-scale model (Liu et al., 2021). Digital objects (such as a digital file describing the construction of a certain structure) have prompted concerns about intellectual property rights because they are easy to copy and resell. There are also dangers associated with cyber security.

2.15. Durability Performance of Printed Concrete.

Additional research is needed to determine the durability performance of printed concrete under harsh environmental conditions. Because of the use of varied mix proportions, high dosages of chemical admixtures, and layer-by-layer production processes, the durability behavior of 3D-printed concrete would differ from that of traditional concrete. Figure 15 depicts the four key important characteristics that dictate the durability behavior of printed concrete (mix design, printing process parameters, transport qualities of hardened printed concrete, and surrounding environment of printed concrete at the site). Binder type, water-binder ratio, binder-aggregate ratio, and the dosage of chemical admixtures such as superplasticizers, retarders, and viscosity modifying admixtures form the material component of printed concrete, which must retain its integrity under harsh environmental conditions. Pore size distribution, pore connectivity, bulk layer porosity, vertical and horizontal interfaces, and concrete permeability define the rate of hostile ion ingress inside the printed concrete, and these properties are affected by printing process parameters such as nozzle height, printing time gap, and printing speed. The exposure environment at the site of printed concrete, such as sulfate, chloride, carbonation, or leaching assault circumstances, specifies the degradation process and its impact on mechanical and microstructural qualities. Future studies should assess durability performance in relation to these four characteristics. (Ur Rehman & Kim, 2021)



2.16. 3-D Concrete Printing Technology Materials and Methods.

The interdependence of the design, material, process and final qualities is a significant feature of 3D printing of concrete. Concrete setting response influences printing speed, pump pressure, filament stacking, and other parameters. (Wolfs et al., 2018)

A crucial point concerning the use of this new technology is whether existing regulation is an impediment to its adoption. The simple answer is no. Legislation should not be an impediment, even though some aspects may be perceived as such in reality. The UK National Strategy for Additive Manufacturing undertook a study of a diverse range of business and public sector organizations to determine the elements most often seen as impediments to 3D printing (Ortega et al., 2020). These barriers include:

- the availability, standardization, and certification of printing materials;
- proper or suitable design methods to overcome the constraints on AM;
- a scarcity of competent and trained 3D-printing operators;
- a costly initial investment compared to other means of manufacturing; and
- existing regulation and the lack of a complete set of standards for 3D printing, with certification and standardization seen as critical factors.

2.16.1. The 3-D printing materials:

In additive manufacturing, two types of cement- based, concrete- based, or mortar- based materials are used: those designed specifically for a certain project and those that were previously accessible on the market. Regardless of where they come from, these materials must fulfill the following technical requirements: (Jayathilakage et al., 2020)

- They must be printable; that is, they must retain fresh-state workability for as long as necessary in order to be readily pumped.
- Simultaneously, upon extrusion, the materials must be sufficiently rigid to hold their shape under their own weight, either by fast setting or as a result of their thixotropy.
- They must gain strength quickly in order to sustain the weight of the successive layers used during printing.
- They must not solidify too quickly; yet, cohesiveness between successive layers can be ensured only if both the bottom and top layers are fresh
- Their mechanical strength must be appropriate for the intended usage.

Figure 24 Vertical printing test with material Vertical printing test with material developed | Source (3D concrete building 2020)

2.16.2. The workflow design:

New forms are required as part of the overall process to fulfill the particular needs of the materialization process of overlapping additive layers, as well as to make use of the special material and process features. The link between form and function, a fundamental conundrum in architectural design, is even more essential for 3D printing, as the geometric volume must fulfill the purpose of the component or item and must be manufactured using new technologies that are constantly evolving.

Furthermore, materials can determine form because it is strongly related to their technical capabilities, and they may even have special configurations that can change during the deposition process, as a changeable admixture or even mechanical hardening of concrete in the mix recipient or lower layers. As a result, variables such as the angle between layers, the broadening of line manufacturing from the extruder, the end diameter, and the thickness of the extruder are all connected to an impact design. Table 4 depicts the overall link between design, materials, and machines. (Le et al., 2017)

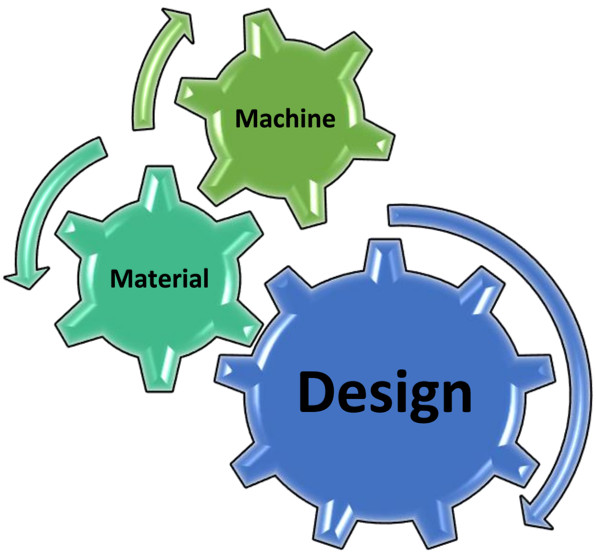


Figure 25 Relationship of design, materials and machines| Source (3D concrete building 2020)

Parametric design is vital in this process because it allows designers to easily personalize designs for diverse settings, demands, material capacities, or simply aesthetic appeal by parametrizing the values of geometric elements.

2.16.3. The 3-D concrete printing product:

Because of the multilayer printing process, 3D printing has a slower build time than cast-based production. The decrease in construction time is proportional to the complexity of the build. The thickness of the layers affects the printing resolution and amount of detail.

Accelerating the printing process can reduce the amount of detail in the printed product. (Lim et al., 2011)

Depending on the intended usage, different sorts of components are subject to varying criteria. Other restrictions are imposed by the formal and functional design of the item to be printed, such as its geometry (thickness, height, and maximum dimensions), equipment and process parameters (extruder diameter and maximum aggregate size), and component material properties (fluidity, thixotropy, temperature, density, setting times and so on).

CHAPTER THREE

3. METHODOLOGY

3.1. Preliminary Consideration

The manner a study is carried out is largely determined by the researchers' research philosophy, the research strategy employed, and the research instruments employed in pursuit of a certain purpose, which in this case refers to the research objectives. The methodology that will be followed in the research is discussed in this chapter. The research philosophy, methodology of the study, study design, data collecting, interview techniques, and data analysis are all covered in this section.

This research paper aims are to gain a knowledge about the 3-Dimantional concrete printing technology and its impact on the engineering field in general, the investigation that was done in chapter two approves many effective and critical factors about the 3D concrete printing technology. Additionally, in this chapter survey research is required, in order to get a target participates opinion in this technology.

3.2. Research Philosophy

Research philosophical paradigms are systems of ideas and practices that govern inquiry within a discipline by offering lenses, frameworks, and methods for research (Edwards & Steven, 2008). The research philosophy guides the viewpoint from which researchers frame research questions, determine how problems might be examined, choose research designs, and specify what methodologies are utilized and how data is gathered, processed, and evaluated (Edwards & Steven, 2008). As a result, before beginning any study, nurse researchers should understand the paradigm since this will allow them to frame their inquiry and choose the best research technique.

Every stage of the research process is predicated on assumptions about the sources and nature of the information. The author's major assumptions will be represented in the research philosophy, which will serve as a foundation for the study strategy. In general, research philosophy has various branches that are connected to a variety of fields. Interpretivism, also known as interpretivism, involves researchers evaluating study components; hence, interpretivism includes human involvement in a study. As a result, interpretive scholars think that access to reality (given or socially created) is only possible through social creations like language, awareness, shared meanings, and tools. The critique of positivism in the social sciences serves as the foundation for the establishment of interpretivism philosophy. As a result, this mindset prioritizes qualitative over quantitative analysis (Myers, 2008).

Interpretivism is related to the philosophical perspective of idealism, and it is used to combine together several approaches, such as social constructivism, phenomenology, and hermeneutics; methods that reject the objectivist concept that meaning exists in the world independently of consciousness. According to the interpretive method, it is critical for the researcher to comprehend distinctions between persons as social actors. Furthermore, interpretivism researches focus primarily on meaning and may apply many methodologies to represent various facets of the topic (Collins, 2010).

The main disadvantages of interpretivism are related to the subjective character of this technique and the large space for bias on the part of the researcher. Because primary data from interpretive research is strongly influenced by personal viewpoints and values, it cannot be generalized. As a result, data reliability and representativeness are jeopardized to some level. On the plus side, because of the acceptance of interpretivism, qualitative research fields such as cross-cultural differences in companies, questions of ethics, leadership, and study of variables influencing leadership, among others, have been expanded (Saunders et al., 2012).

The belief about how data regarding a phenomenon should be gathered, processed, and used is referred to as research philosophy. It is the main belief system that leads research and determines the approach to be followed in the investigation. Epistemology, ontology, and axiology are the three major parts of research philosophy. Phenomenology is a well-known term, especially in the sphere of study and research. (Scotland, 2012)

According to Scotland (2012), epistemology is concerned with what constitutes acceptable knowledge in a certain field of study. In other words, it refers to what is recognized to be true, as opposed to what is thought to be true, as in the term doxology. The term "ontology" refers to the study of social beings (Scotland, 2012). Its main focus is on the nature of reality, which includes both subjectivism and objectivism. The third significant part of research philosophy is axiology, which is one of the areas of philosophy that studies value judgments. There are four types of research philosophies: positivist, interpretivism, realism, and postmodernism, in addition to pragmatism. (Frowe, 2001) Positivist paradigm, often defined as scientific philosophy, is based on the idea that reality is constantly steady and that it can only be defined and evaluated objectively.

According to (Kura et al., n.d.) this theory holds that reality may be changed by modifying a different variable with the goal of finding existing links between actual-world elements. Predictions can then be formed on the basis of these interrelationships. The positivist worldview has long been connected with natural sciences. This has spurred discussions over whether the paradigm is appropriate for sociological research. With this paradigm, researchers are required to preserve data independence as well as an impartial point of view. Furthermore, one of the things highlighted in this paradigm is replication, which is seen to be the greatest technique of assessing the validity of information since various observers or participants reviewing the same data should come to comparable discoveries or outcomes.

According to the interpretivism paradigm, in order to properly comprehend reality, there must be a subjective assessment of as well as interpretation of reality. It also emphasizes the power of those involved in the research to influence the phenomena being examined (Thanh et al., 2015). This paradigm denotes the concept that truth is not only multifaceted but also relative. It goes on to say that throughout research, both the researcher and the informants must stay interdependent and interact in order to comprehend and interpret the varied human behaviors, instead of focusing on generalization and prediction of the causes and consequences of the displayed human psychology.

3.3. Research Strategy

Research professionals have discovered a huge number of research strategies. This study relies on a single primary research approach, a questionnaire survey.

The conceptual foundations of qualitative and quantitative research are found in naturalistic and positivistic philosophies, respectfully. Regardless of theoretical differences, almost all qualitative researchers reflect some type of subjective phenomenological perspective. Regardless of theoretical differences, most quantitative research methodologies stress the existence of a shared reality on which individuals may agree (Newman & Ridenour, 1998).

The research intended to analyze or identify how 3-D concrete printing components affect the engineering profession, particularly the construction sector, based on the aims of this study. In order to conduct the research, a survey question was created to get participants' thoughts or ideas on the subject. The survey was delivered to participants throughout the majority of the trial, and it was an important data-gathering instrument.

The survey was distributed online by using a google form, and the close-ended questions were developed in order to get the participates or the engineer’s opinions in their different position and field. By using quantitative research strategies, we get numerical data that can be analyzed.

3.4. The Survey Method

The survey research means collecting information or data from group of people by asking some questions then analyze the results, the steps that should be followed for successful survey research is:

- Determine who will participate in the survey: before we start the survey, we should have clear research questions that define what we want to find out about our subject so we should determine the target of participate in the survey.
- Decide one type of the survey:
  - A questionnaire: where a list of question is distributed by email, online or in person.
  - An interview: where the researcher asks a set of questions by the phone or in person and records the response.
- Design the survey questions: the type of the questions, the contact of the questions, the phrasing of the questions, the ordering and layout of the survey (logical order, start with easy non-sensitive- closed questions), there is 2 types of the question
  - Open-ended questions: it’s for qualitative research which is more common for interviews.
  - Closed-ended questions: it’s for the quantitative research that provides numerical data that can be statistically analyzed, also gives the respondent set of answers to choose, (yes-no questions, agree-disagree questions, a scale of options, list of options with single or multiple answer).
- Distribute the survey and collect responses form the target participate.
- Analyze the survey results: first the data should be processed, to sort all the response, second statically analysis is usually conducted using software program.
- Write-up the survey results

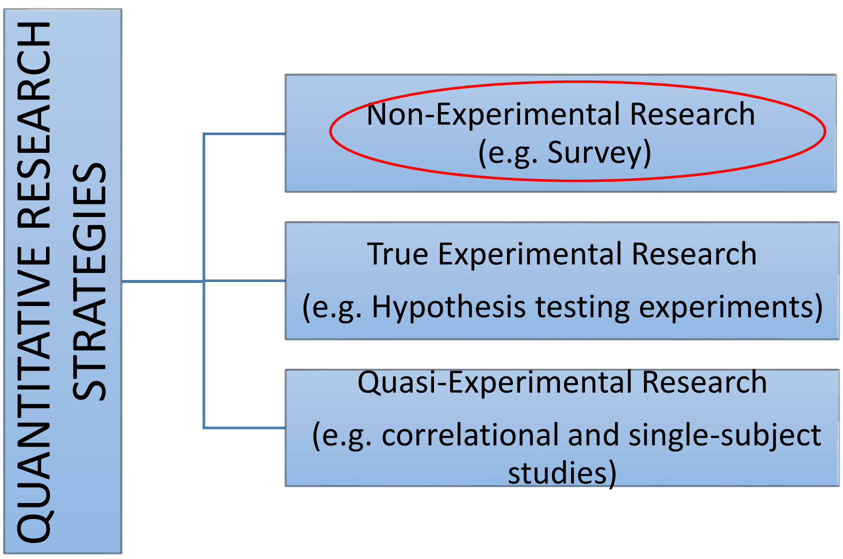
3.5. Research Design

The researcher's approach for selecting different sources and types of information that serve to answer the study question is known as a research design (Labaree & Robert V, 2009). In most circumstances, the study design is a structure that assists researchers in specifying numerous correlations between variables as well as providing an outline for every technique conducted from hypotheses through data analysis. Many researchers employ either quantitative or qualitative research designs, while mixed research methodologies, which blend quantitative and qualitative designs, can also be employed.

The research design can also be characterized, ranging from simple reporting research to sophisticated predictive research. A variety of research designs exist between basic reporting research and more sophisticated prediction research, including exploratory, experimental, descriptive, observational, and causal-explanatory research. The descriptive design was employed for the goals of this study, with the goal of learning how 3-D concrete printing components affect the engineering construction area. In other words, the emphasis was on how 3-D concrete printing components affect architectural, structural, and construction engineering.

The quantitative research strategies have three methods, in our case non-experimental research method were used (survey method), which means it involve no treatment of subjects, its method that used in order to have a number of cases, each case give their own opinion from their point of view, question that was selected developed based on the advantages and the disadvantages of the 3-D concrete printing in engineering field.

QUANTITATIVE RESEARCH STRATEGIES



3.5.1. Non-Experimental Research (Quantitative Survey):

In the quantitative research survey that focus on numbers, numerical and statically data, the chosen method was questionnaire method, then the questions were distributed online by using google form. The questions were closed-ended type of question, this type of questions allow us to get numbers that helps with developing a case study and provide significant data. An internet survey is a type of written survey. Respondents are encouraged to take the survey via e-mail, or social media when they visit a specific web page. Advantages: Quick to perform and tabulate, some software solutions allow surveys to be tailored based on respondent responses, prevent interviewer bias and distortion, answers are unlikely to be socially influenced, quick to administer, and relatively cheap cost (Roopa & Rani, 2012).

A questionnaire is a research tool that can be used in any type of study. This article is designed to provide detailed information regarding requirements such as creating a questionnaire, pilot testing it, standardizing it, and reframing problematic questions. It is recommended that you 'pilot' or pretest your questionnaire with a small sample of responders. Highlight it before utilizing it to assess people's comprehension and ability to answer questions (Kothari CR., 2017).

3.6. Sample Size and Population

The study's target group was construction professionals who are familiar with and use 3-D concrete printing technology. Project managers, architects, and structural engineers were among the professions targeted. Because this was a quantitative study, the sample size was limited to 30 people of various categories and backgrounds. According to authors and research specialists, quantitative research or analysis necessitates the use of closed-ended questions.

The number of individual samples measured or observations utilized in a study is known as sample size. A total of 30 participants were recruited for this study, and they were chosen at random. 1 of the participates was a project director, 1 were design manager, 1 were interior design engineer, 2 were general manager, 6 were civil engineers, 6 Architectural engineers, 4 were construction site engineers, 8 were structural engineers. The fiber-reinforced 3-D concrete printing components used in building construction that were investigated in this study included carbon fiber, glass fiber, aramid fiber, nylon-filled polyamide, glass-filled polyamide, polystyrene, and others. The expenses involved in the purchase of equipment, operation, and maintenance of a building structure indicate their impact on the engineering or construction fields.

3.7. Collection of The Data

A questionnaire was chosen as the data collection instrument for this investigation, as indicated in the preceding sections. The following data gathering procedures are presented to do this.

3.7.1. Questionnaire Research Ethics:

We committed that all participants in the survey research know why they should participate in the research, through a simplified explanation that we attached to the questionnaire survey link, which clarifies what the purpose of the questions, and why we are doing this questionnaire survey, and in addition to this we have attached a document that was It states that: (i) all information provided will be kept confidential, (ii) your participation in this research is voluntary and that you are free to stop at any time if you feel uncomfortable, and (iii) the research team does not intend to cause any harm. All these was done in order to make the participates feel more comfortable and freer, adding to that the type of question was chosen in very critical way so it was not personal or sensitive questions.

The brief explanation latter that we attached to the questionnaire survey link on social media:

(السلام عليكم و رحمة الله و بركاته)

اسمي نوران عامر عبدالجواد مهندسة مدنية و بيئية، طالبة ماجستير في الهندسة الانشائية، وباحثة مشاركة.
اقوم الأن بعمل بحث علمي عن تكنلوجيا الطباعة ثلاثية الأبعاد للخرسانة و سيتم تطوير دراسة علمية بناء على ردودكم على الاستبيان المرفق.
يحتوي الاستبيان المرفق على عدد من الاسئلة التي تم اخيارها بناء على عوامل اساسية تمت دراستها اثناء البحث.

My name is Noran Amer Abduljawad, a civil and environmental engineer, a master's student in structural engineering, and a research associate.
I am doing a scientific research on 3-D concrete printing technology, and a scientific study will be developed based on your responses to the attached questionnaire.
The attached questionnaire contains a number of questions that were chosen based on basic factors studied during the research.

The cover letter questionnaire that attached to the survey like by E-mail:

(السلام عليكم و رحمة الله و بركاته)

أعزائي المشاركين ،

تعد صناعة البناء و التشييد من أهم الصناعات في العالم ، وذلك لكثرة عدد العاملين فيها ، والذي يقدر بحوالي 180 مليون شخص حول العالم. شهدت الصناعة البناء و التشييد العديد من التحسينات لضمان السلامة والمتانة والاستدامة ، ولكنها لا تزال بحاجة إلى إيجاد تقنيات جديدة وطرق جديدة لتحسين هذه الصناعة من حيث معدل شغلها عالي المخاطر والتطور الناتج عن التصاميم المعقدة. الغرض من هذه الدراسة هو تقييم تأثير استخدام تقنية طباعة الخرسانة ثلاثية الأبعاد على أداء صناعة البناء و التشييد.

