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Exploring the Key Factors that Influence the 3D Printing Implementation in Construction

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Abstract:

Due to its wider applications and advantages, 3D printing has attracted the attention of a number of industries in the past years. Although the implementation of 3D printing in many industries still has challenges, the progress in the construction industry is particularly slow. This article, therefore, attempts to explore the key factors that highly influence the 3D printing adaptation and implementation in construction. A qualitative research method considering the systematic review was adopted to achieve this aim. Relevant data spanning over a period of 20 years (2000-2019) considering four main databases were collected using specified keywords. A total of 137 articles were downloaded and 43 were finally selected after the screening criteria were imposed. The results from this review enabled to categorize the derived factors broadly into four categories including Technology, Organization, Environment, and Cost. Each of these main factors is constituted by sub-factors. An understanding of these factors would be helpful to develop effective strategies towards the adaptation and implementation of 3D printing in the construction industry. Since construction industry characteristics vary from region to region, the significance of these factors in different regions could be different and thus need to be investigated further.

Keywords: Management, Concrete technology & manufacture, Infrastructure planning.

1. Introduction:

One of the most important trends in manufacturing over the past decade has been the rise of additive manufacture or 3D printing (Attaran, 2017). 3D printing allows direct manufacture of finished components from computer models that require expensive tools or molds if using traditional mass-production techniques. 3D printing, therefore, allows mass customization where it is no more expensive to produce unique components than multiples. 3D printing techniques have been gaining attention in various industries as technology has evolved (Holt et al., 2019). Some industries have embraced 3D printing much more rapidly than others. For example, direct manufacture of titanium parts through 3D printing has generated significant interest as it minimizes waste of the costly metal and allows highly complex shapes to be created (Berman, 2012). 3D printing has also generated interest in objects as diverse as bicycle frames, firearms, and chocolates.

The construction industry is known as one of the world's major industrial sectors, which Include sub-sectors such as building, civil engineering, demolition and maintenance. It accounts for a considerable proportion of gross domestic product in different countries, for instance, 6.10% in the UK, 5.50% in Japan and 9.0% in Oman. The construction industry is rapidly growing in different developing countries and thus recognized as a main source for providing a number of jobs to different labour categories. It is expected that expenditure in the construction sector will rise up to US$14 trillion in 2025, which was only US$9·5 trillion in 2014 (Umar et al., 2019-a). The construction industry is particularly well-suited to take advantage of the benefits of 3D printing (Avrutis et al., 2019). 3D printing could bring improvements in safety, reductions in labor and time, and advances in customization and form. Perhaps the largest drawcard for 3D printing in construction is the reduction in labor requirements, as this can translate to savings in both cost and time (Hager et al., 2016; Umar, 2017; Umar et al., 2018). 3D printers would allow a house to be built by a skeleton crew, rather than a full team spanning multiple trades (Starr, 2015). This reduction in labor would result in both decreased cost and an increased level of site safety, particularly in harsh and dangerous environments. Automated construction could also minimize costly errors and defects. Apart from the improved cost, timeline, and safety, 3D printing also removes many design limitations. Rectilinear forms are known to be structurally weaker than curvilinear forms (Abrams, 2014). However, the creation of curvilinear forms in construction requires specialty formwork or engineering. This usually comes at a dramatic increase in expense and time. The use of 3D printing would enable curvilinear designs to be executed as easily as more traditional angular structures. This offers a structural advantage as well as an aesthetic one. Similarly, components that are precast are limited to being solid whereas those which are printed are able to be created with cavities, saving on material and also creating channels for essential utilities (Khoshnevis, 2004). Overall, the enhanced applications and adaptation of the 3D printing in construction sector will help to increase the suitability performance of the industry, and this will pave the road towards achievement of the United Nations (UN) Sustainable Development Goals (Umar et al., 2020; UN, 2015). Different studies reveal the progress of most of the countries towards UN Goals is not satisfactory that these goals would not be achieved by 2030 (Umar and Egbu, 2019; Umar et al., 2019-b).