ستساعدنا ملاحظاتك في تحديد الروابط بين هذه التكنولوجيا الجديدة وتحسين الأداء في صناعة البناء والتشييد. نقدر أن الاستطلاع سيستغرق حوالي 10-15 دقيقة لإكماله. سيتم الاحتفاظ بالردود الفردية خاصة ، وسيتم دمج بيانات الدراسة وتحليلها ككل. للحفاظ على السرية ، سيتم الإبلاغ عن نتائج البحث في شكل موجز.

إذا كانت لديك أي مخاوف أو أسئلة حول الاستبيان أو مشاركتك في هذه الدراسة ، فلا تتردد بالتواصل معي على

20192085@student.ac.ae

رقم الهاتف: 00971509758917

Dear Respondents,

The construction industry is one of the most important industries in the world, due to its large number of employees, which is considered to be around 180 million people worldwide. The industry has seen a number of improvements to ensure safety, durability, and sustainability, but still needs to find new technology and new methods to improve this industry in terms of its high-risk occupation rate and the development that resulted from complex designs. The purpose of this study is to assess the impact of using 3-D concrete printing technology on the performance of the construction industry.

Your feedback will assist us in determining the links between this new technology and performance improvement in the construction industry. We estimate that the survey will take you about 10-15 minutes to complete. Individual responses will be kept private, and study data will be combined and analyzed as a whole. To maintain confidentiality, the research findings will be reported in summary form.

If you have any concerns or questions about the questionnaire or your participation in this study, please feel free to contact me at

20192085@student.buid.ac.ae

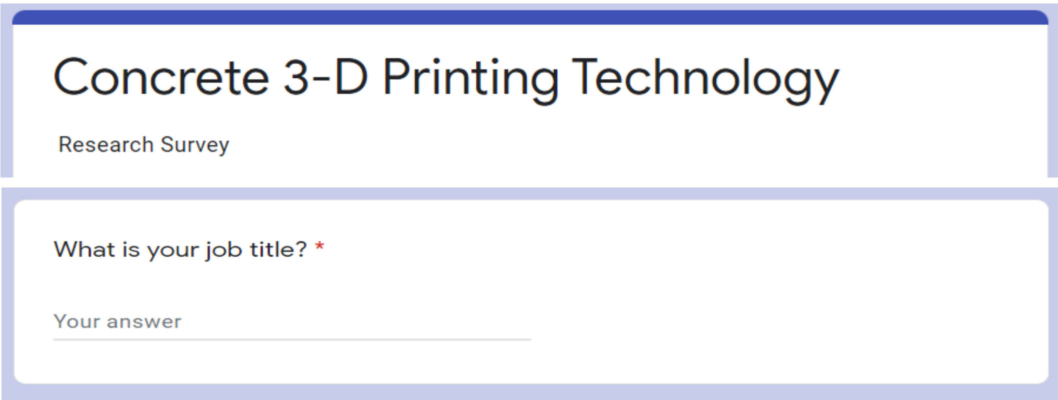
phone number: 00971509758917

3.7.2. The Protocol Design of the Questionnaire Survey:

The questionnaire protocol consists of three main concepts. The first concept is the general information that the participant knows about 3-D concrete printing through his title and his position at his working place. The second concept is gradual sentences, through which we take the participant's opinion and his agreement or disagreement with the aforementioned sentences. The third concept talks about several important factors, whether positive or We ask the participant to rank them in order of importance from his point of view.

All the collected data from google form responses are included in the appendix section.

3.7.2.1.Questionnaire Survey Theme:

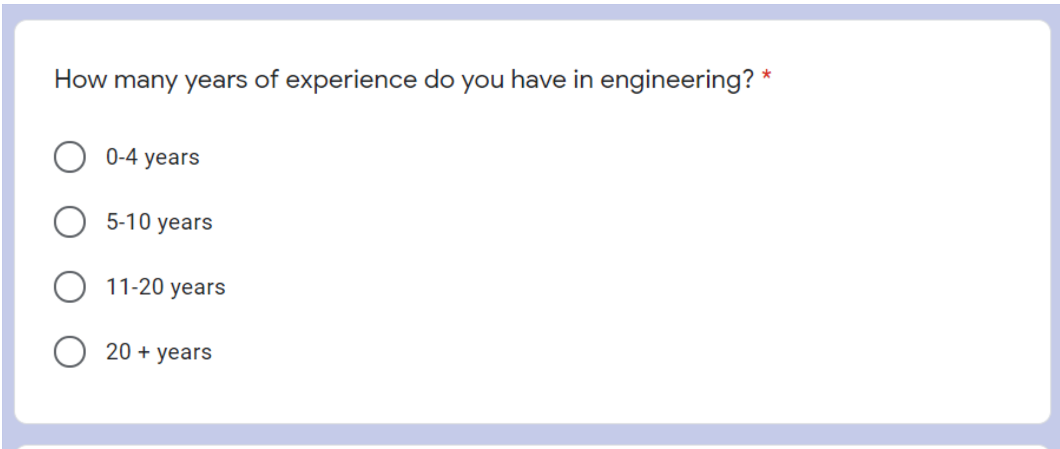


Concrete 3-D Printing Technology

Research Survey

What is your job title? *

Your answer



How many years of experience do you have in engineering? *

- 0-4 years
- 5-10 years
- 11-20 years
- 20 + years

What is your position? *

Your answer

What is the size of the organization or company you work for? *

- ◯ Regional
- ◯ National
- ◯ International
- ◯ Other:

Do you have any knowledge about concrete 3-D printing? *

- ◯ Yes
- ◯ No
- ◯ Maybe

Are you aware of any 3-D concrete printing projects in your region that are related to the construction industry? *

- ◯ Yes
- ◯ No

According to your expectations, what are the sectors that recommend the use of 3-D concrete printing? *

- ◯ Residential
- ◯ Ephemeral Architecture and Emergency Housing
- ◯ Rehabilitation and Reconstruction
- ◯ Bridges
- ◯ All of the above

According to your expectation, what are the recommended areas using 3-D concrete printing in the construction industry? *

- ◯ Construct the whole building
- ◯ Construct decoration parts/features
- ◯ Construct complex building parts
- ◯ Other: ____________

Do you agree or disagree with the following statement: the 3-D concrete printing technology will become widely used in the construction industry because the conventional construction methods are no longer efficient like before. *

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree

Do you agree or disagree with the following statement: the 3-D concrete printed elements on-site greatly reduce the transportation cost. *

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Do you agree or disagree with the following statement: complex CAD (Computer-Aided-Design) models can progress from prototype to finished product in a short period like hours by using 3-D concrete printing technology, which allows you to quickly test and validate designs, saving more time and effort in the long run. *

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Do you agree or disagree with the following statement: 3-D concrete printing offers huge scope for innovation and creativity for engineers, complex designs and curves can be built using this technology in a simple and easy way. *

- ◯ Strongly Disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly Agree

Do you agree or disagree with the following statement: 3-D concrete printing technology reduces the employee numbers in the construction industry since the 3D printer does most of the work. *

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree

Below is a list of the perceived advantages that 3-D concrete printing can bring to the construction industry, please arrange them on a scale of 7 in order of most influence (1) to least influence (7) in adopting this technology. *

	1	2	3	4	5	6	7
Increased investment in small companies.	○	○	○	○	○	○	○
Quick customization.	○	○	○	○	○	○	○
Reduce the construction cost	○	○	○	○	○	○	○
Reduce shortage of skilled labor.	○	○	○	○	○	○	○
Reduce the construction period.	○	○	○	○	○	○	○
Improved the health and safety in the construction site	○	○	○	○	○	○	○
Improved the sustainability in construction industry.	○	○	○	○	○	○	○

The below list of the perceived limitations/disadvantages to implementing 3-D concrete printing in the construction industry, please arrange them on a scale of 7 in order of most influence (1) to least influence (7) in adopting this technology. *

	1	2	3	4	5	6	7
Shortage in current codes and regulations.	○	○	○	○	○	○	○
The start-up cost is high.	○	○	○	○	○	○	○
Compatibility issues with current design and construction methods	○	○	○	○	○	○	○
Shortage in professional employment	○	○	○	○	○	○	○
Shortage in suppliers.	○	○	○	○	○	○	○
Limitation in materials choice.	○	○	○	○	○	○	○
Fewer opportunities for labors	○	○	○	○	○	○	○

On a scale from 1 (Extremely effective) to 5 (Not at all effective), rate the below list of the main factors that help the success of 3-D printing technology implemented in the construction industry. *

	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Cooperation between suppliers and contractors.	○	○	○	○	○
Develop academic and scientific research such as codes to be followed.	○	○	○	○	○
Follow a strategy to develop Skilled employment for Operation	○	○	○	○	○
Leadership commitment.	○	○	○	○	○
Increase the number of suppliers	○	○	○	○	○

3.8. Data Analysis of the Methodology

The data gathered from the questionnaires survey was quantitative in nature. The process of speculating, collecting evidence, testing hypothesis, updating theory, and repeating the cycle is the foundation of science. When utilizing quantitative approaches to analyze data, the theory is just as crucial. All statistical textbooks devote considerable space to describing the assumptions of statistical tests, the data requirements for a given estimation process, and the limits to the inferences that may be derived from results. Theory about the phenomenon being studied through quantitative data analysis drives not only the methods used to collect evidence but also the decisions made about how to model and test that theory. (Pigott, n.d.)

Quantitative approaches stress objective measurements and statistical, mathematical, or numerical analysis of data gathered through polls, questionnaires, and surveys, or by modifying pre-existing statistical data with computing tools. Quantitative research is concerned with collecting numerical data and generalizing it across groups of individuals or explaining a specific phenomenon.

CHAPTER FOUR

4. DATA ANALYSIS

4.1. Preliminary Consideration

The goal of this thesis is to look into the understanding and influence of 3-D concrete printing in the engineering and building fields. As a result, the analysis chapter will concentrate on facts gathered during research and will be centered on two key prospects. The first prospect is the impact of 3-D concrete printing on the engineering industry is one of the prospects examined. The results address two aspects of 3D printing in construction the main advantages and disadvantages factors. The second aspect is about the present and expected degree of implementation. On the other hand, the aspect is about expected cost issues. The impact of 3-D concrete printing components on engineering inventiveness is the second prospect examined. The emphasis will be on how factors or qualities of 3-D concrete printing components, such as replacement and maintenance, affect operational cost

4.2. The Demographic Questions.

Demographic data allows you to have a deeper understanding of an audience's background characteristics, such as age, race, income, job title, marital status, and so on. By asking demographic questions in surveys, you may obtain demographic information about current and potential consumers on a large scale, which can help you design a market segmentation plan to target the appropriate audience. Simply said, demographic inquiries are any questions that seek to better comprehend a certain respondent's identification. Demographic surveys (surveys that utilize demographic questions) seek fundamental information about respondents in order for the survey designer to determine where each person belongs in the overall population. (Griffith et al., 2016)

4.2.1. The Participant knowledge and experience:

The 30 participates in the questionnaire survey had different backgrounds and different knowledge, one of the questions in the survey was about the experience in the engineering field of each participant according to their major. The survey shows that 36.7% of the participant experience was 0-4 years, 13.3% of them 5-10 years, 26.7% was 11-20 years, and 23.3% was 20+ years. It present that the survey almost covers all the experiences level.

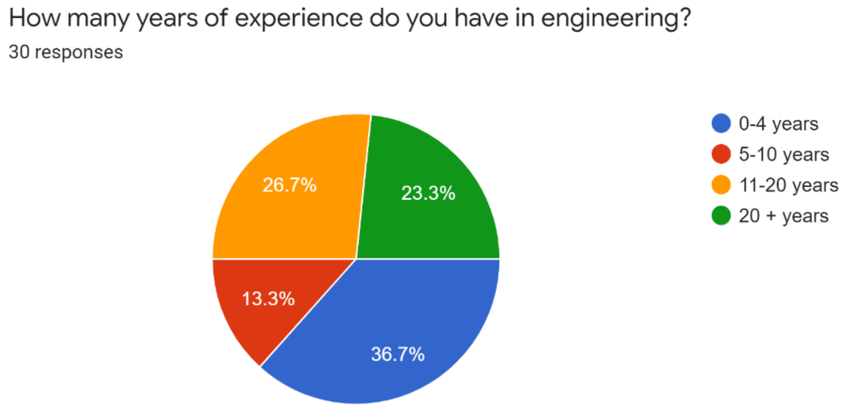


Chart 1: The years of experience / source: google form

There was three question about the participant job. The first question is the position, then job title which was discussed in the methodology chapter. The third question is the size of the organization or company they work for. This type of questions gives us more information about the background of each participant. the result show that 36.7% of the response works in regional organization, and the same percentage 36.7% works for national organization, while 26.7% works in international organization.

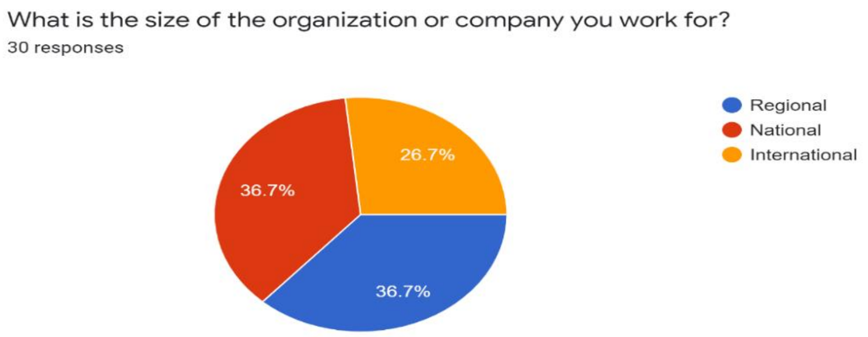


Chart 2: The size of organization / source: google form

On the other hand, other questions were about the participant knowledge about the 3-D concrete printing technology. 70% of the response had a good knowledge about this technology, while 10% only they didn't have any information regarding this technology, and 20% of them select (maybe) which means they are not sure if they know about the technology or no.

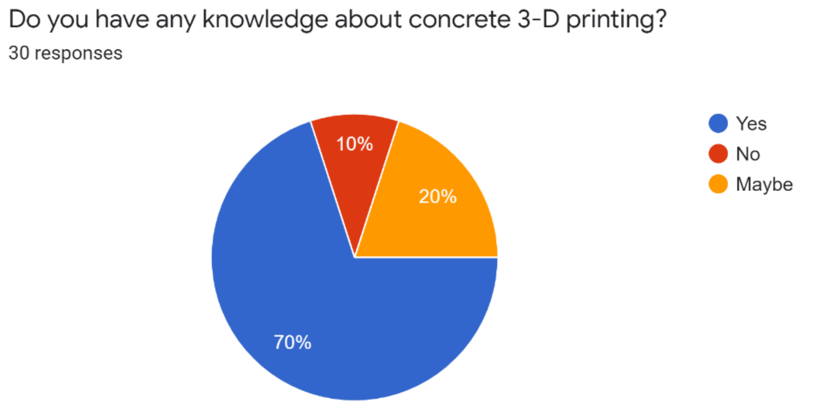


Chart 3: The response knowledge / source: google form

Another question was about if the responses have any idea or aware of any 3-D concrete printing technology projects in construction industry in their region, the result shows that 50% of the participant have seen project related to this technology, and 50% of them they didn’t seen any project before.

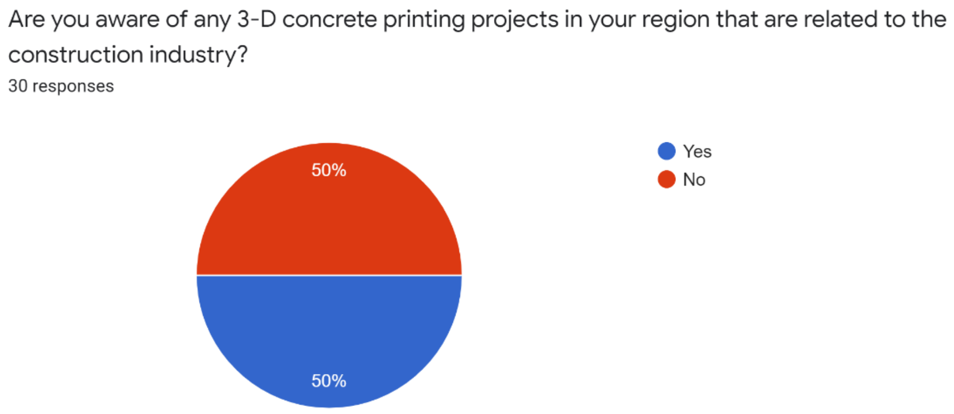


Chart 4: The 3-D concrete project in construction industry / source: google form

4.3. The Potential Impact of 3-D Concrete Printing Technology on the Engineering Industry.

In order to understand the impact of this technology on the engineering and construction sector, the first stage is to identify the most important features of 3-D concrete printing components that have an impact on the engineering construction industry. The features of 3-D concrete printing components can be investigated from the perspectives of list of advantages, list of disadvantages, and applicability, as well as maintainability, as discussed in the Literature Review chapter.

4.3.1. The recommended sectors and areas to use the 3-D concrete printing technology:

In the questionnaire survey, there was two multiple choice question that concentration on sectors and areas that recommended to use 3-D concrete printing technology in the construction industry from the participant's point of view. The result shows that only 10% from the 30 participants choose the residential option, 26.7% decide to choose the ephemeral architecture and emergency housing, 3.3% choose the rehabilitation and reconstruction, 6.7% goes with the bridges option, while the largest number of respondents in the survey suggest that, the 3-D concrete printing technology can be used in all of the above areas, which means that most of the participant believe in this technology and its effectiveness.

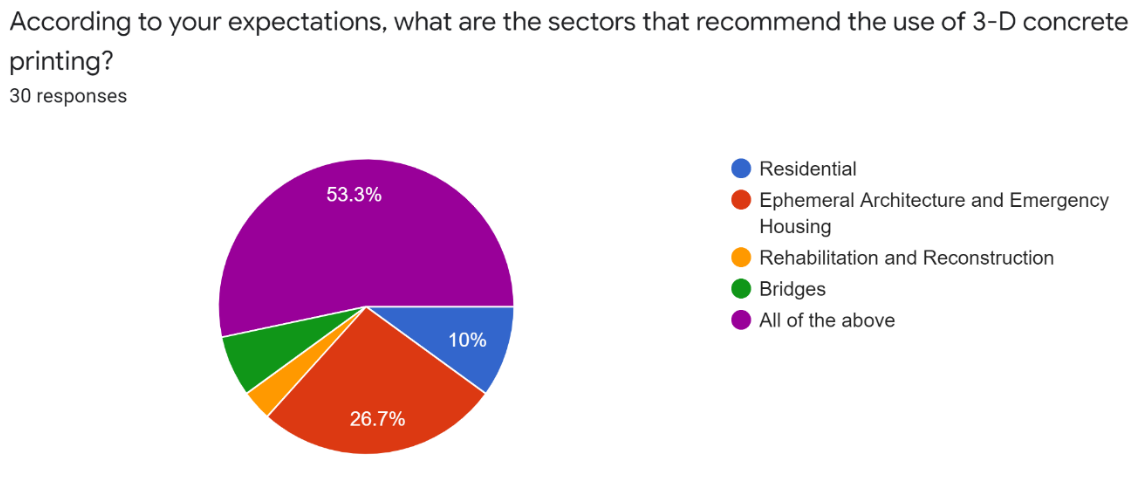


Chart 5: The 3-D concrete project in construction industry / source: google form

Another deep question in the survey was about what is the recommended area to use this technology in the construction industry, there was five different multiple choices, also there was other option where the participant can write he's own answer if he has another point of view. 26.7% choose construct the whole building, 23.3% choose construct decoration parts or features, the highest percentage 36.7% goes with construct the complex parts. In the short answer option there was 4 different opinions, one of the participant's answers was "The main parts of the buildings that do not affect the future vision of the buildings in requesting the latest development or changes as a result of the user changing the building with the change of time period". Another point of view, two responses have almost the same opinion, which is there is no limitation since it doesn't affect the environment, also developing a code with guidelines is very important, one of the responses wrote in the short answer all of the above.