The construction industry is well-positioned to capitalize on the benefits of 3D printing as the use of modeling is already commonplace. In fact, the majority of information needed to create a 3D blueprint is generated during the design of a building. In building information modeling, which is rapidly growing in popularity, it is standard procedure to create three-dimensional CAD models of buildings (Eastman et al., 2011). It is a relatively small step to move from this type of model to instructions for a 3D printer. Recently there have been significant improvements in 3D printing applications in the construction industry and the output of such improvement has been globally evident. The world's first 3D printed office inaugurated in 2016 is considered the most advanced 3D printed building in the world which is fully functional and inhabited (DFF, 2016).

Although there is progress in adopting 3D printing technologies in construction, apparently the progress is slow. There have been a number of studies that have explored different attributes that affect the 3D printing adaptation in many industries, however, these attributes sometimes are overwhelming and could cause confusion among decision-makers. For instance, a recent study conducted by Tsai and Yeh (2019) concluded a total of 12 different attributes that also include the employee's age, education, position, and experience. This is somehow misleading considering the general rules of the organizations. As the age of the employee is increasing his or her experience increases as well. Similarly, employees experience allows them to rise to a higher position in the organization. Thus employee age, experience, and position are interconnected to each other and can be counted as one attribute. Similarly, an important factor to which would have more attraction of the decision-makers is the cost of 3D printing. The cost of 3D printing would be arising from materials, machines, software, hardware, operation and maintenance (Thomas, 2016; Yeh and Chen, 2018). Thus theoretically these cost factors can be divided into six attributes, however, for a decision-maker; it is counted as one component which is the cost. Likewise, another study conducted by Attaran (2017) on 3D printing concluded that the main barriers to 3D printing adaptation are technology, materials, and cost. The size of the manufactured products, government rules and regulations, and constrains on cost also influence 3D printing adaptation. Additionally, as in the case of other technologies, many researchers conclude that costs play an important role in 3D printing adaptation (Kreiger et al., 2014; Weller et al., 2015). Another study associated with the cost-benefit analysis of 3D printing conducted by Thomas (2016) discussed societal investments and incomes from 3D printing adaptation. Similarly, Weller et al. (2015) explained the technological and economic factors of manufacturing companies during the stage of 3D printing implementation.

This article, therefore, attempts to explore the factors which influence 3D printing in construction. A qualitative research approach using a systematic literature review method was adapted to identify these success factors (Umar and Egbu, 2020). The next section briefly describes the research methods in construction followed by the research methodology adopted to achieve the aims and objectives of this research.

2. Research Methods in Construction:

Broadly, research approaches commonly used in construction can be classified as quantitative and qualitative research methods (Umar and Egbu, 2017). Briefly, quantitative research stresses quantification in data collection and examination. It applies a deducible approach to the connection between theory and research, and stress is kept on the confirmation of theories. The quantitative research method integrates the norms and practices of the natural scientific model and positivism. It views the social phenomenon as an outer objective truth (Cooper and Schindler, 2006).
On the other hand, a qualitative research approach stresses words and contexts rather than quantification in data collection (Opdenakker, 2006). It stresses an introductory approach in the relationship between theory and research, and the focus is on the formation of theories. The majority of researchers prefer to incorporate both quantitative and qualitative methods, referred to as a combined research method and highly

appreciated in the literature due to certain advantages (Umar, 2018). Both of the research methods (quantitative and qualitative) are mainly different from each other in a) systematic objectives, b) question types and postures, c) data collection technique, d) data production, and flexibility. Researchers generally give more credit to the flexibility and regard this as the leading difference between the two methods. Overall, qualitative research methods are considered to be more flexible than quantitative research methods. The reason for this is that in the quantitative methods, such as using a structured questionnaire, the researcher needs to ask all the respondents the same questions in identical order. The answers of the respondents are recorded on a liker scale. Thus the participants have to choose their answers from limited categories provided on the questionnaire itself. The participants have no other choice than to select their choice provided with the question. This inflexibility of the quantitative research method, however, results in an advantage of this method which allows the researcher to arrive on a meaningful comparison between the respondents. With regard to the key differences in both research methods, table 1 is presented to illustrate them.