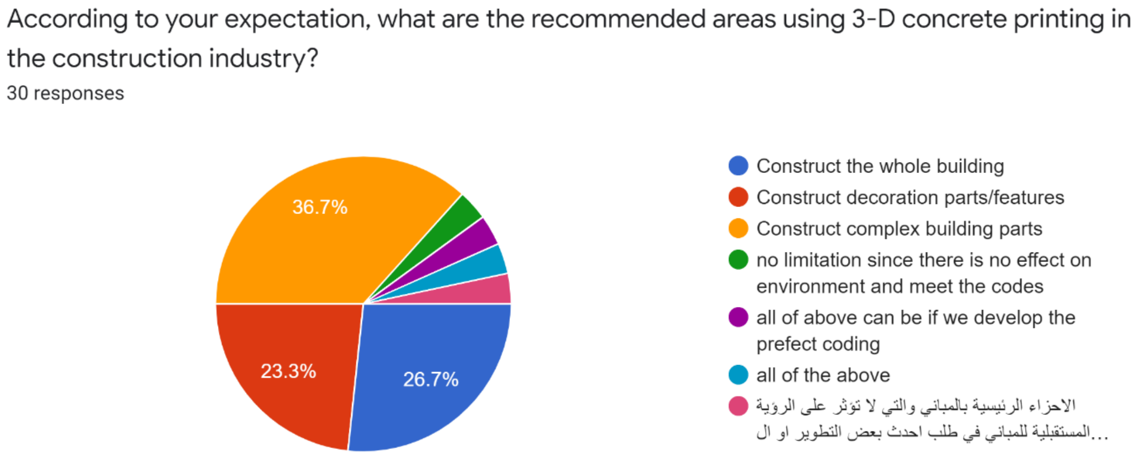


Chart 7: The 3-D concrete project in construction industry / source: google form

4.3.2. Likert Scale Questions

That scale of agree or disagree is a type of question known as a Likert scale. Likert scales are commonly used to assess attitudes and views with more depth than a basic "yes/no" inquiry. To comprehend the Likert rating scale, you must first comprehend the concept of a survey scale. A survey scale is a collection of answer options—either numeric or verbal—that encompass a wide range of opinions on a given issue. It is usually asked as part of a closed-ended inquiry (a question that presents respondents with pre-populated answer choices). So, what exactly is a survey question on a Likert scale? It's a question with a 5 or 7-point scale, often known as a satisfaction scale, that runs from one extreme attitude to the other. In most cases, a mild or neutral option is included in the Likert survey question's scale. Likert scales (named after their originator, American social scientist Rensis Likert) are widely used because they are one of the most dependable methods of measuring attitudes, perceptions, and actions. Unlike binary questions, which only have two answer alternatives, Likert-type questions will provide you with more nuanced feedback on whether your product was "good enough" or (ideally) "great." And Likert scale inquiries might assist you in determining if a recent corporate outing left employees feeling "extremely happy," "slightly disappointed," or "neutral." This strategy will allow you to find differences of opinion that might make a significant impact on your comprehension of the input you're receiving. It can also show up areas where your service or product could be improved. (Boone et al., 2012)

The first likert scale question was about if the participant agree nor disagree with the conventional construction method is no longer efficient like before, so the 3-D concrete printing technology will supersede it. 10% only strongly disagree, 30% from them disagree, however, the same percentage 30% goes with neutral, while 26.7% agree, and 3.3% strongly agree.

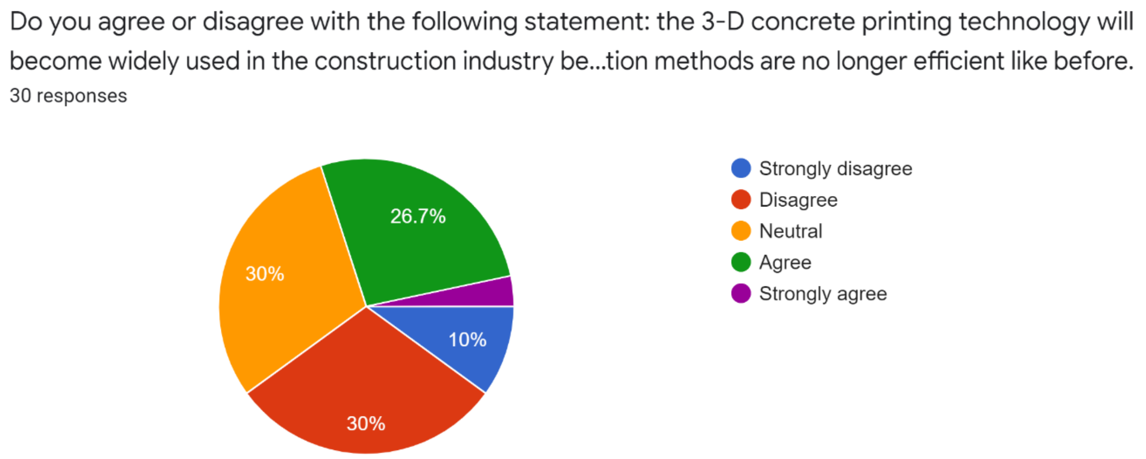


Chart 8: The 3-D concrete project in construction industry / source: google form

Additionally, the next likert scale question was about the transportation cost, if the 3-D concrete printing technology can affect the transportation cost. No one chooses the strongly disagree option, but 20% of the response choose disagree, while 13.3% of them choose neutral, more than the half of the percentage 56.7% select agree option, and finally 10% only goes with strongly agree.

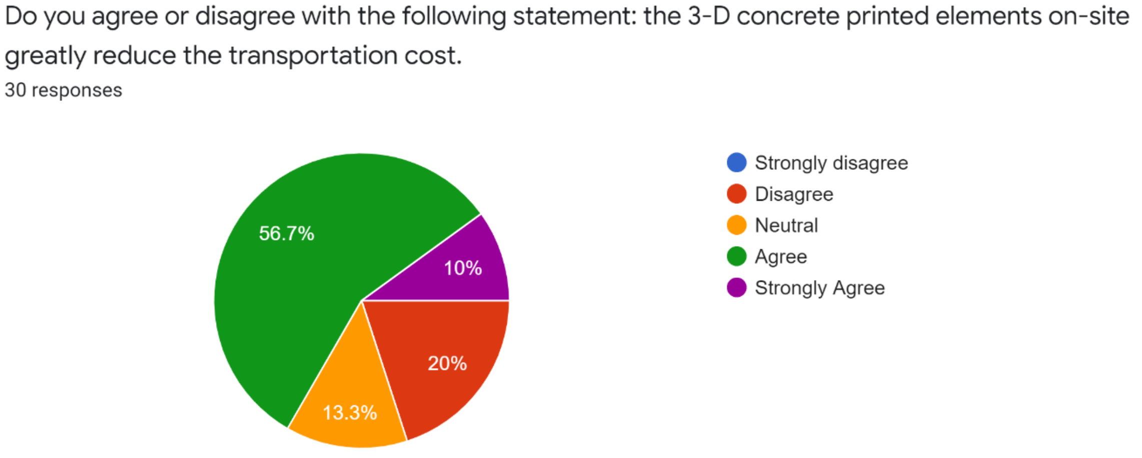


Chart 9: The 3-D concrete project in construction industry / source: google form

On the other hand, one question was about if the 3-D concrete printing technology can increase the innovation of the engineers, also here no one select the option strongly disagree, 3.3% goes with disagree, also 16.7% choose neutral, and the highest percentage of the response 60% choose agree, 20% of them choose strongly agree.

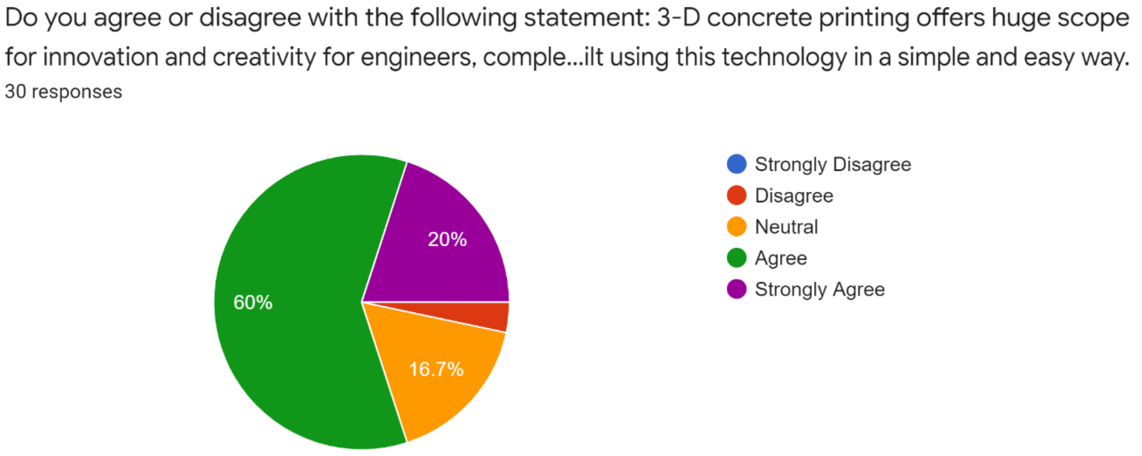


Chart 10: The 3-D concrete project in construction industry / source: google form

Another question was about the ease of use this technology even in complex designs. No one strongly disagree in this question, but 3.3% disagree, 13.3% choose neutral, almost half of the response 46.7% agree with this statement, also 36.7% strongly agree.

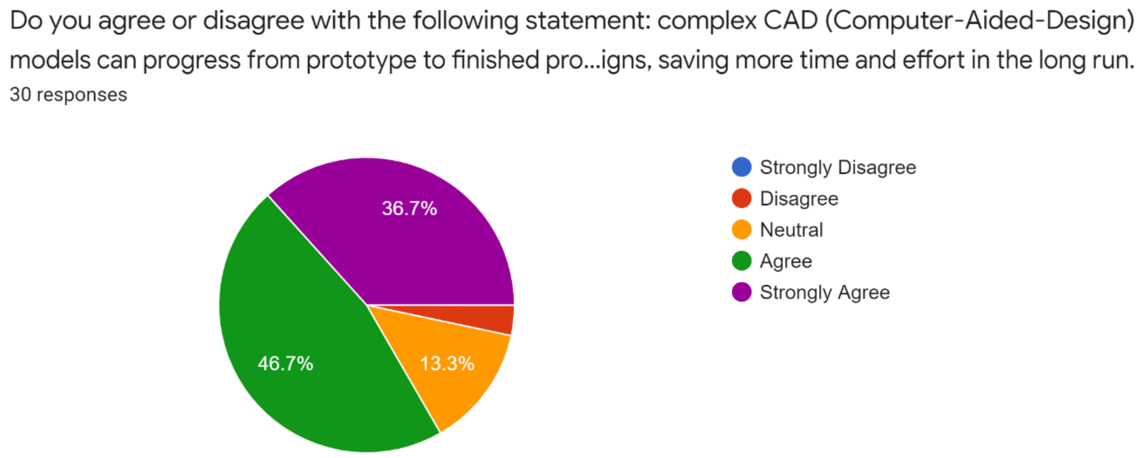


Chart 11: The 3-D concrete project in construction industry / source: google form

Its known that the 3-Dprinting technology dose most of the work and as it was mention earlier in the literature review chapter no molds needed, no casing needed and so on, that's why it decreases the labor number, and this also raises doubts. 3.3% strongly disagree, again 3.3% disagree, 23.3% choose neutral, 40% agree with this statement, 30% strongly agree about this issue.

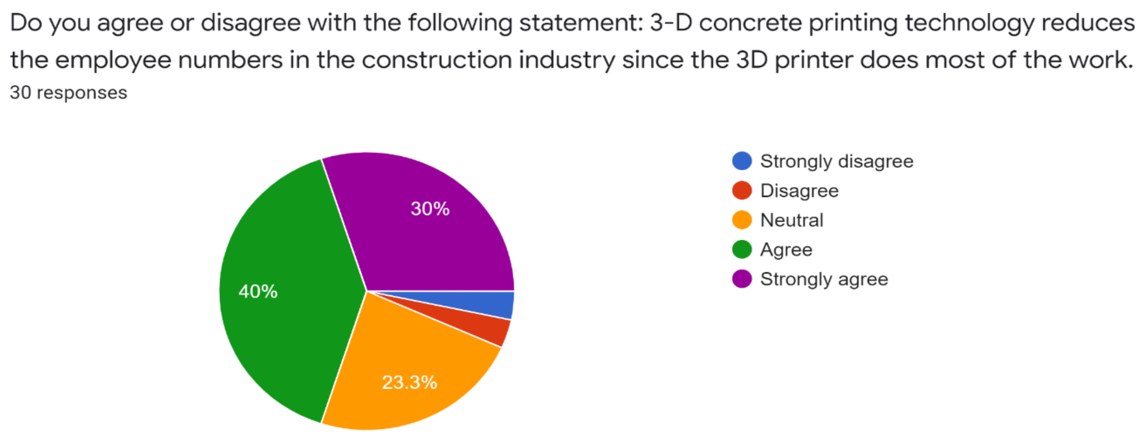


Chart 12: The 3-D concrete project in construction industry / source: google form

4.4. The Substantial Advantages and Disadvantages of 3-D Concrete Printing in the Engineering and Construction Field.

The last part of the questionnaire includes three important questions, each question contains many points, and these points and their importance are evaluated by the participants according to their point of view. The answer of each participant was recorded separately for each factor in order to get the accurate answer from each response.

4.4.1. The Ranking Questions:

A ranking question is a form of a survey question that asks respondents to compare and arrange a list of things in order of preference. Market analysts use it to determine the rank of the relevance of numerous goods. It is essential to product development since it is one of the most commonly utilized surveys question kinds by market researchers. Before launching a new product, a company must first understand what its target market values the most. In addition, while developing an upgrade to a current product, they must understand what consumers desire in an upgrade. (Moors et al., 2016)

A ranking scale is a closed-ended scale that allows respondents in a ranking survey to evaluate numerous row items in respect to one column item or a question and then rate the row items. It is the scale that market researchers use to rate questions. On a scale, the query might be in terms of product characteristics, demands, desires, and so on. It is suitable for both online and offline surveys. A ranking scale for an existing product provides a more precise response as to whether customers enjoy the product in question or not. (Mouter et al., 2013)

Without a doubt, ranking questions are one of the most crucial components of conducting a market research survey. It assists market researchers and organizations in determining which aspects of their product customers like. They can simply provide the elements known to affect a customer's decision and ask them to rate them in order of preference. This assists firms in developing items that are well-liked by clients. It enables survey respondents to compare different goods by arranging them in the order of how they score (or rank) in a given attribute, such as design, pricing, utility, or importance. Most of the time, the most essential or favored item was ranked first or near the top of the list. (Lievaart & Noordhuizen, 2011)

For each factor or point there was a table created, this table contain the 30 responses participant, and the scale answer for each response was recorded in order to get the number of response (N) for the each and every factor. In the other hand, an excel chart was created for each factor, and that's help with gain and understand the participant ranking for each factor in clearer way.

4.4.1.1.Evaluation the advantages of using 3-D concrete printing technology in construction industry:

The first ranking question covers the main advantages of using 3-D concrete printing technology in construction and engineering sector. There was a list includes the main factors that affect the construction field positively. The participant was asked to rank them according to what they think is the most important factor to the least important on a scale from one important to seven less important. The list contains 7 different factors; each factor was studied separately in order to identify facts from the participant's point of view.

In 3-D concrete printing technology many major and minor advantages, attempts have been made to organize a list containing the most important features of this technology.
As it was mentioned earlier at the literature review chapter, there are many nice advantages that contribute to the development of building and construction if 3-D concrete printing is used. When the list of features was chosen in the survey research, the selection was based on the previous studies discussed in the beginning of the paper research, where the list was carefully selected to include all the advantages. Survey participants were asked to rate each of the seven factors according to their importance and effectiveness in engineering and construction sector.

4.4.1.1.1. Increased investment in small companies:

The first factor or point is "increase investment in small businesses", and this point means that concrete 3D printing technology can affect small businesses and raise or develop investment in them, especially as it is considered a new tool for production, while 3D printing is a major factor. Especially useful for prototyping, an increasing number of organizations are using this 3D technology to improve their manufacturing process. In fact, according to most recent survey of the 3D printing sector, 51% of respondents use additive manufacturing for production, up from 38% in the previous year refer to (*Top 3D Printing*

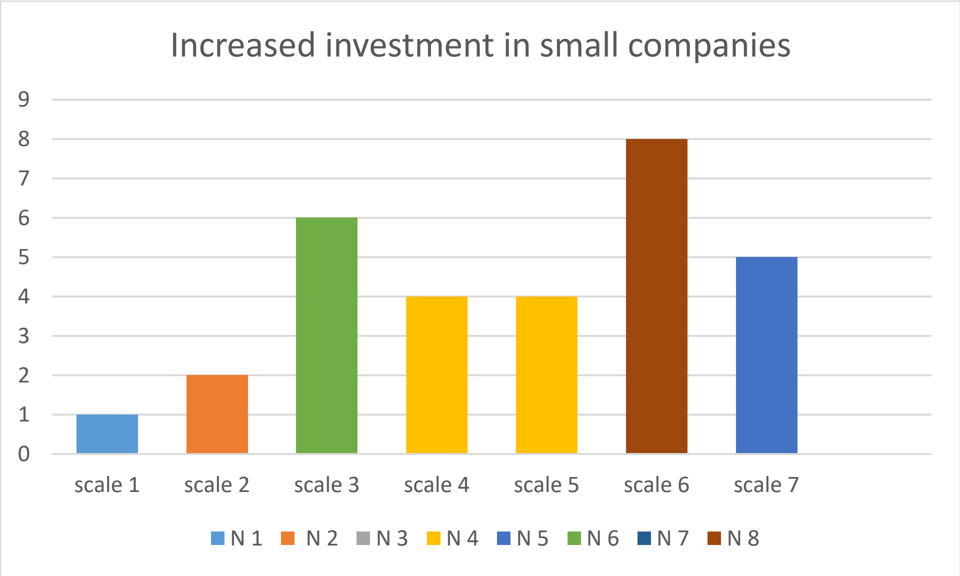
Benefits for Small Businesses, n.d.). In addition, low cost and short term, easier storage and better quality. According to (*Top 3D Printing Benefits for Small Businesses*, n.d.) .

Table 2 The table below shows an individual ranking answer for each response. | *Source:* google form

Increased investment in small companies	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Response 1							✓
Response 2						✓	
Response 3				✓			
Response 4					✓		
Response 5						✓	
Response 6				✓			
Response 7			✓				
Response 8						✓	
Response 9						✓	
Response 10			✓				
Response 11							✓
Response 12			✓				
Response 13				✓			
Response 14		✓					
Response 15				✓			
Response 16			✓				
Response 17		✓					
Response 18			✓				
Response 19			✓				
Response 20							✓
Response 21						✓	
Response 22					✓		
Response 23	✓						
Response 24						✓	
Response 25						✓	
Response 26					✓		
Response 27						✓	
Response 28							✓
Response 29							✓
Response 30					✓		

The result of the first factor appears that, only one participant selects the scale 1^{st}, two participants select scale 2^{nd}, six participants chose scale 3^{rd}, four select 4^{th} scale, also four participants select 5^{th} scale, and the largest number of the participant 8 chose the 6^{th} scale, and finally five of the participants decide to choose scale 7^{th}. At the average most of the response agrees that the 3-D concrete printing technology does not affect greatly the investment in small companies.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.2. Improved the sustainability in construction industry

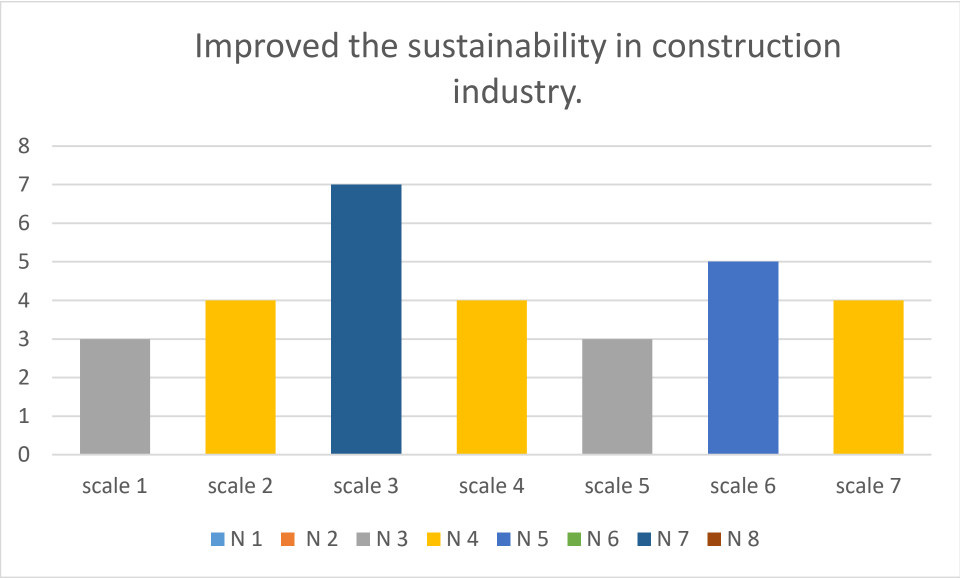
The second factor was 'Improved the sustainability in the construction industry' the participants were asked to rate from 1 to 7, does the 3-D concrete printing technology influences sustainability and the environmentally friendly. since this technology requires fewer logistical processes and produces less waste, contractors questioned for the study feel that 3D printing can eliminate three significant problems related to transportation logistics. For starters, many components get damaged in transit, which might be avoided with on-site printing. Second, in order to resist shipping, parts must be over-engineered, incurring additional expenditures. On-site 3D printing would eliminate such over-engineering. Third, secure transportation and lifting necessitate the attachment of characteristics to pieces, necessitating additional post-assembly labor. These features would be unnecessary if 3D printing was available on-site. Furthermore, 3D printing eliminates the need for wooden molds, which are commonly used in conventional buildings, because the raw material is immediately molded into construction in 3D printing. Refer to (Kothman & Faber, 2016)

Table 3 The table below shows an individual ranking answer for each response. | Source: google form

Improved the sustainability in construction industry.	1	2	3	4	5	6	7
Response 1				✓			
Response 2				✓			
Response 3			✓				
Response 4						✓	
Response 5			✓				
Response 6					✓		
Response 7						✓	
Response 8		✓					
Response 9					✓		
Response 10						✓	
Response 11				✓			
Response 12		✓					
Response 13							✓
Response 14						✓	
Response 15			✓				
Response 16	✓						
Response 17							✓
Response 18						✓	
Response 19					✓		
Response 20			✓				
Response 21		✓					
Response 22			✓				
Response 23		✓					
Response 24			✓				
Response 25	✓						
Response 26				✓			
Response 27							✓
Response 28	✓						
Response 29			✓				
Response 30							✓

The second factor result shows that, three participant selects the scale 1st, four participants select scale 2nd, largest number of the participant seven chose 3rd scale, four select 4th scale, three participants select 5th scale, five select 6th scale, and finally four of the participants decide to choose scale 7th. On average, the majority of respondents feel that 3-D concrete printing technology has a positive impact on the construction industry's sustainability.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.3. Improved the health and safety in the construction site:

The third factor is 'Improved the health and safety in the construction site' which means if the 3-D concrete printing technology can impact the labor safety and health on the construction site. 3-D concrete printing technology helps to make workplaces safer and eliminate health and safety issues. Dangerous occupations and duties on construction sites may soon be substituted by printing technologies, removing the need for humans to perform these tasks. (*3D Printing: 8 Major Changes Coming to Construction - Construction World*, n.d.)

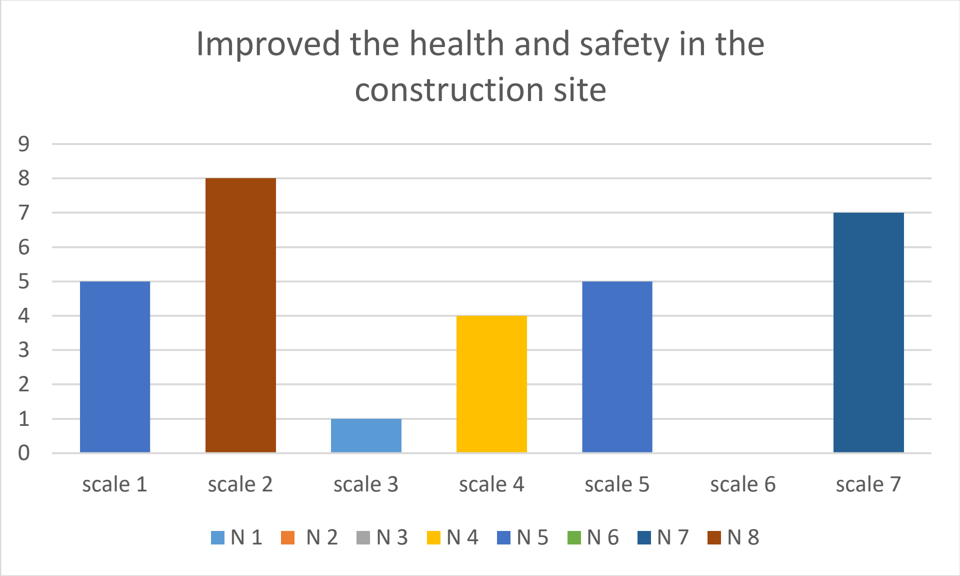
Construction, particularly concrete work, may be risky, but with 3D printing, the hazards are minimized, resulting in far less worker's compensation paperwork to submit. Nonetheless, despite its promise and some amazing early applications, 3D printing has yet to become a common tool in most building projects. (*What Role Will 3D Printing Play in the Construction Industry? | Construction Dive*, n.d.)

Table 4 The table below shows an individual ranking answer for each response. | Source: google form

Improved the health and safety in the construction site	1	2	3	4	5	6	7
Response 1		✓					
Response 2							✓
Response 3		✓					
Response 4	✓						
Response 5							✓
Response 6		✓					
Response 7					✓		
Response 8				✓			
Response 9		✓					
Response 10				✓			
Response 11	✓						
Response 12					✓		
Response 13		✓					
Response 14							✓
Response 15							✓
Response 16					✓		
Response 17				✓			
Response 18	✓						
Response 19							✓
Response 20					✓		
Response 21							✓
Response 22	✓						
Response 23				✓			
Response 24					✓		
Response 25							✓
Response 26			✓				
Response 27		✓					
Response 28		✓					
Response 29		✓					
Response 30	✓						

The third factor result show that, five participant selects the scale 1st, largest number of the participant eight select scale 2nd, only one participant selects the 3rd scale, four select 4th scale, five participants select 5th scale, zero participant select 6th scale, and finally seven of the participants decide to choose scale 7th. On average, the results seem to be uneven. There are participants who emphasized that this technique contributes significantly to reducing the risk to workers, and there is another party of the participants who support that safety must be provided by any constructive method and that the worker must be in a safe place no matter how different it is. construction methods. The worker must be provided with complete safety so that his health is not exposed to any risks.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.4. Reduce shortage of skilled labor:

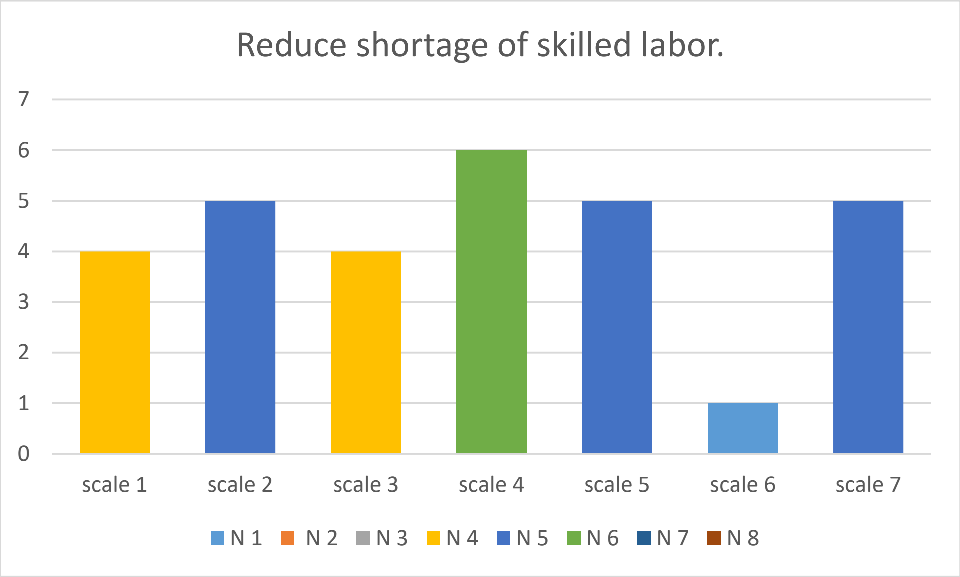
The fourth factor is 'Reduce shortage of skilled labor' which means if 3-D printing technology is used in the construction sector, this will enhance the labor skills, additionally this technology helps the labors to get better job opportunities. According to (*The Disruptive Technological of 3D Printing*, n.d.) the 3-D printing has a significant impact on labor since the disruptive technology will eliminate much-unskilled labor employment while increasing demand for skilled jobs. Many jobs will be lost to technology as a result of 3D printing automation and the removal of human input from the manufacturing line. Because of the technology, there is a requirement for qualified technical employees to run the systems. Many careers will be lost as a result of 3D printing in the beginning; however, this will boost the need for competent employees, which will lead to the creation of many new jobs in the future.

Table 5 The table below shows an individual ranking answer for each response. | *Source:* google form

Reduce shortage of skilled labor.	1	2	3	4	5	6	7
Response 1					✓		
Response 2			✓				
Response 3					✓		
Response 4							✓
Response 5				✓			
Response 6			✓				
Response 7		✓					
Response 8					✓		
Response 9				✓			
Response 10		✓					
Response 11						✓	
Response 12							✓
Response 13	✓						
Response 14					✓		
Response 15	✓						
Response 16				✓			
Response 17	✓						
Response 18		✓					
Response 19				✓			
Response 20		✓					
Response 21				✓			
Response 22							✓
Response 23							✓
Response 24							✓
Response 25				✓			
Response 26		✓					
Response 27					✓		
Response 28			✓				
Response 29	✓						
Response 30			✓				

The fourth factor result show that, four participant selects the scale 1st, five select scale 2nd, four participant selects the 3rd scale, largest number of the participant six select 4th scale, five participants select 5th scale, only one participant select 6th scale, and finally five of the participants decide to choose scale 7th. In this factor as well, there is a supporter of the idea that 3D concrete printing contributes to raising the rate of empowered and skilled labor, and there are those who believe that empowered and skilled labor does not depend on this technology. Workers or labors must be highly skilled and meticulous, no matter how

different the construction method may be. But we all know that 3D concrete printing creates better and easier job opportunities than traditional construction methods.
The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.5. Quick customization.

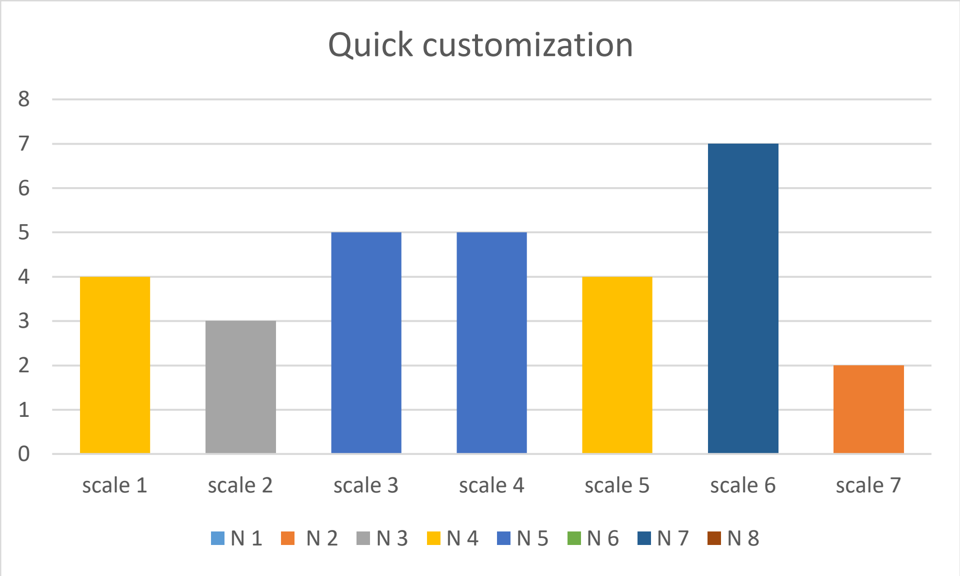
The fifth factor is 'Quick customization' this factor means, due to the ease and speed of 3-D concrete printing technology, it is possible to quickly customize any shape, whether it is an easy or complex shape. This feature of this technology contributes to reducing costs and time for custom-made objects. According to According to one of the leading companies in the field of concrete printing (*BESIX 3D - BESIX Group's Innovative 3D Concrete Printing Solutions*, n.d.) mentioned that, one of the most significant advantages of 3D concrete printing is the ability to mass customize. It can generate customized units on a big scale using optimization software. Regardless of how complicated the forms or how many there are, this technology provides for the delivery of concrete solutions without increasing manufacturing time or expense. Lay down the design limitations first, then develop the best-suited geometry for it.

Table 6 The table below shows an individual ranking answer for each response. | *Source:* google form

Quick customization.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Response 1						✓	
Response 2					✓		
Response 3						✓	
Response 4				✓			
Response 5	✓						
Response 6						✓	
Response 7							✓
Response 8			✓				
Response 9	✓						
Response 10					✓		
Response 11					✓		
Response 12				✓			
Response 13			✓				
Response 14			✓				
Response 15		✓					
Response 16						✓	
Response 17						✓	
Response 18							✓
Response 19		✓					
Response 20	✓						
Response 21			✓				
Response 22						✓	
Response 23			✓				
Response 24				✓			
Response 25		✓					
Response 26	✓						
Response 27				✓			
Response 28						✓	
Response 29					✓		
Response 30				✓			

The fifth factor result show that, four participant selects the scale 1^{st}, three select scale 2^{nd}, five participant selects the 3^{rd} scale, five select 4^{th} scale, four participants select 5^{th} scale, largest number of the participant seven select 6^{th} scale, and finally two of the participants decide to choose scale 7^{th}. According to the results shown, participants believe that rapid allocation is not one of the main factors affecting building and construction, but there are more important factors that can be highlighted, and there are participants who believe that it is necessary but not to the same extent as the previously mentioned factors.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.6. Reduce the construction cost:

The sixth factor is 'Reduce the construction cost' This factor means that 3D concrete printing helps greatly in reducing construction costs due to reduced waste and material waste. 3D printers are extremely quick and can build indefinitely. Some building businesses claim to be able to print a full house in 24 hours. Because the sole input is printing material, the whole production process is cost-effective. This lowers the cost of labor. 3D printers can create a house anywhere at an inexpensive cost, providing a better and faster alternative for the needy. Refer to (*3D Printed Concrete Buildings- Working & Features - The Constructor*, n.d.).

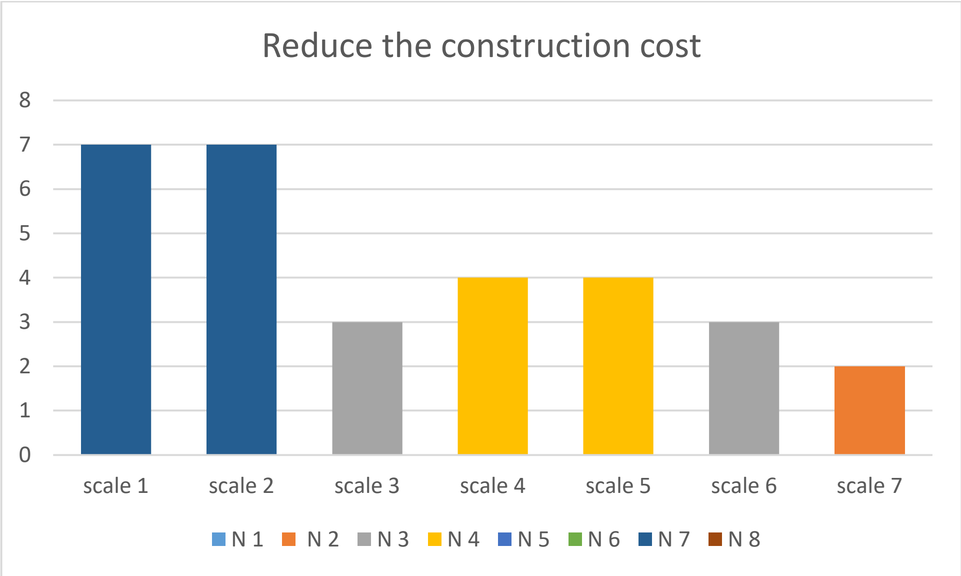
Because of savings in raw materials and, more crucially, labor, 3D printed buildings have substantially cheaper construction costs than traditional techniques. By using 3D printers to accomplish the majority of an architectural project's construction, labor expenses can be lowered by up to 80%. Production expenses are also decreased by removing the requirement for vast storage rooms and daily transportation of building materials in 3D printed buildings. (Pros and Cons Of 3D Printed Construction – Architect Outsourcing, n.d.)