Description	**Quantitative**	**Qualitative**
General Framework	Attempt to pledge the hypothesis of a study Tools used are more rigid and tend to categorize the responses Adopt structure tools such as structured questionnaire / observation / experiments	Attempt to explore the study Tools are more flexible which provide the respondents to categorize their responses Adopt semi-structured methods, such as interviews/participant observation
Systematic Objectives	Measure differences Estimate causal connections Delineate attributes of a population	Outline differences Outline and describe connections Outline group standards

Question Structure	Closed-ended questions	Open-ended questions
Data Structure	Numerical	Textual
Flexibility in Research Design	Study design remains stable from starting to end Participant response to one question doesn't change the sequence of the remaining questions in the survey Research design is based on the statistical assumptions and conditions	Some characteristics of the study are flexible, for example, changing the wording of the question so that the respondents understand it easily Participant response to one question may force the researcher to change the sequence of the questions Research design (data collection and questions) can be changed based on the results

Table 1: Key difference in Quantitative and Qualitative Research Methods

Research in construction is regarded as young or intermediate in maturity and in matching to the fieldwork context. Hence, accentuation of exploratory studies using qualitative methods, rather than hypothesis testing or quantitative methods that are appropriate for mature disciplines; is considered more appropriate to foster the development of construction knowledge (Fellows and Liu, 2015). The research approach adopted in this research is therefore qualitative in nature. The research methodology used in this research is further explained in the next section.

2.1 Research Methodology:

Since the research presented in this paper is exploratory in nature, a qualitative method was considered as the most suitable method to collect the data. The process of the research adopted here was guided by Bryman (2016) as shown in figure 1. To ensure that the study presents a critical review, the guidelines provided by some of the lead authors for conducting the literature review were followed. For instance, Randolph (2009) suggested that a defective literature review is one of the many reasons which can derail the thesis, paper or dissertation. A faulty literature review may result in a flawed thesis, dissertation or paper due to the fact that comprehensive research cannot be performed without a full understanding of the existing literature in the relevant area (Boote and Beile, 2005). The literature review of the paper or thesis also gets due considerations by the reviewer or examiner as well. A research conducted by the Mullins and Kiley (2002) concluded that most of the reviewers and examiners get a perception of the whole paper or thesis from the literature review. If the literature review is found poor, the examiners assume that the rest of the thesis would also have problems. Fellows and Liu (2015) argued that the literature should not merely be found and reviewed; the body of relevant literature from previous research must be reviewed critically. Thus, literature must not be accepted 'at face value' but different sources should be reviewed for different perspectives. There is a possibility that the same authors will change their views over time (Alexander, 1983). It was ensured that the review involves comparing a set of literature against an established set of criteria. The existing research was not aggregated or synthesized with respect to each other, but was judged against this standard and found to be more or less acceptable (Grant and Booth, 2009; Paré et al. 2015; Xiao and Watson, 2019).

The most prevailing factors were extracted from the existing published literature related to 3D printing through a systematic review (Martins et al., 2019). This was done using specific keywords in a number of databases and by selecting a period of the past 20 years, from 2000 to 2019. The typical keywords used for the databases search along with the number of items found are 'Additive Manufacturing' (12 items), '3D Printing in Construction' (22 items), '3D Printing Success Factors' (16 items), '3D Printing Adoption

Criteria' (14 items), 'Cost Reduction' (9 items), 'Technology Adoption' (12 items), 'RFID' (4 items), 'Organizational Readiness' (13 items), 'Critical Factors' (9 items), 'Technology-Organization-Environment (TOE)' (15 items), and 'Rapid Manufacturing (RM)' (11 items). The results from these keywords were only included in the final record when a clear relationship of the record was established with the construction industry and 3D printing. The search period was aligned with the fact that most of the research related to the application of 3D printing was carried out during this period (Tay et al., 2017). For this review study, the 'Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA)' guidelines were followed (Moher et al., 2009; Umar et al., 2019-c). The PRISMA guidelines are broadly divided into four categories. In the first step which is the 'identification', it is important to indicate the record identified through different databases. In this research, this record stood at 137. The next step of PRISMA is the screening stage. In this stage, the records which are screened and removed due to duplication are indicated. In this stage a total of 31 items were removed, leaving the balance items to 106. In the third step of PRISMA guidelines, the eligibility check is carried out. In the stage, the records were checked if they are eligible to be included in the final study. The number of items removed at this stage stood at 63. The fourth stage of the PRISMA is the inclusion stage. In this step, the records which are finally considered to be included in the study are presented. In this study, the record included stood at 43. Briefly, the key factors identified using this approach considering a total of 43 research articles are shown in Appendix I. The selected papers were divided into broad factors based on the theme of the papers. Based on the themes of the papers, four major areas were considered for their classification. If the paper theme was aiming to present the work on 3D technology, it was categorized under the main category of "Technology". To classify a paper under the 'technology category', the paper should deal with one of the aspects of the technology infrastructure, technology integration or related to the relative advantages of technology. Similarly, if a paper was presenting a work related to could be related to organizational and managerial issues influencing 3D printing, it was categorized under the broad category of "Organization". Three aspects were considered to classify a paper under the 'organization category'. These aspects include organizational readiness, management support, and managerial obstacles. The papers which were discussing the environment related to business or performance of the organization and were considered to have an implication on the organizations which aim to adopt 3D printing; such papers were classified under the "Environment" category. Papers discussing the competitive pressure, expectations of market trends, trading partners, and government policy were classified under the 'environment category'. Finally, the papers associated with the cost of 3D printing or were discussing the cost as a factor that influences technological adaptation were considered under the "Cost" factor. The classification of papers under the 'cost category' was based on the fact if the paper is discussing one of the aspects of the 3D printing costs related machine, labour or materials.