Table 7 The table below shows an individual ranking answer for each response. | *Source:* google form

Reduce the construction cost	1	2	3	4	5	6	7
Response 1	✓						
Response 2		✓					
Response 3	✓						
Response 4			✓				
Response 5		✓					
Response 6	✓						
Response 7				✓			
Response 8	✓						
Response 9							✓
Response 10	✓						
Response 11		✓					
Response 12						✓	
Response 13					✓		
Response 14				✓			
Response 15					✓		
Response 16		✓					
Response 17					✓		
Response 18					✓		
Response 19	✓						
Response 20				✓			
Response 21	✓						
Response 22		✓					
Response 23						✓	
Response 24		✓					
Response 25			✓				
Response 26							✓
Response 27			✓				
Response 28				✓			
Response 29						✓	
Response 30		✓					

The sixth factor result show that, the largest number of participants seven decide to choose 1st scale, and 2nd scale, three participant selects the 3rd scale, four select 4th scale, four participants select 5th scale, three participants select 6th scale, and finally two of the participants decide to choose scale 7th. As explained above, the majority of participants believe that 3D concrete printing greatly reduces construction costs in one way or another, and there is a small group of participants who believe that it reduces construction costs, but as a result the project start-up cost is high because printers and their needs are costly.

The chart below shows the number of participant’s response (N), with the rank scale from 1 important to 7 less important.



4.4.1.1.7. Reduce the construction period:

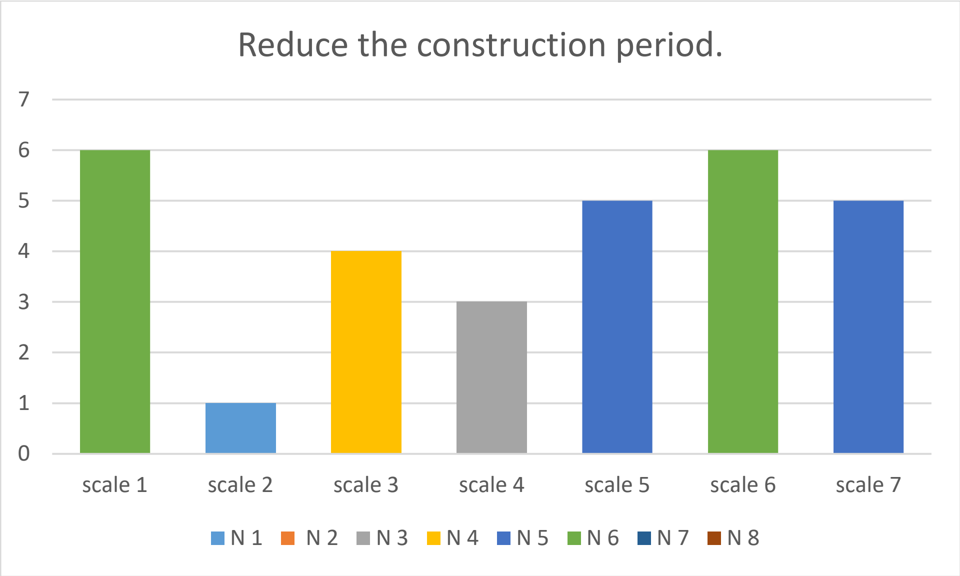
The seventh and last factor is ‘Reduce the construction period’ which means the usually construction period might take months or even years, but with this technology any parts or elements of the project can be printed and installed in the construction site within one day, which helps to reduce the construction period to less than half. According to (*Pros And Cons Of 3D Printed Construction – Architect Outsourcing*, n.d.) using a 3D printer to accomplish a building project can significantly shorten the construction time. When opposed to the standard 6-month building period, having a house made with 3D technology may be done in roughly a month and a half. This may be highly useful in an emergency case where buildings must be created in the shortest amount of time feasible.

Table 8 The table below shows an individual ranking answer for each response. | *Source:* google form

Reduce the construction period.	1	2	3	4	5	6	7
Response 1			✓				
Response 2	✓						
Response 3							✓
Response 4		✓					
Response 5					✓		
Response 6							✓
Response 7	✓						
Response 8							✓
Response 9			✓				
Response 10							✓
Response 11			✓				
Response 12	✓						
Response 13						✓	
Response 14	✓						
Response 15						✓	
Response 16							✓
Response 17			✓				
Response 18				✓			
Response 19						✓	
Response 20						✓	
Response 21					✓		
Response 22				✓			
Response 23					✓		
Response 24	✓						
Response 25					✓		
Response 26						✓	
Response 27	✓						
Response 28					✓		
Response 29				✓			
Response 30						✓	

The seventh factor result show that, six participant selects the scale 1st, only one participant select scale 2nd, four participants selects the 3rd scale, three select 4th scale, five participants select 5th scale, six participants select 6th scale, and finally five of the participants decide to choose scale 7th. As explained above, the answers are different. There are those who support that this technology reduces the construction period because it shortens many steps, and there are those who oppose this idea, and this is due to the fact that any simple mistake in giving the order to the printer leads to wasting time, effort and cost, and it cannot fix any error after typing and giving the order from the computer

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.Evaluation the disadvantages of using 3-D concrete printing technology in construction industry:

The second ranking question focuses on the key drawbacks of adopting 3-D concrete printing technology in the building and engineering sectors. There was a list that included the primary elements that have a negative impact on the construction industry. The participants were asked to rate them from the most important to the least important on a scale of one important to seven less important. The list covers seven distinct criteria, each of which was researched independently in order to identify facts from the participants' perspectives.

Many major and small disadvantages of 3-D concrete printing technology have been identified, and efforts have been made to compile a list of the most significant limitations of this technology. As previously stated in the literature review chapter, there are several benefits to using 3-D concrete printing that contribute to the advancement of building and construction.

On the other side, the drawbacks may impede the growth of this technology, which is why it is critical to discover solutions to every weakness in this technology. When the list of drawbacks in the survey study was created, it was based on the prior studies described at the start of the paper research, where the list was carefully picked to contain all of the downsides. Participants in the survey were asked to rank each of the seven characteristics based on their relevance and efficacy in the engineering and construction sector.

4.4.1.2.1. The start-up cost is high:

The first factor of the disadvantage's is 'the start-up cost is high' which means to start a project using 3-D concrete printing technology it needs a higher cost than the traditional construction methods, due to the type of 3-D printer, tools, software, and marketing all have an impact on the start-up cost. The cost of a 3D printer varies depending on the size, capabilities, and quality desired.

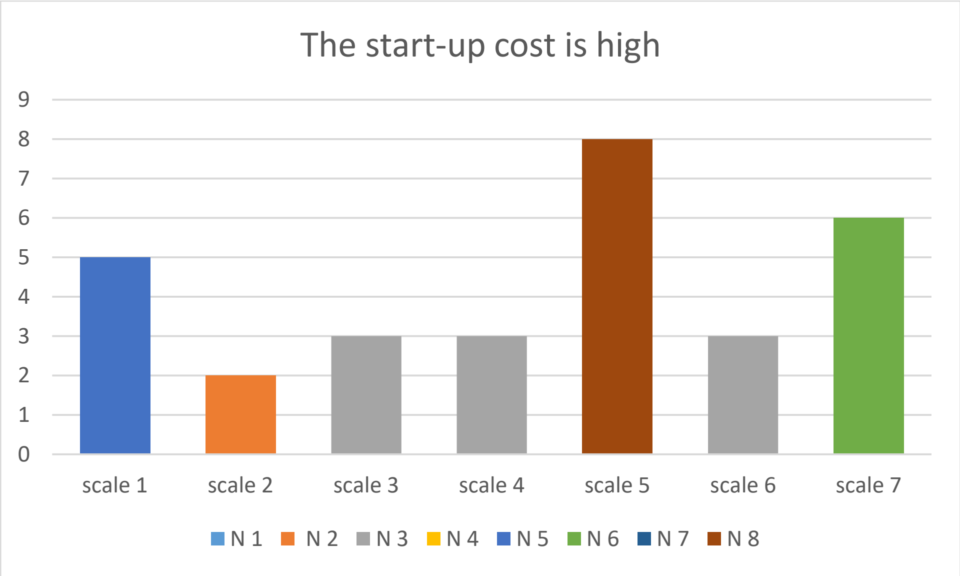
According to (*A Cost Perspective on 3D Printing | PwC Belgium*, n.d.), there are main factors cause the increasement in the start-up cost in this technology, as a direct cost like the machine, materials, labor. Without a doubt, the two most important cost components are material and machine expenses. In general, the price per component rises sharply with the size of the part, because the volume of a product impacts the material cost and the length of time it takes the machine to construct it. The machine component becomes increasingly important in the total cost as the product size decreases, and vice versa. Furthermore, the indirect cost (overhead) which driven by many factors, such as the machine maintenance, production overhead, depreciation.

Table 9 The table below shows an individual ranking answer for each response. | Source: google form

The start-up cost is high.	1	2	3	4	5	6	7
Response 1							✓
Response 2	✓						
Response 3					✓		
Response 4					✓		
Response 5	✓						
Response 6					✓		
Response 7							✓
Response 8							✓
Response 9				✓			
Response 10							✓
Response 11					✓		
Response 12						✓	
Response 13						✓	
Response 14		✓					
Response 15							✓
Response 16		✓					
Response 17	✓						
Response 18	✓						
Response 19			✓				
Response 20					✓		
Response 21					✓		
Response 22			✓				
Response 23					✓		
Response 24					✓		
Response 25						✓	
Response 26				✓			
Response 27				✓			
Response 28							✓
Response 29			✓				
Response 30	✓						

The first factor result show that, five participant selects the scale 1^{st}, two participants select scale 2^{nd}, three participants selects the 3^{rd} scale, three select 4^{th} scale, and the largest number of participants eight has chosen 5^{th} scale, three participants select 6^{th} scale, and finally six of the participants decide to choose scale 7^{th}. On average, as usual, there were both supporters and opponents of this idea, encouraging the idea that 3-D concrete printing technology had a high start-up cost, was their point of view is the machine and material cost higher than the traditional method also if any mistake happen while printing it cannot be treated, so it may increase the wastage in the production stage, as a result the cost will increase. The other side opposed to the point was from their point of view, even if there are large initial costs, but in return, it shortens greater costs during the project's work stages and is able to complete the project in less time, and this helps greatly in reducing costs

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.2. Limitation in materials choice:

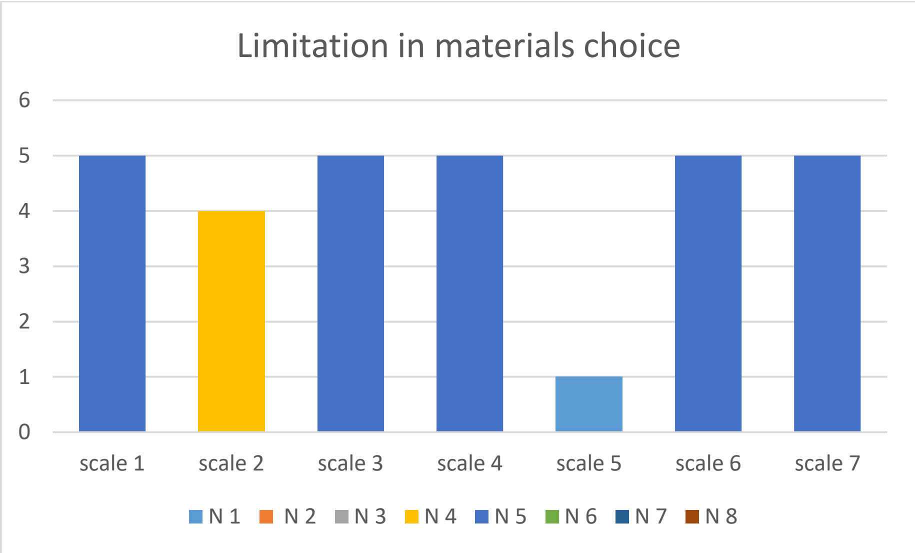
The second factor is 'Limitation in materials choice' which means since the 3-D concrete printing is new technology used in construction, so there is some limitation in the material used in the printer. When unable to select the required material for printing, the restriction of 3D printing is immediately felt. Although the number of material options is expanding in tandem with demand, it is still significantly fewer than those accessible in the traditional production. Plastic is now the most extensively used 3D printing material since it is inexpensive and simple to work with due to its lower melting point. Due to a lack of material options, it is difficult to use 3D printing for a wider range of applications. If you want to print with different materials, you may need to purchase multiple 3D printers. Because each printer only supports a limited amount of materials. A 3D printing procedure that uses metal will not print with polymers and vice versa. Furthermore, when it comes to polymers, certain 3D printers can only print with PLA. Some allow you to print with various plastic materials. (*10 Limitations of 3D Printing Technology - Pick 3D Printer*, n.d.)

Table 10 The table below shows an individual ranking answer for each response. | *Source:* google form

Limitation in materials choice.	1	2	3	4	5	6	7
Response 1		✓					
Response 2						✓	
Response 3						✓	
Response 4						✓	
Response 5				✓			
Response 6		✓					
Response 7				✓			
Response 8				✓			
Response 9			✓				
Response 10				✓			
Response 11			✓				
Response 12							✓
Response 13	✓						
Response 14			✓				
Response 15		✓					
Response 16			✓				
Response 17							✓
Response 18				✓			
Response 19					✓		
Response 20							✓
Response 21			✓				
Response 22						✓	
Response 23						✓	
Response 24							✓
Response 25	✓						
Response 26	✓						
Response 27	✓						
Response 28	✓						
Response 29							✓
Response 30		✓					

The second factor result appear that, five participant selects the scale 1st, four participants select scale 2nd, six participants selects the 3rd scale, five select 4th scale, only one participant has chosen 5th scale, five participants select 6th scale, and again five of the participants decide to choose scale 7th. The results were different, there were those who supported this idea and said that the materials used, especially in the field of construction and erection, are very specific, and there are those who opposed and said that the existing materials are sufficient to some extent and it is possible through the development of technology so that there are greater uses for this technology.

The chart below shows the number of participant’s response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.3. Fewer opportunities for labors:

The third factor ‘Fewer opportunities for labors’ which means that since the printer machine do all the work, the labor opportunities will be less which might cause unemployment. according to (*3D Printing in Construction - Advantages and Innovation*, n.d.), One of the most significant advantages that 3D printers have provided to construction labors is a decrease in on-the-job accidents. Given the difficulty, if not risk, of building with concrete, this is a welcome development. Workers not only have an easier time doing their duties, but employers have less worker's compensation paperwork to sort through as a result of on-the-job accidents. Nevertheless, this technology actually reduces opportunities for the workforce, but on the other hand it reduces the rate of danger and horrific accidents that occur on construction sites.

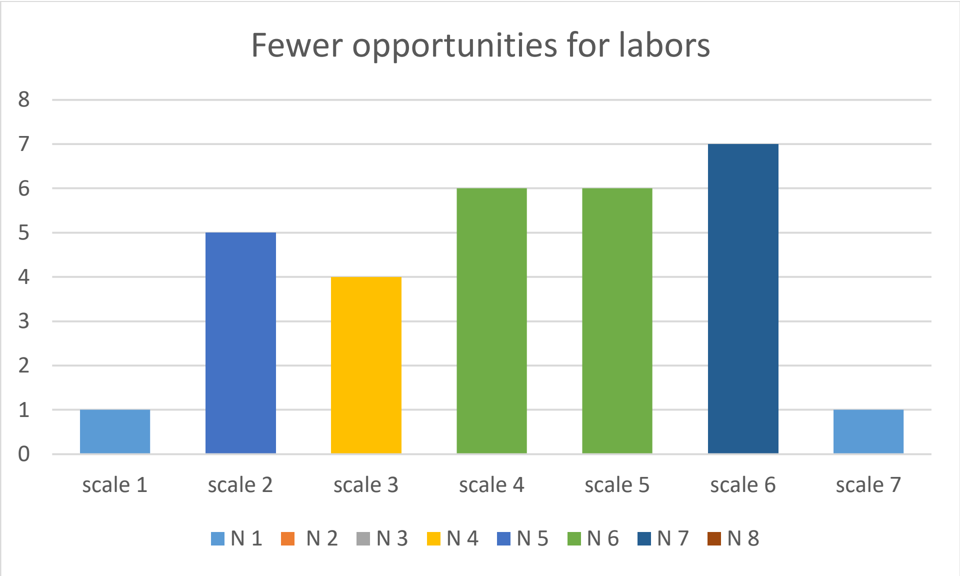
Construction is often a relatively labor-intensive sector; simply look at any big construction site. Building employees will understandably be suspicious of technology that eventually eliminates the need for trained or semi-skilled labor. Should employees and contractors be concerned about the impact of 3D printing adoption in the construction sector on their jobs and career prospects? Mr. Bermejo of Lafarge Hoclim is upbeat, pointing out that 3D printing is only one component of the construction industry's broader modernization and digitalization. "As has been the case in other sectors," he continues, "this will result in a transition to higher-skilled people and newly developing job profiles along the construction value chain." "Education and training are critical for workers to adjust to this transition, and digitization can help in this regard." We also see the potential for 3D printing and digitalization to improve construction worker safety." However, concrete 3D printing is still in its infancy. However, ambitious goals, such as those established in Dubai, will undoubtedly assist to accelerate the development of the technology and bring it closer to the mass building market. (*Will 3D Printing Revolutionise the Construction Industry?*, n.d.)

Table 11 The table below shows an individual ranking answer for each response. | *Source:* google fom

Fewer opportunities for labors	1	2	3	4	5	6	7
Response 1					✓		
Response 2				✓			
Response 3			✓				
Response 4				✓			
Response 5						✓	
Response 6						✓	
Response 7						✓	
Response 8					✓		
Response 9					✓		
Response 10						✓	
Response 11						✓	
Response 12	✓						
Response 13			✓				
Response 14				✓			
Response 15					✓		
Response 16				✓			
Response 17		✓					
Response 18							✓
Response 19				✓			
Response 20						✓	
Response 21		✓					
Response 22					✓		
Response 23		✓					
Response 24						✓	
Response 25					✓		
Response 26			✓				
Response 27			✓				
Response 28		✓					
Response 29		✓					
Response 30				✓			

The third factor result appear that, only one participant selects the scale 1st, five participants select scale 2nd, four participants selects the 3rd scale, six participants select 4th scale, also six participants has chosen 5th scale, largest number of participants seven select 6th scale, and again only one of the participants decide to choose scale 7th. As in the previous evaluation question, there are supporters and opponents, but the largest number of participants rated this factor in the sixth place, and this means that 3D concrete printing does not reduce job opportunities, but rather improves the work atmosphere and gives better opportunities than the traditional method of construction

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.4. Shortage in current codes and regulations:

The fourth factor is 'Shortage in current codes and regulations' because of the lack of references and codes for this technology, it is difficult to develop it to some extent, and it is difficult to draw a clear plan for its use in complex or difficult construction. According to (*3D Printer Safety – Environment, Health, and Safety*, n.d.) 3-D printing is subject to little regulation, and no applicable 3D printing rules could be discovered for the purposes of this paper. To get building code authority clearance for 3D printed construction in jurisdictions, builders must demonstrate that the 3D printed constructions conform with applicable building or residential codes. Because building and residential codes currently lack prescriptive standards for 3D printed structures, code compliance provides a difficulty for both the builder and the code authority. Even code requirements for concrete construction are not directly applicable to cementitious-based 3D printed concrete construction, because the mortar and cement-based manufacturing, printed in a layer-by-layer fashion without trying to form members, is not particularly covered by the concrete standards referred to in the model codes.

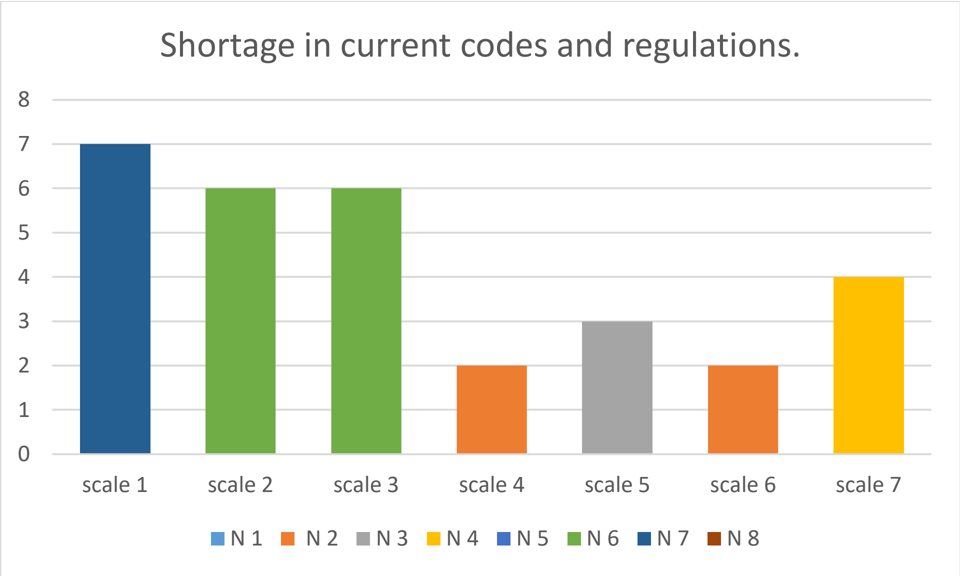
Because there are no prescriptive code requirements for 3D printed building, code authorities must evaluate and approve each project using the code's alternate materials and techniques provisions. (*Build Trust in 3D Manufactured Buildings with UL 3401 | UL*, n.d.)

Table 12 The table below shows an individual ranking answer for each response. | Source: google form

Shortage in current codes and regulations.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Response 1	✓						
Response 2		✓					
Response 3				✓			
Response 4	✓						
Response 5							✓
Response 6			✓				
Response 7		✓					
Response 8			✓				
Response 9	✓						
Response 10			✓				
Response 11	✓						
Response 12		✓					
Response 13							✓
Response 14	✓						
Response 15	✓						
Response 16	✓						
Response 17			✓				
Response 18					✓		
Response 19							✓
Response 20			✓				
Response 21				✓			
Response 22		✓					
Response 23			✓				
Response 24		✓					
Response 25							✓
Response 26		✓					
Response 27					✓		
Response 28					✓		
Response 29						✓	
Response 30						✓	

The fourth factor result appear that, seven participants selects the scale 1st, six participants select scale 2nd, again six participants selects the 3rd scale, two participants select 4th scale, three participants has chosen 5th scale, two select 6th scale, four of the participants decide to choose scale 7th. In general, there were more supporters of this point than its opponents, that there is a greater shortage of codes and provisions related to this technology, and this means that studies must be developed in a large and extensive manner in this field, and research must also be developed to codes building requirements using this technology.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.5. Shortage in suppliers:

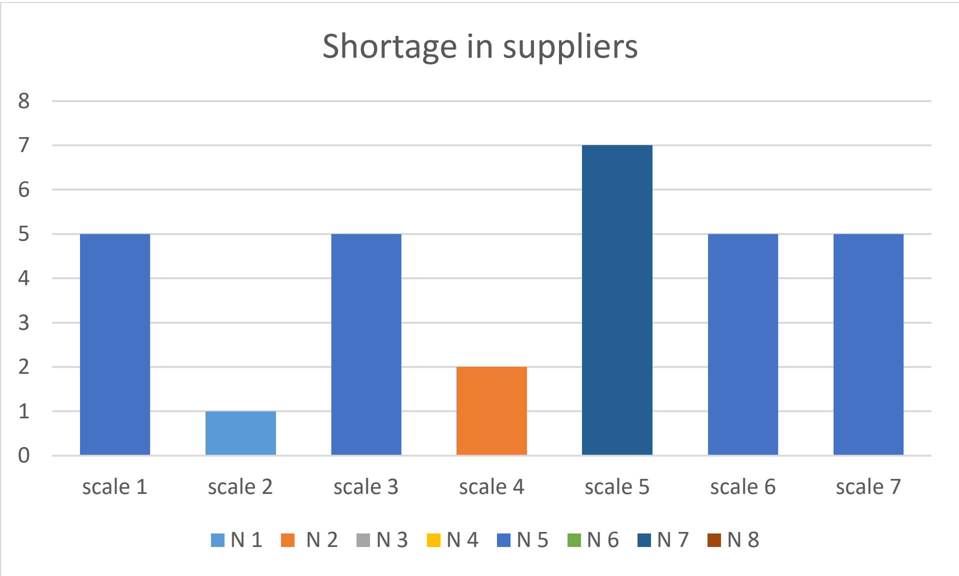
The fifth point is 'shortage in suppliers' it means that the suppliers are very limited all over the world and in some countries, there is no suppliers for this technology so in order to help the improvement of this technology the number of suppliers should be increased. According to many suppliers of the 3D printing industry like , the shortage of suppliers in some countries is not the main obstacle to the development of this technology in construction, the investment will open the doors for global suppliers to open multiple branches in these countries, the beginning is the essential point that will attract the few suppliers In the world and will push many investors to open the supply in the 3D concrete printing industry, many designers consider that the shortage of suppliers is the obstacle, but in fact there are two companies in the United Arab Emirates engaged in 3D concrete printing and these two licensed companies managed to produce more than A project. There are also projects under implementation. It is expected that the number of companies licensed for 3D concrete printing will increase during the coming period. (*3D Construction Printing*, n.d.).

Table 13 The table below shows an individual ranking answer for each response. | *Source:* google form

Shortage in suppliers.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Response 1				✓			
Response 2					✓		
Response 3	✓						
Response 4							✓
Response 5					✓		
Response 6							✓
Response 7			✓				
Response 8	✓						
Response 9							✓
Response 10	✓						
Response 11		✓					
Response 12					✓		
Response 13					✓		
Response 14						✓	
Response 15			✓				
Response 16						✓	
Response 17						✓	
Response 18						✓	
Response 19	✓						
Response 20	✓						
Response 21						✓	
Response 22				✓			
Response 23							✓
Response 24			✓				
Response 25			✓				
Response 26					✓		
Response 27							✓
Response 28			✓				
Response 29					✓		
Response 30					✓		

The fifth factor result show that, five participants selects the scale 1st, only one of the participants select scale 2nd, again five participants selects the 3rd scale, two participants select 4th scale, seven participants has chosen 5th scale, five select 6th scale, again five of the participants decide to choose scale 7th. The largest number were opposed to the idea that the lack of suppliers is a major reason for the delay in 3D concrete printing, and they stressed that if there is encouragement and motivation to build using this technology, everyone will go to identifying resources even if it is outside the country, but the basis of weakness is that there is no codes and instructions for building with this technology, so international suppliers have not tended to invest in areas that do not develop in terms of this technology. And there is a side who believes that suppliers are an essential factor that makes technology develop more and makes it easier for people to deal with this technology.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.6. Compatibility issues with current design and construction methods:

The sixth factor is 'Compatibility issues with current design and construction methods' this means that the current methods are not compatible with 3D concrete printing, as each method has a different construction method and different devices and equipment, and the work on the site is different and it is difficult to combine the two methods together. According to (*5 Problems With 3D Printing and Proposed Solutions for the Industry*, n.d.) ,the workflow is old and out of date, and it is still based on the traditional sequential method of Human: Design, Computer: Document, and Analyze. Typically, the 3D-printing procedure does not make use of generative design or other manufacturing advances. The difficulty with the existing approach is that designers sketch something first, and then the robot draws stuff in the 3D printer. That means people are still designing the same old pieces and expecting the

3D-printed results to be unique. People are squandering the power of 3D printing as long as their sketching talents get in the way. Delegating more of the actual design to the computer would be preferable. In fact, if designers truly embraced that approach, they might allow the program to generate designs that were more complex than anything they could sketch. Using the outdated attitude that designers must perform all of the work, the outcome of their efforts will always be limited by their time, money, and patience constraints. They are frequently limited to only one or two options at a time and then only print the better one, rather than the greatest potential design. Designers must change their perspective and cease viewing their computers as just drawing
tools. They are not just used for execution. They should broaden their exploration.

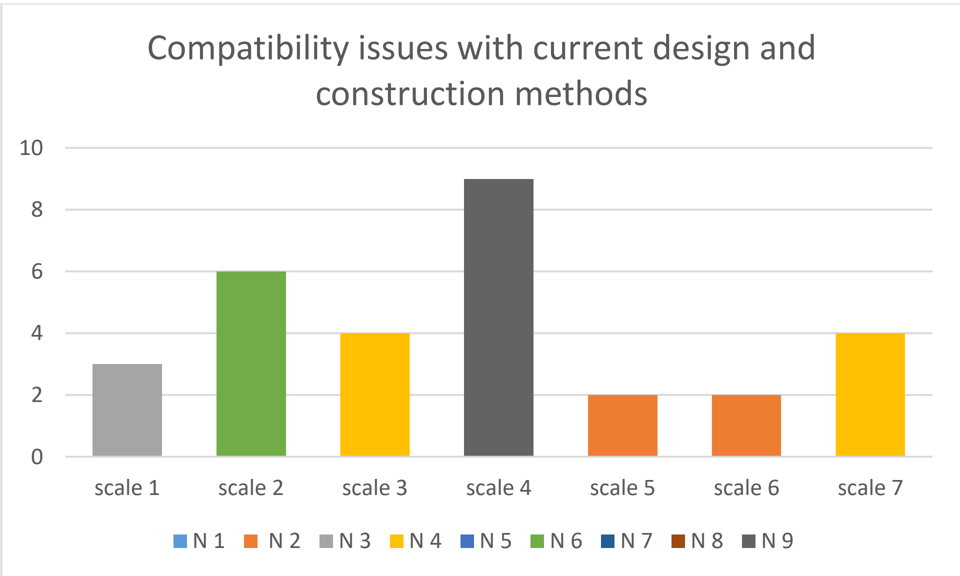
Table 14 The table below shows an individual ranking answer for each response. | Source: google form

Compatibility issues with current design and construction methods	1	2	3	4	5	6	7
Response 1						✓	
Response 2							✓
Response 3		✓					
Response 4			✓				
Response 5			✓				
Response 6				✓			
Response 7	✓						
Response 8		✓					
Response 9		✓					
Response 10		✓					
Response 11				✓			
Response 12			✓				
Response 13		✓					
Response 14					✓		
Response 15				✓			
Response 16					✓		
Response 17				✓			
Response 18			✓				
Response 19		✓					
Response 20				✓			
Response 21	✓						
Response 22							✓

Response 23				✓			
Response 24	✓						
Response 25				✓			
Response 26							✓
Response 27						✓	
Response 28				✓			
Response 29				✓			
Response 30							✓

The sixth factor result show that, three participants selects the scale 1st, sex participants select scale 2nd, four participants selects the 3rd scale, nine participants select 4th scale, two participants has chosen 5th scale, again two select 6th scale, four of the participants decide to choose scale 7th. Most of the participants evaluated the importance of this factor in the middle. They did not consider it a factor of great importance because they believe that if the engineers and designers find a solution or a way to integrate the two methods in the construction, it will be easy to address this problem.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.1.2.7. Shortage in professional employment.

The last factor is 'the shortage in professional employment' which means, the 3-D concrete printing This factor means that 3D concrete printing is a machine, computer and design, and to implement a project that consists of this technology, workers who have knowledge of how to deal with these machines and devices must be available, because a single mistake in this technology may cause a lot of losses material and time wasting, and also the workers must be immunized and aware of how to use such machines because they are dangerous to health if used incorrectly.

What use are these positions if no one is qualified to fill them? Schools are planning (and some have already begun) 3D printing programs at all grade levels to cover the skills gap. This will create opportunities for educators to educate the technical and business elements of 3D printing. "Understanding 3D modeling and 3D printing processes will be helpful for educators as the culture of fab labs gains traction as a major element of education. Teachers with 3D modeling and fabrication experience have a variety of opportunities in educational programs that are incorporating this new technology "Gunduz stated. (*Hot 3D Printing Jobs on the Rise - Businessnewsdaily.Com*, n.d.)

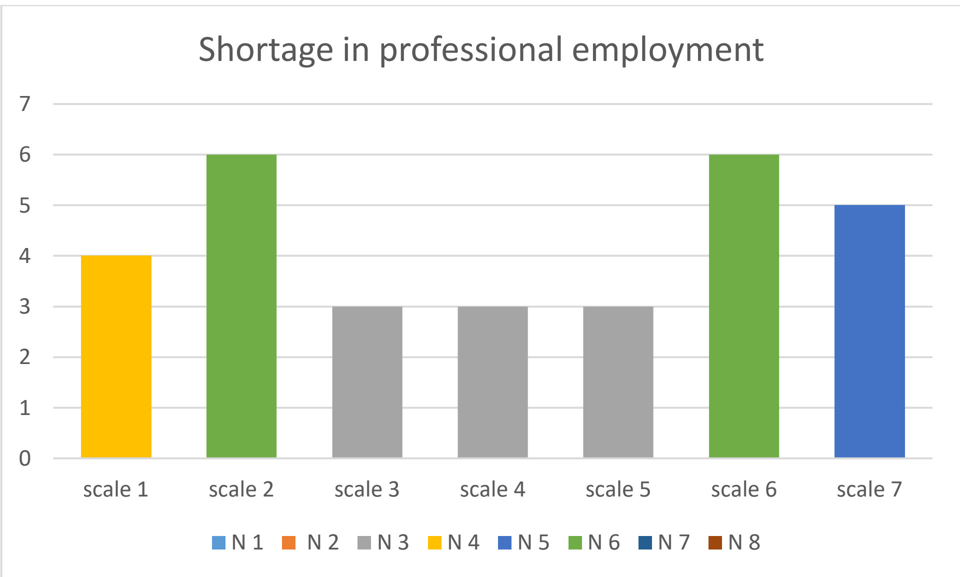
Table 15 The table below shows an individual ranking answer for each response. | Source: google form

Shortage in professional employment	1	2	3	4	5	6	7
Response 1			✓				
Response 2			✓				
Response 3							✓
Response 4		✓					
Response 5		✓					
Response 6	✓						
Response 7					✓		
Response 8						✓	
Response 9						✓	
Response 10					✓		
Response 11							✓
Response 12				✓			
Response 13				✓			
Response 14							✓
Response 15						✓	
Response 16							✓
Response 17					✓		
Response 18		✓					
Response 19						✓	
Response 20		✓					

Response 21							✓
Response 22	✓						
Response 23	✓						
Response 24				✓			
Response 25		✓					
Response 26						✓	
Response 27		✓					
Response 28						✓	
Response 29	✓						
Response 30			✓				

The seventh and last factor show that, four participants selects the scale 1st, sex participants select scale 2nd, three participants selects the 3rd scale, again three participants select 4th scale, also three participants has chosen 5th scale, six select 6th scale, five of the participants decide to choose scale 7th. As in the previous factors, there were supporters and opponents of the idea, and supporters said that this industry can only be developed through education and education requires time and effort and teachers who have experience in this field. On the other hand, opponents said that this point is not considered a major obstacle to the development of this industry, and with the development of programs, this technology can be learned smoothly.

The chart below shows the number of participant's response (N), with the rank scale from 1 important to 7 less important.



4.4.2. Unipolar Rating Scales Questions:

Unipolar scales ask respondents to score the existence (or absence) of a certain quality or feature, such as usefulness or satisfaction. A five-point scale is commonly used for this.

Linear scale questions allow users to respond to a statement or inquiry with a number response. You may compute the score by assigning standard points or weights to each response. (*Scorecery - How to Assign Points for Linear Scale Question?*, n.d.).

In this question five important factors were listed, and the participants were asked to rate each factor from 1 extremely effective to 5 not at all effective. Each factor will be discussed below.

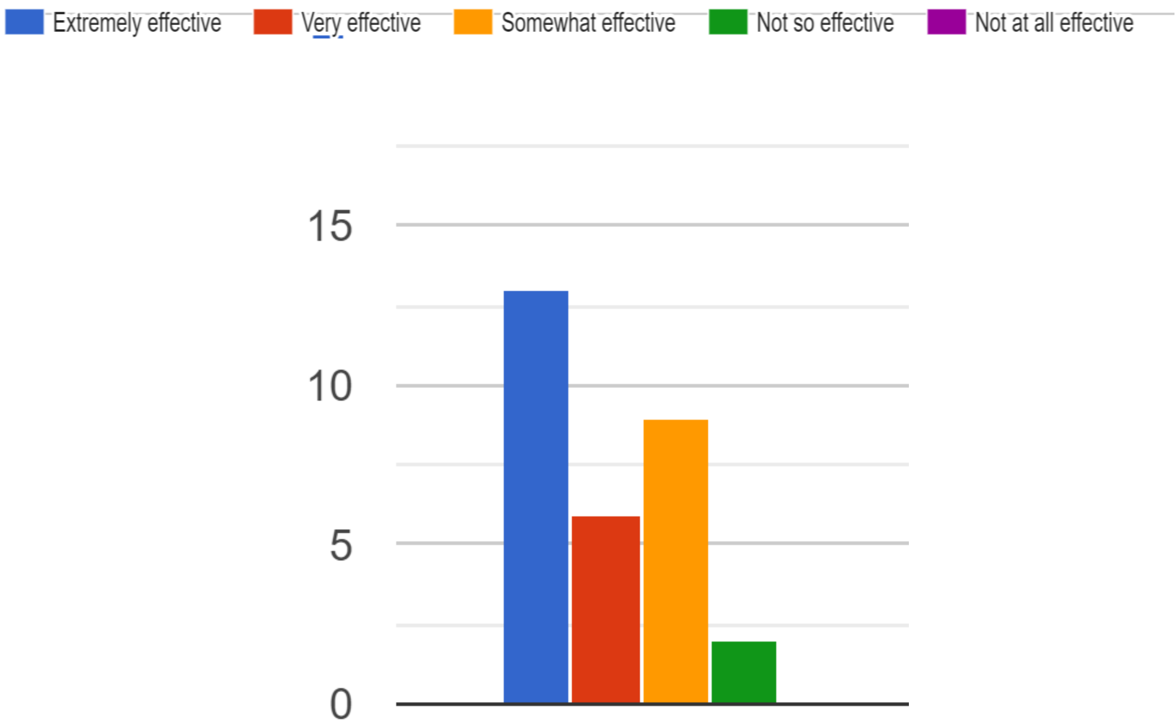
4.4.2.1.Cooperation between suppliers and contractors:

Cooperation between suppliers for the 3D concrete printing industry and contractors is an active and main factor for every growth and development of this industry in the future and this cooperation occurs when there is a unified pattern that all those responsible for this type of industries can emulate.

Table 16 The table below show how the participants rate each factor| Source: google form

Cooperation between suppliers and contractors.	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Response 1	✓				
Response 2	✓				
Response 3			✓		
Response 4			✓		
Response 5		✓			
Response 6				✓	
Response 7				✓	
Response 8	✓				
Response 9		✓			
Response 10	✓				
Response 11	✓				
Response 12			✓		
Response 13		✓			
Response 14	✓				
Response 15	✓				
Response 16		✓			
Response 17			✓		
Response 18		✓			

Response 19	✓				
Response 20	✓				
Response 21			✓		
Response 22			✓		
Response 23			✓		
Response 24	✓				
Response 25	✓				
Response 26	✓				
Response 27			✓		
Response 28	✓				
Response 29			✓		
Response 30		✓			



Cooperation between suppliers and contractors.