These factors are further discussed in more detail in the next section.

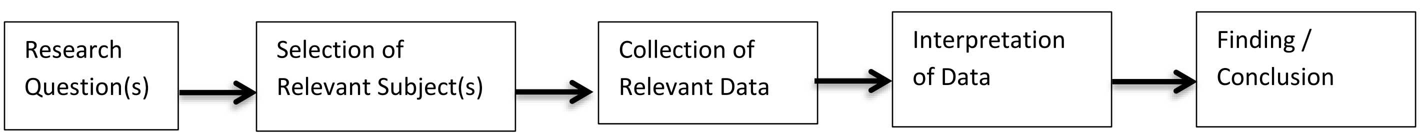

Figure 1. The Process of Qualitative Research Adopted (Umar, 2020)

3. Results and Discussion:

As discussed in the methodology section, a total of 137 research articles were downloaded. The distribution of the downloaded articles based on the selected years and databases are presented in table 2. This table also presents the number and the proportion of papers (year wise) finally selected for the review. A large number the total downloaded papers (30.23%) were from "Web of Science", followed by "Scopus" (27.90%), "Pro-Quest" (23.26%) and "Science Direct" (18.60%) as shown in figure 2. 2018 stood on the top based on a large number of downloaded papers (11 papers). Based on the final selected papers, 2014 and 2015 give the highest number of papers. The overall ratio of the selected articles after the screening process was applied stood at 31%. Among the final selected papers, the papers which were discussing the technological aspect of the 3D printing technology or the associated technologies stood at the top (34.88%), thus the factor “Technology” was ranked first. Likewise, the papers which were discussing the organizational aspects of the technological adaptation counted as 30.23% of the total papers, thus the organizational factor is ranked is second. Similarly, the papers associated with the organizational or business environment and the cost of the technological adaptation were accounted for 20.93% and 13.95% of the total papers. These two factors i.e. “Environment” and “Cost” were therefore ranked at 3rd and 4th factors which could highly influence the 3D printing in construction. Overall, the ranking of all these four factors is presented in figure 2.

Apart from classifying the publications based on the main four categories, the publications were also classified based on the sub-items considered in the main categories. The top leading trend was "Organizational Readiness", which falls under the main category of "Organization", where 53.84% of the publications were observed to contain this sub-item under this group. Likewise, "Organizational Readiness" via machine cost is found in 50% of the publications within the "Cost" category. Similarly, this was followed by technology infrastructure which was evident in 46.66% of publication classified under the main theme of technology. "Trading Partners", one of the sub-categories under "environment" was observed in only 11.11% of the publications. The overall trend of the selected publications is presented in figure 3.

The next sections provided a detail critical review of these factors.