This chart shows around 13 responses select extremely effective, 6 of them select very effective, 9 of them choose somewhat effective, 2 response select not so effective, finally no one selects not at all effective. Most of the response goes with extremely effective which means that this point should be taken under consideration, and should be studied in order to develop the 3-D printing concrete technology.

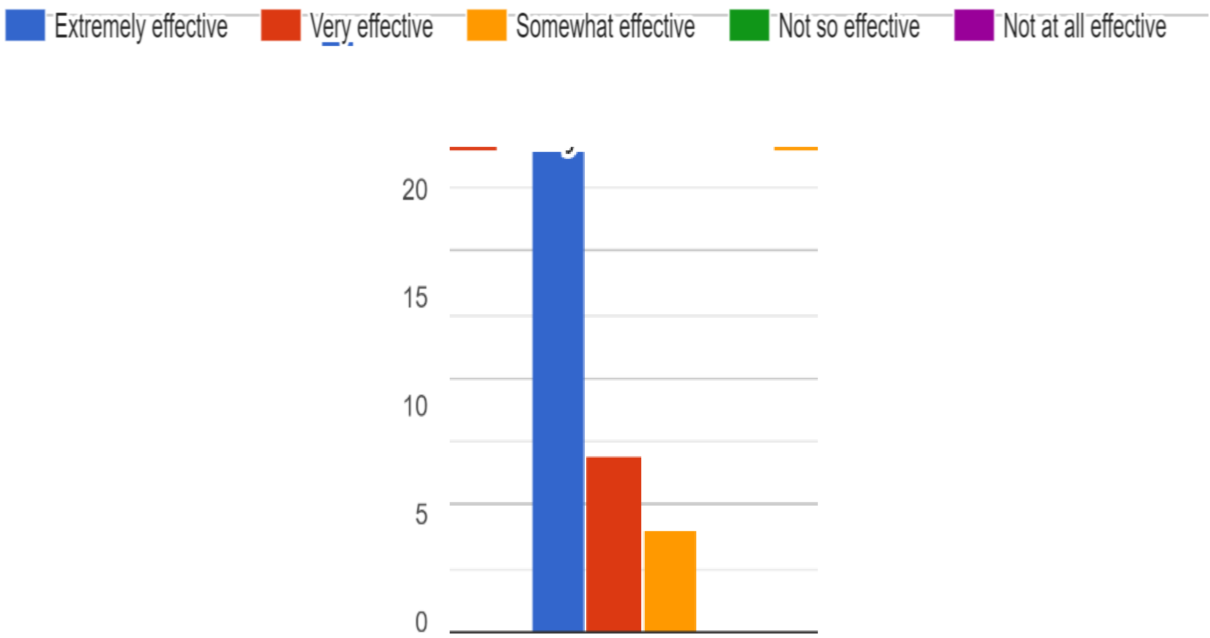
4.4.2.2.Develop academic and scientific research such as codes to be followed:

As it is known that the development of each industry depends on the scientific aspect, and the development of the practical aspect is very necessary, especially in the construction industry, so 3D concrete printing must be fortified and supported with research and scientific studies in order to spread its use and at the same time facilitate its use.

Table 17 The table below show how the participants rate each factor| Source: google form

Develop academic and scientific research such as codes to be followed.	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Response 1	✓				
Response 2	✓				
Response 3	✓				
Response 4	✓				
Response 5		✓			
Response 6			✓		
Response 7			✓		
Response 8	✓				
Response 9	✓				
Response 10		✓			
Response 11		✓			
Response 12			✓		
Response 13		✓			
Response 14	✓				
Response 15	✓				
Response 16			✓		
Response 17		✓			
Response 18	✓				
Response 19	✓				
Response 20	✓				
Response 21		✓			
Response 22	✓				
Response 23	✓				
Response 24	✓				
Response 25		✓			

Response 26	✓				
Response 27	✓				
Response 28	✓				
Response 29	✓				
Response 30	✓				



Develop academic and scientific research such as codes to be followed.

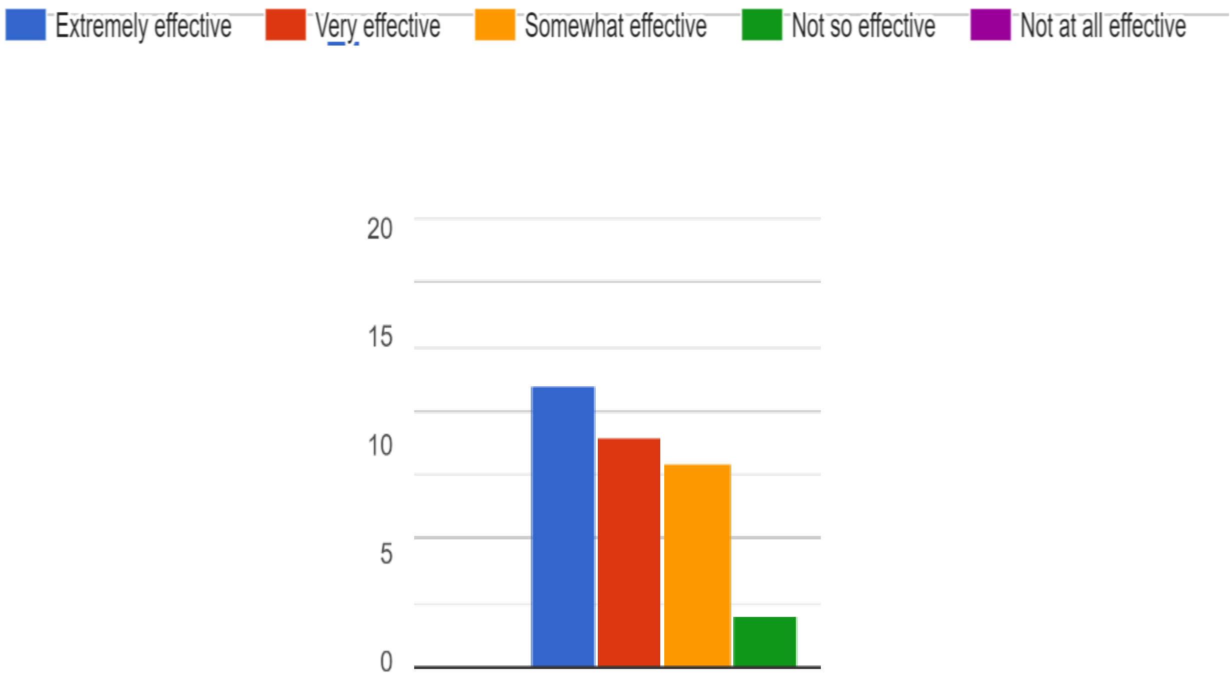
The above table and chart show that, 19 of the response select extremely effective, 7 of them select very effective, 4 only goes with somewhat effective, and no one choose not so effective or not at all effective. This means that this factor is an essential factor, and real measures must be taken for it to develop this technology.

4.4.2.3.Follow a strategy to develop Skilled employment for Operation:

There is no doubt that any industry in the world needs professional craftsmen and workers in it, as is the case in 3D concrete printing. This technology needs very skilled workers, although most of the work is done by the machine, but there are basic touches that the professional worker must put in order to help the computer and machine to produce a perfect final model.

Table 18 The table below show how the participants rate each factor| Source: google form

Follow a strategy to develop Skilled employment for Operation	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Response 1	✓				
Response 2	✓				
Response 3	✓				
Response 4		✓			
Response 5		✓			
Response 6			✓		
Response 7				✓	
Response 8	✓				
Response 9		✓			
Response 10		✓			
Response 11	✓				
Response 12			✓		
Response 13				✓	
Response 14	✓				
Response 15	✓				
Response 16			✓		
Response 17		✓			
Response 18			✓		
Response 19	✓				
Response 20			✓		
Response 21		✓			
Response 22			✓		
Response 23	✓				
Response 24			✓		
Response 25			✓		
Response 26	✓				
Response 27		✓			
Response 28	✓				
Response 29		✓			
Response 30		✓			



Follow a strategy to develop Skilled employment for Operation

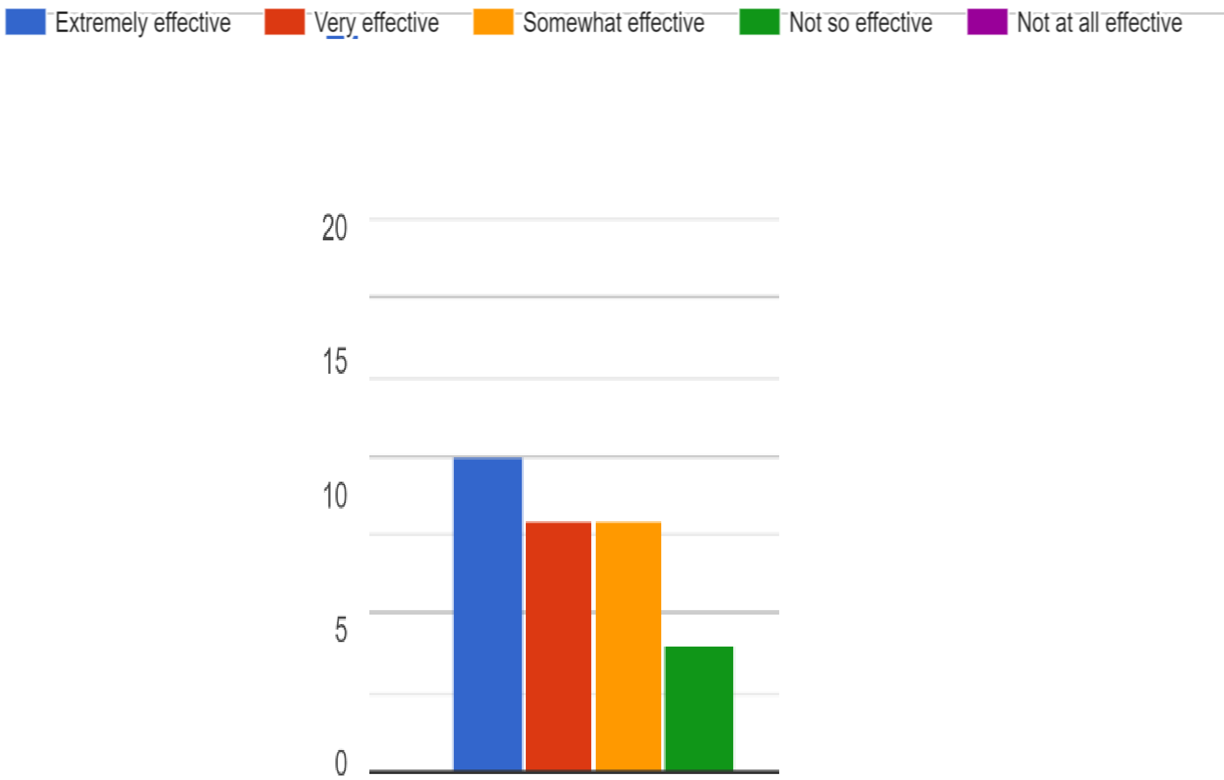
From the table and chart above its clear that, 11 response choose extremely effective, 9 of them select very effective, 8 response goes with somewhat effective, and 2 select not so effective, finally zero select not at all effective. This means that the development of this technology is linked to the development of manpower and the treatment of shortages and weaknesses in this field.

4.4.2.4.Leadership commitment:

In all cases, wise leadership is always the basis for the development of any business, and in the case of 3D concrete printing, the leadership and its support are a major incentive for development in this field, especially since the technology is new and needs to be adopted. For example, the Emirate of Dubai adopted this technology and developed more than one scientific research and learned about projects that were completed, and all this is due to the wise leadership.

Table 19 The table below show how the participants rate each factor| Source: google form

Leadership commitment.	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Response 1	✓				
Response 2	✓				
Response 3	✓				
Response 4				✓	
Response 5		✓			
Response 6	✓				
Response 7				✓	
Response 8		✓			
Response 9		✓			
Response 10	✓				
Response 11		✓			
Response 12			✓		
Response 13				✓	
Response 14			✓		
Response 15	✓				
Response 16			✓		
Response 17		✓			
Response 18			✓		
Response 19	✓				
Response 20			✓		
Response 21				✓	
Response 22		✓			
Response 23	✓				
Response 24			✓		
Response 25	✓				
Response 26	✓				
Response 27			✓		
Response 28			✓		
Response 29		✓			
Response 30		✓			



Leadership commitment.

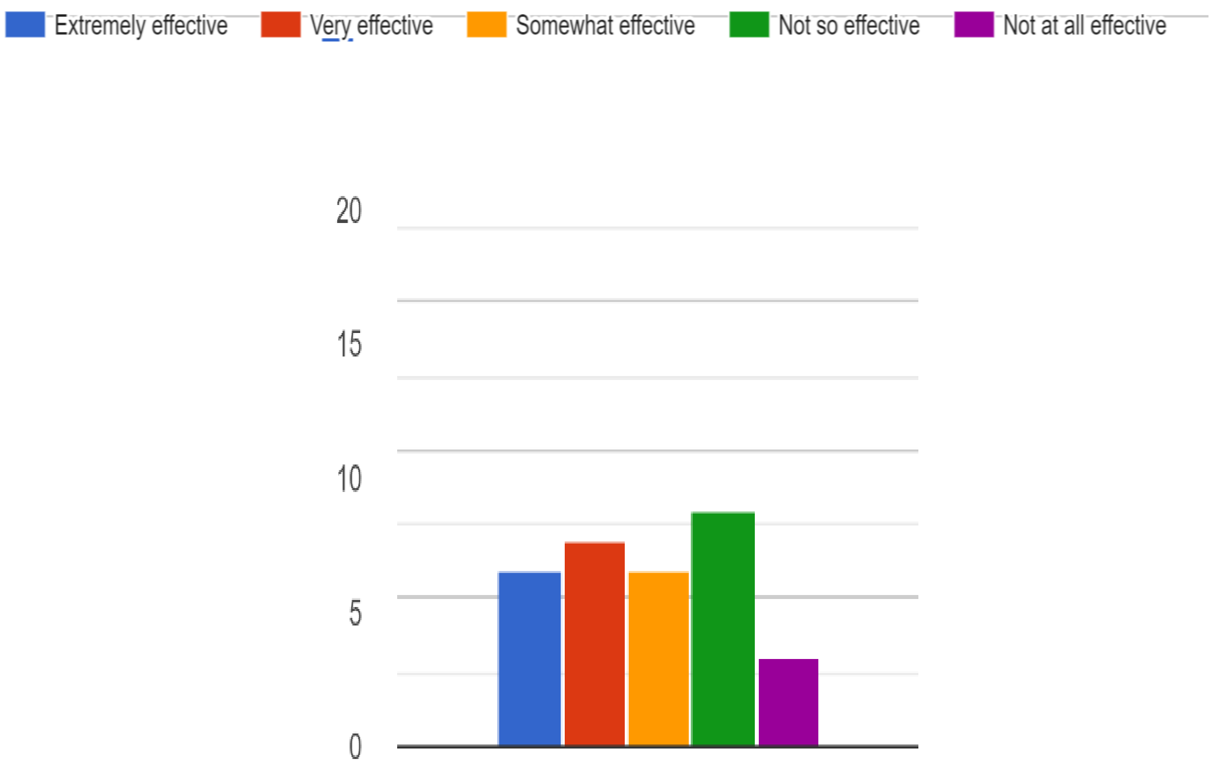
From the information above, 10 of the response select extremely effective, 8 of them select very effective, again 8 choose somewhat effective, 4 choose not so effective, finally no one selects not at all effective. This means that there is a supportive part and a large part also neutral to this idea, but from my point of view that the leadership has an influence in one way or another in the development of any modern science or technology by setting a clear plan and following it.

4.4.2.5.Increase the number of suppliers:

As with the previous questions, the participants differed between supporters and opponents of this factor. But in fact, the presence of many suppliers in the country is an important point to allow the contractor to choose the appropriate supplier. This also contributes to reducing prices from suppliers. This factor must also be taken under consideration.

Table 20 The table below show how the participants rate each factor| Source: google form

Increase the number of suppliers	Extremely effective	Very effective	Somewhat effective	Not so effective	Not at all effective
Response 1		✓			
Response 2	✓				
Response 3			✓		
Response 4					✓
Response 5		✓			
Response 6		✓			
Response 7				✓	
Response 8		✓			
Response 9		✓			
Response 10	✓				
Response 11		✓			
Response 12			✓		
Response 13					✓
Response 14			✓		
Response 15	✓				
Response 16			✓		
Response 17		✓			
Response 18				✓	
Response 19	✓				
Response 20				✓	
Response 21					✓
Response 22				✓	
Response 23			✓		
Response 24				✓	
Response 25				✓	
Response 26	✓				
Response 27				✓	
Response 28			✓		
Response 29				✓	
Response 30	✓				



Increase the number of suppliers

The final point results approve that, 8 response select not so effective, 7 of the response goes with very effective, 6 choose extremely effective, again 6 select somewhat effective, finally only three select not at all effective. A large part of the participants believe that this factor is not necessary to this extent, and if the number of suppliers is few, it does not significantly affect the development of this technology.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

Following our studies and survey, it became clear that 3D concrete printing technology is the future of construction, and I believe that many investors and contractors will turn to this technology due to the numerous benefits we mentioned earlier, but I believe that what limits the spread of this technology and work with it is a lack of references. As a result, it is advised that this technology be investigated further and that efforts be made to develop and facilitate its usage by offering a scientifically accepted code as well as suppliers of printers and materials used all over the world. Most importantly, workers with strong experience are developed inside Private schools and in the hands of professionals in this sector to support the usage of printers in the proper manner and without any hazards to the workers or printers.

It was clear from the answers that we got from the questionnaire that all participants are largely supportive of this technology, but they suffer from one obstacle, which is the lack of references, suppliers and experience in this field. If these shortcomings are provided, this technology will work more than construction methods traditional

The world is continuously changing, therefore all sectors must keep up, especially construction, which is one of the greatest areas in which money is spent, as well as one of the most areas that employ people and in which nations' economies are constructed, so we must constantly work properly developed. 3D printing of concrete is a construction revolution that we must capitalize on and expand, especially because 3D printing in other industries such as medical and industry has advanced significantly and has become one of the most essential technologies accessible today.

Finally, with the recent surge in 3D printer manufacturing and how rapidly they have been updated to appeal to the market, there are many opportunities to expand into other fields. It has progressed from a printer that manufactured little plastic products to the point where it may possibly take over a lot of manufacturing enterprises in a short amount of time. Over time, many institutions such as schools, hospitals, and the workplace will be introduced to this technology, and people will be able to see what can be done to make 3D printers useful.
As time passes, developers and tech businesses will collaborate to invent and enhance 3D printers.

6. REFERENCES

Anissimov, M. (2021). *What is the 3D printing technology*. Retrieved from INFO BLOOM: http://www.infobloom.com

EcoMEN. (2020). *Green building sector in UAE*. Retrieved from EcoMEN: http://www.ecomena.org

Grand, R. (2021). *3D printing market size.* market analysis report.

Markerbot. (2019). *Top 3D printing applecation* . Retrieved from markerbot: http//www.markerbot.com

MarketDataForecast. (2019). *Global 3D printing market segmentation by componant*. Retrieved from MarketDataForecast: http//:marketforecast.com

Martin, Robert L., Bowsen, Nicholass, Marrill Chris. (2014). 3D printing technology. *3D printing technology & engineering education*.