Year	**Database**					**Final Selected Papers**	%
	Web of Science	**Pro Quest**	**Scopus**	**Science Direct**	**Total**		
2000	0	0	0	1	1	1	2.32
2001	1	0	0	1	2	0	0.0
2002	0	1	0	1	2	0	0.0
2003	2	1	2	0	5	0	0.0

2004	1	1	3	0	5	1	2.32
2005	0	2	4	0	6	1	2.32
2006	3	1	3	3	10	3	6.97
2007	2	2	2	2	8	2	4.65
2008	4	1	1	2	8	0	0.0
2009	1	1	0	2	4	4	9.30
2010	3	1	0	2	6	2	4.65
2011	4	1	4	0	9	2	4.65
2012	3	3	3	0	9	2	4.65
2013	2	3	2	3	10	1	2.32
2014	2	3	1	2	8	5	11.62
2015	2	2	1	3	8	7	16.27
2016	2	2	3	1	8	3	6.97
2017	2	1	2	2	7	3	6.97
2018	3	2	4	2	11	3	6.97
2019	4	2	3	1	10	3	6.97
Total	**41**	**30**	**38**	**28**	**137**	**43**	100.0
Final Selected Articles	**13**	**12**	**10**	**8**	**--**		
%	**30.23**	**27.90**	**23.26**	**18.60**	**--**		