Municipility, D. (2014). *Green building stratgic*. Retrieved from Dubai Municipility: http://www.dm.gov.ae

N.N., V. (2016). Ready mix concrete. *3D printing technology on site construction*.

T.W.I. (2020). *The types of the 3D printing technology* . Retrieved from TWI global : http://www.TWI-GLOBAL.com

3D Construction Printing. (n.d.). Retrieved January 24, 2022, from https://www.peri.com/en/business-segments/3d-construction-printing.html

3D Printed Concrete Buildings- Working & Features - The Constructor. (n.d.). Retrieved January 7, 2022, from https://theconstructor.org/concrete/3d-printed-concrete-buildings-working-features/39027/

3D Printer Safety – Environment, Health, and Safety. (n.d.). Retrieved January 12, 2022, from https://aeroastro-ehs.mit.edu/resources/3d-printer-safety/

3D Printing: 8 Major Changes Coming to Construction - Construction World. (n.d.). Retrieved January 6, 2022, from http://www.constructionworld.org/impact-3d-printing-construction-industry/

3D Printing in construction - advantages and innovation. (n.d.). Retrieved January 12, 2022, from https://www.constrofacilitator.com/3d-printing-in-construction-advantages-and-innovation/

5 Problems With 3D Printing and Proposed Solutions for the Industry. (n.d.). Retrieved January 24, 2022, from https://redshift.autodesk.com/5-problems-with-3d-printing-and-how-to-fix-them/

10 Limitations of 3D Printing Technology - Pick 3D Printer. (n.d.). Retrieved January 9, 2022, from https://pick3dprinter.com/limitations-of-3d-printing/#the-printing-materials-are-limited

A cost perspective on 3D printing | PwC Belgium. (n.d.). Retrieved January 9, 2022, from https://www.pwc.be/en/news-publications/insights/2017/cost-perspective-3d-printing.html

Bai, G., Wang, L., Wang, F., & Ma, G. (2021). In-process reinforcing method: dual 3D printing procedure for ultra-high performance concrete reinforced cementitious composites. *Materials Letters, 304*, 130594. https://doi.org/10.1016/J.MATLET.2021.130594

BESIX 3D - BESIX Group's innovative 3D concrete printing solutions. (n.d.). Retrieved January 7, 2022, from https://3d.besix.com/

Boone, H. N., Associate Professor, J., & Boone Associate Professor, D. A. (2012). *Number 2 Article Number 2TOT2* (Vol. 50). http://www.joe.org/joe/2012april/tt2p.shtml[8/20/20129:07:48AM]

Bos, F., Wolfs, R., Ahmed, Z., & Salet, T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing. *Virtual and Physical Prototyping*, *11*(3), 209–225. https://doi.org/10.1080/17452759.2016.1209867

Build Trust in 3D Manufactured Buildings with UL 3401 | UL. (n.d.). Retrieved January 12, 2022, from https://www.ul.com/news/build-trust-3d-manufactured-buildings-ul-3401

Buswell, R. A., Soar, R. C., Gibb, A. G. F., & Thorpe, A. (2007). Freeform Construction: Mega-scale Rapid Manufacturing for construction. *Automation in Construction*, *16*(2), 224–231. https://doi.org/10.1016/J.AUTCON.2006.05.002

Collins, H. (2010). Creative Research: The Theory and Practice of Research for the Creative Industries. *AVA Publications*.

Demyanenko, O., Sorokina, E., Kopanitsa, N., & Sarkisov, Y. (2018). Mortars for 3D printing. *MATEC Web of Conferences*, *143*. https://doi.org/10.1051/matecconf/201714302013

Edwards, & Steven. (2008). Death's Dominion, Ethics at the end of life. *Nursing Philosophy*, *9*.

Frowe, I. (2001). Language and Educational Research. *Journal of Philosophy of Education*, *35*(2), 175–186. https://doi.org/10.1111/1467-9752.00219

Gibson, I. (2002). *Software solutions for Rapid Prototyping: Vol. 380 P*.

Gjørv, O. E. (2011). Durability of concrete structures. In *Arabian Journal for Science and Engineering* (Vol. 36, Issue 2, pp. 151–172). Springer Verlag. https://doi.org/10.1007/s13369-010-0033-5

Gosselin, C., Duballet, R., Roux, P., Gaudillière, N., Dirrenberger, J., & Morel, P. (2016). Large-scale 3D printing of ultra-high performance concrete – a new processing route for architects and builders. *Materials & Design*, *100*, 102–109. https://doi.org/10.1016/J.MATDES.2016.03.097

Griffith, A. B., Salguero-Gómez, R., Merow, C., & Mcmahon, S. (2016). Demography beyond the population. *Journal of Ecology*, *104*(2), 271–280. https://doi.org/10.1111/1365-2745.12547

Hager, I., Golonka, A., & Putanowicz, R. (2016). 3D Printing of Buildings and Building Components as the Future of Sustainable Construction? *Procedia Engineering*, *151*, 292–299. https://doi.org/10.1016/J.PROENG.2016.07.357

Hanna, M., Schwede, L.-N., & Krause, D. (n.d.). Model-Based Consistency for Design for Variety and Modularization. In *20 TH INTERNATIONAL DEPENDENCY AND STRUCTURE MODELING CONFERENCE*.

Hot 3D Printing Jobs on the Rise - businessnewsdaily.com. (n.d.). Retrieved January 25, 2022, from https://www.businessnewsdaily.com/10211-hot-3d-printing-jobs-on-the-rise.html

Hou, S., Xiao, J., Duan, Z., & Ma, G. (2021). Fresh properties of 3D printed mortar with recycled powder. *Construction and Building Materials*, *309*, 125186. https://doi.org/10.1016/J.CONBUILDMAT.2021.125186

Jayathilakage, R., Rajeev, P., & Sanjayan, J. (2020). Yield stress criteria to assess the buildability of 3D concrete printing. *Construction and Building Materials*, *240*, 117989. https://doi.org/10.1016/J.CONBUILDMAT.2019.117989

JOHN BIGGS. (2021, January 25). *6 of the World's Most Impressive 3D Printed Buildings*. JOBSITE.

Khoshnevis, B. (2004a). Automated construction by contour crafting—related robotics and information technologies. *Automation in Construction*, *13*(1), 5–19. https://doi.org/10.1016/J.AUTCON.2003.08.012
Khoshnevis, B. (2004b). Automated construction by contour crafting - Related robotics and information technologies. *Automation in Construction*, *13*(1), 5–19. https://doi.org/10.1016/j.autcon.2003.08.012
Ko, C. H. (2021). Constraints and limitations of concrete 3D printing in architecture. In *Journal of Engineering, Design and Technology*. Emerald Group Holdings Ltd. https://doi.org/10.1108/JEDT-11-2020-0456
Kothari CR. (2017). Research Methodolgy, Revised (2nd ed). *New Age International Publishers*.
Kothman, I., & Faber, N. (2016). How 3D printing technology changes the rules of the game Insights from the construction sector. *Journal of Manufacturing Technology Management*, *27*(7), 932–943. https://doi.org/10.1108/JMTM-01-2016-0010
Kura, T., Tangata, M., & Beasley, A. (n.d.). *SCHOOL OF SOCIAL AND CULTURAL STUDIES*.
Kuzmenko, K. , Gaudillière, N., Feraille, A., Dirrenberger, J., & Baverel, O. (2019). Assessing the environmental viability of 3D concrete printing technology. *In Design Modelling Symposium Berlin*, 517–528.
Labaree, & Robert V. (2009). Research Guides: Organizing Your Social Sciences Research Paper: *5. The Literature Review*.
Le, V. T., Paris, H., & Mandil, G. (2017). Process planning for combined additive and subtractive manufacturing technologies in a remanufacturing context. *Journal of Manufacturing Systems*, *44*, 243–254. https://doi.org/10.1016/J.JMSY.2017.06.003
Lievaart, J. J., & Noordhuizen, J. P. T. M. (2011). Ranking experts' preferences regarding measures and methods of assessment of welfare in dairy herds using Adaptive Conjoint Analysis. *Journal of Dairy Science*, *94*(7), 3420–3427. https://doi.org/10.3168/JDS.2010-3954
Lim, S., Buswell, R., Le, T., Wackrow, R., Austin, S., Gibb, A., & Thorpe, T. (2011). Development of a viable concrete printing process. *Proceedings of the 28th International Symposium on Automation and Robotics in Construction, ISARC 2011*, 665–670. https://doi.org/10.22260/isarc2011/0124
Moors, G., Vriens, I., Gelissen, J. P. T. M., & Vermunt, J. K. (2016). Two of a kind. Similarities between ranking and rating data in measuring work values. *Survey Research Methods*, *10*(1), 15–33. https://doi.org/10.18148/srm/2016.v10i1.6209
Mouter, N., Annema, J. A., & van Wee, B. (2013). Ranking the substantive problems in the Dutch Cost–Benefit Analysis practice. *Transportation Research Part A: Policy and Practice*, *49*, 241–255. https://doi.org/10.1016/J.TRA.2013.01.020
Myers, M. D. (2008). Qualitative Research in Business & Management. *SAGE Publications*.
Nerella, V. N., Hempel, S., & Mechtcherine, V. (2019). Effects of layer-interface properties on mechanical performance of concrete elements produced by extrusion-based 3D-printing. *Construction and Building Materials*, *205*, 586–601. https://doi.org/10.1016/J.CONBUILDMAT.2019.01.235
Newman, I., & Ridenour, C. (1998). *Qualitative-Quantitative Research Methodology: Exploring the Interactive Continuum Qualitative-Quantitative Research: A False Dichotomy*.

http://ecommons.udayton.edu/eda_fac_pubhttp://ecommons.udayton.edu/eda_fac_pub/122
Nithesh. (n.d.). *Development of concrete 3D printing*.
Ortega, G. S., Madrid, J. A., Olsson, N. O. E., & Tenorio Ríos, J. A. (2020). The application of 3D-printing techniques in the manufacturing of cement-based construction products and experiences based on the assessment of such products. *Buildings*, *10*(9). https://doi.org/10.3390/BUILDINGS10090144
Paul, S. C., van Zijl, G. P. A. G., Tan, M. J., & Gibson, I. (2018). A review of 3D concrete printing systems and materials properties: current status and future research prospects. *Rapid Prototyping Journal*, *24*(4). https://doi.org/10.1108/RPJ-09-2016-0154
Pigott, T. D. (n.d.). *Loyola eCommons Loyola eCommons The Role of Theory in Quantitative Data Analysis The Role of Theory in Quantitative Data Analysis*. https://ecommons.luc.edu/education_facpubs
Pros And Cons Of 3D Printed Construction – Architect Outsourcing. (n.d.). Retrieved January 7, 2022, from https://architectoutsourcing.com/blogs/pros-and-cons-of-3d-printed-construction/
Roopa, S., & Rani, M. (2012). Questionnaire Designing for a Survey. *The Journal of Indian Orthodontic Society*, *46*, 273–277. https://doi.org/10.5005/jp-journals-10021-1104
Saleh, A., & Elfatah, A. (2019). 3D Printing in Architecture, Engineering and Construction. In *Ahmed Saleh /Engineering Research Journal* (Vol. 162). https://www.archdaily.com/890494/interior-design-and-3d-
Saunders, M., Lewis, P., & Thornhill, A. (2012). Research Methods for Business Students. In *Pearson Education Limited* (6th edition).
Scorecery - How to assign points for linear scale question? (n.d.). Retrieved January 25, 2022, from https://scorecery.com/calculate/assign-points-linear-scale-question-calculate-score-google-forms.html
Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching*, *5*(9), 9–16. https://doi.org/10.5539/elt.v5n9p9
Serelis, E., Vaitkevicius, V., Rudzionis, Z., & Kersevicius, V. (2018). Waste of granite dust utilization in ultra-light weight concrete. *IOP Conference Series: Materials Science and Engineering*, *442*(1). https://doi.org/10.1088/1757-899X/442/1/012004
Siddika, A., Mamun, M. A. al, Ferdous, W., & Alyousef, R. (2020). Performances, challenges and opportunities in strengthening reinforced concrete structures by using FRPs – A state-of-the-art review. In *Engineering Failure Analysis* (Vol. 111). Elsevier Ltd. https://doi.org/10.1016/j.engfailanal.2020.104480
Sun, J., Huang, Y., Aslani, F., Wang, X., & Ma, G. (2021). Mechanical enhancement for EMW-absorbing cementitious material using 3D concrete printing. *Journal of Building Engineering*, *41*. https://doi.org/10.1016/j.jobe.2021.102763
Thanh, Nguyen Cao, & Thanh, T. (2015). The interconnection between interpretivist paradigm and qualitative methods in education. *American Journal of Educational Science*, *1*, 24–27.
The Disruptive Technological of 3D Printing. (n.d.). Retrieved January 7, 2022, from https://storymaps.arcgis.com/stories/bbf377b347424c8ab79684346105082e

Top 3D printing benefits for small businesses. (n.d.). Retrieved January 6, 2022, from https://www.sculpteo.com/en/3d-learning-hub/3d-printing-business/3d-printing-benefits-for-small-businesses/

Ur Rehman, A., & Kim, J.-H. (2021). *materials 3D Concrete Printing: A Systematic Review of Rheology, Mix Designs, Mechanical, Microstructural, and Durability Characteristics*. https://doi.org/10.3390/ma14143800

Wangler, T., Lloret, E., Reiter, L., Hack, N., Gramazio, F., Kohler, M., Bernhard, M., Dillenburger, B., Buchli, J., Roussel, N., & Flatt, R. (2016). Digital Concrete: Opportunities and Challenges. *RILEM Technical Letters*, *1*, 67. https://doi.org/10.21809/rilemtechlett.2016.16

Weger, D., Lowke, D., & Gehlen, C. (n.d.). *3D printing of concrete structures using the selective binding method-Effect of concrete technology on contour precision and compressive strength Adaptive Armierung zementgebundener Formkörper View project A Numerical Model for Simulation and Design of Particle-Bed 3D-Printing Process View project*. https://www.researchgate.net/publication/321491235

What role will 3D printing play in the construction industry? | Construction Dive. (n.d.). Retrieved January 6, 2022, from https://www.constructiondive.com/spons/what-role-will-3d-printing-play-in-the-construction-industry/608411/

Will 3D printing revolutionise the construction industry? (n.d.). Retrieved January 24, 2022, from https://www.raconteur.net/construction/3d-printing-construction/

Wolfs, R. J. M., Bos, F. P., & Salet, T. A. M. (2018). Early age mechanical behaviour of 3D printed concrete: Numerical modelling and experimental testing. *Cement and Concrete Research*, *106*, 103–116. https://doi.org/10.1016/J.CEMCONRES.2018.02.001

Yossef, M., & Chen, A. (2015). *Applicability and Limitations of 3D Printing for Civil Structures*. http://lib.dr.iastate.edu/ccee_conf/35

Yu, S., Du, H., & Sanjayan, J. (2020). Aggregate-bed 3D concrete printing with cement paste binder. *Cement and Concrete Research*, *136*, 106169. https://doi.org/10.1016/J.CEMCONRES.2020.106169

Anton, A., Reiter, L., Wangler, T., Frangez, V., Flatt, R.J. and Dillenburger, B., 2021. A 3D concrete printing prefabrication platform for bespoke columns. *Automation in Construction*, *122*, p.103467.

Classen, M., Ungermann, J. and Sharma, R., 2020. Additive manufacturing of reinforced concrete—development of a 3D printing technology for cementitious composites with metallic reinforcement. *Applied sciences*, *10*(11), p.3791.

Hack, N. and Kloft, H., 2020, July. Shotcrete 3d printing technology for the fabrication of slender fully reinforced freeform concrete elements with high surface quality: a real-scale demonstrator. In *RILEM International Conference on Concrete and Digital Fabrication* (pp. 1128-1137). Springer, Cham.

Hack, N., Dressler, I., Brohmann, L., Gantner, S., Lowke, D. and Kloft, H., 2020. Injection 3D concrete printing (I3DCP): basic principles and case studies. *Materials*, *13*(5), p.1093.

Ji, G., Ding, T., Xiao, J., Du, S., Li, J. and Duan, Z., 2019. A 3D Printed ready-mixed concrete power distribution substation: Materials and construction technology. *Materials*, *12*(9), p.1540.

Kloft, H., Empelmann, M., Hack, N., Herrmann, E. and Lowke, D., 2020. Reinforcement strategies for 3D-concrete-printing. *Civil Engineering Design*, *2*(4), pp.131-139.

Krause, M., Otto, J., Bulgakov, A. and Sayfeddine, D., 2018. Strategic optimisation of 3D concrete printing using the method of CONPrint3D®. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 35, pp. 1-7). IAARC Publications.

Lao, W., Li, M. and Tjahjowidodo, T., 2021. Variable-geometry nozzle for surface quality enhancement in 3D concrete printing. *Additive Manufacturing*, *37*, p.101638.

Lediga, R. and Kruger, D., 2017. Optimising concrete mix design for application in 3D printing technology for the construction industry. In *Solid State Phenomena* (Vol. 263, pp. 24-29). Trans Tech Publications Ltd.

Liu, M., Zhang, Q., Tan, Z., Wang, L., Li, Z. and Ma, G., 2021. Investigation of steel wire mesh reinforcement method for 3D concrete printing. *Archives of Civil and Mechanical Engineering*, *21*(1), pp.1-18.

Ma, G., Wang, L. and Ju, Y., 2018. State-of-the-art of 3D printing technology of cementitious material—An emerging technique for construction. *Science China Technological Sciences*, *61*(4), pp.475-495.

Marchment, T. and Sanjayan, J., 2020, July. Penetration reinforcing method for 3D concrete printing. In *RILEM International Conference on Concrete and Digital Fabrication* (pp. 680-690). Springer, Cham.

Marchment, T. and Sanjayan, J., 2020. Bond properties of reinforcing bar penetrations in 3D concrete printing. *Automation in Construction*, *120*, p.103394.

Marchment, T. and Sanjayan, J., 2020. Mesh reinforcing method for 3D Concrete Printing. *Automation in Construction*, *109*, p.102992.

Nematollahi, B., Xia, M. and Sanjayan, J., 2017. Current progress of 3D concrete printing technologies. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 34). IAARC Publications.

Panda, B. and Tan, M.J., 2018. Experimental study on mix proportion and fresh properties of fly ash based geopolymer for 3D concrete printing. *Ceramics International*, *44*(9), pp.10258-10265.

Rehman, A.U. and Kim, J.H., 2021. 3D Concrete Printing: A Systematic Review of Rheology, Mix Designs, Mechanical, Microstructural, and Durability Characteristics. *Materials*, *14*(14), p.3800.

Salet, T.A.M., Bos, F.P., Wolfs, R.J.M. and Ahmed, Z.Y., 2017. 3D concrete printing–a structural engineering perspective. In *2017 fib Symposium-High Tech Concrete: Where Technology and Engineering Meet* (pp. xliii-lvii). Springer.

Sanjayan, J.G., Nazari, A. and Nematollahi, B., 2019. *3D concrete printing technology: construction and building applications*. Butterworth-Heinemann.

Vaitkevičius, V., Šerelis, E. and Kerševičius, V., 2018. Effect of ultra-sonic activation on early hydration process in 3D concrete printing technology. *Construction and Building Materials*, *169*, pp.354-363.