Table 2: Results of the Systematic Review

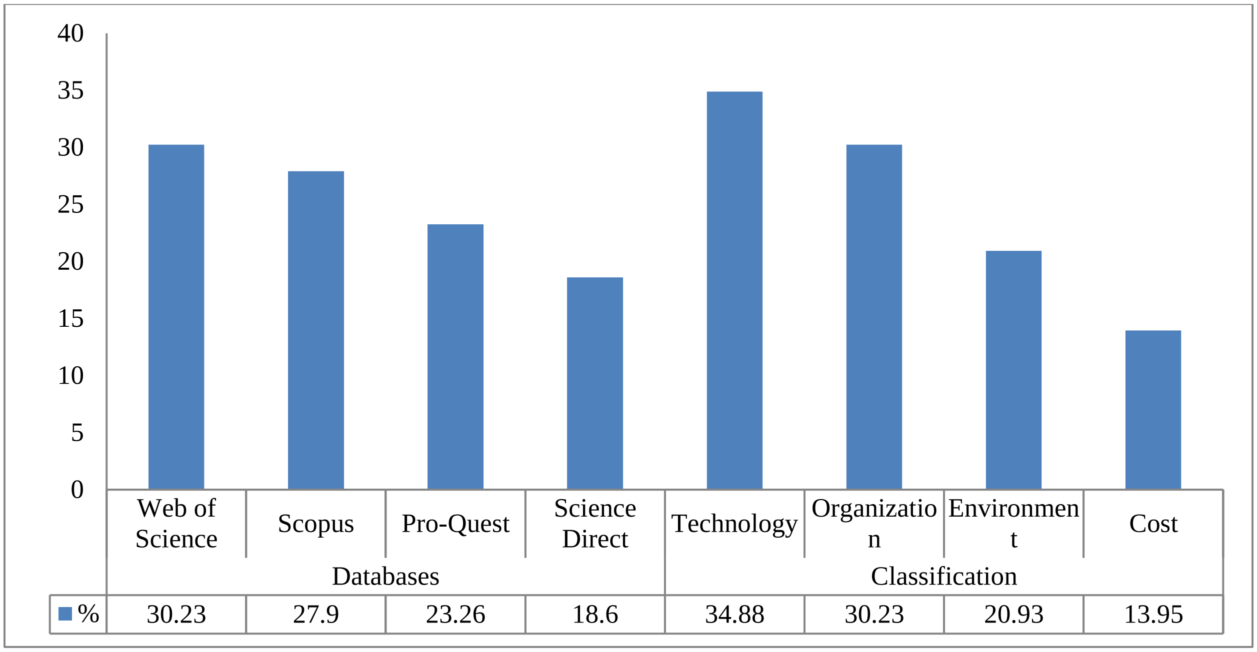

Figure 2: Items from Different Databases and their Classification

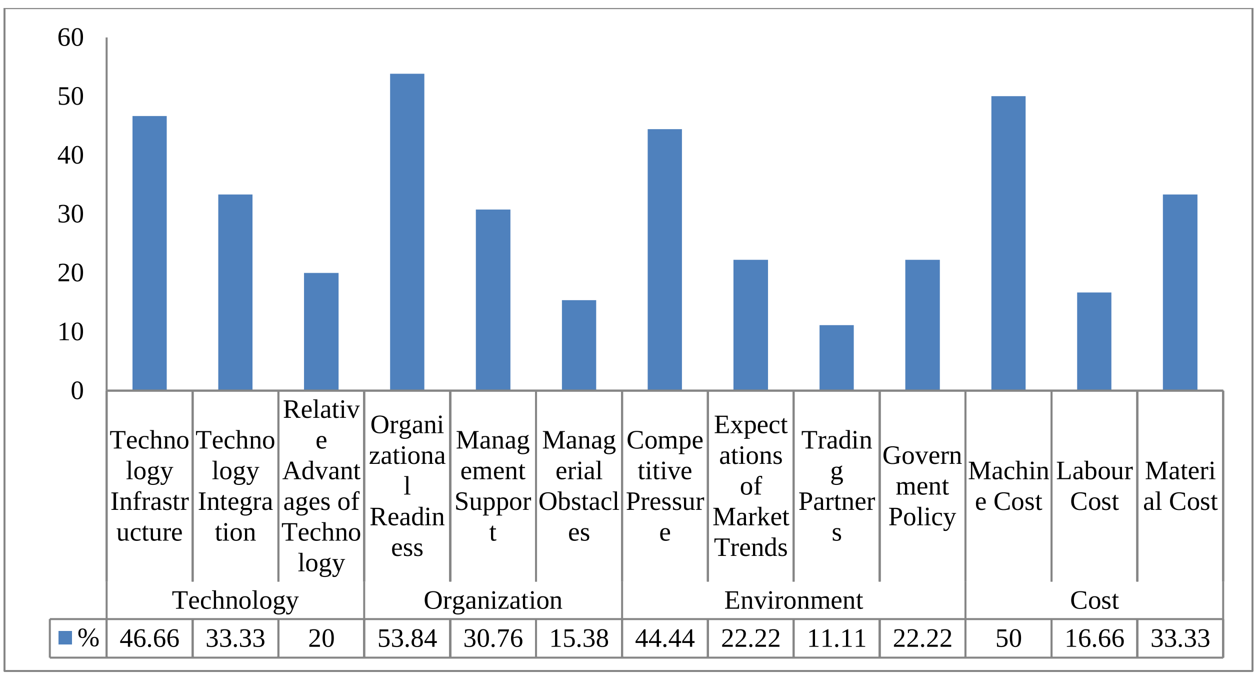

Figure 3: Trends in Selected Publications

3.1 Technology:

Different studies have confirmed that the technological factor carries both internal and external effects of a technological application in companies. Bharadwaj (2000) concluded that information technology (IT), operating as a type of assets, which normally enriches competitiveness when it mixes with or enhances pre-existing assets or approaches. In a stage of technology application, technological resource plays a basic part which also impacts the ultimate utilization of 3D technology. 3D printers have the ability to incorporate technology smoothly with computer-aided design software as well as other digital approaches including magnetic resonance imaging (Quan et al., 2015; Ludwig et al., 2014; Petrick and Simpson, 2013; Berman, 2012). Under this environment, organizations with complicated technology resources are prepared with adequate potentials for adopting 3D technology into their routine functions.

The research conducted by a number of researchers also concluded that technological integration plays a positive role in Information Technology implementation (Lin, 2009; Liu and Sun, 2011). Zhu et al. (2006) in their research concluded that technological integration can be referred to the degree of the correlation among an organization's back-end information system and its database. Thus, how to integrate 3D printing with information systems is important for decision-makers within these organizations (Pearce et al., 2010; Mellor et al., 2014). If 3D printing is successfully integrated with the information systems of these organizations and with the information systems or databases of their trading partners, then it can be confirmed that 3D technology will be successfully implemented which could lead to greater benefits. An organization’s relative benefit is also regarded as another important dimension for new technology applications and is characterized by evaluating the operation that 3D printing technology plays in reducing operational costs and in increasing relative business profits. In this regard, a number of benefits achieved from 3D printing applications have already been discussed in many kinds of research (Thomas, 2016; Despeisse and Ford, 2015; Ford, 2014; Mellor et al., 2014; Petrick and Simpson, 2013). This above discussion reveals that the technological advancement of the construction industry is crucial for the successful implementation of 3D in construction. In relation to the technological solution available to be adopted in construction, two of them are very commonly used. They are Fused Deposition Modeling (FDM) and Contour crafting (Armillotta, 2019; Sanjayan et al., 2019). Fused Deposition Modeling is one of the most commonly used 3D printing processes in the production of prototypes and final parts. The parts are built up layer by layer using an additive process without needing a forming tool (Wohlers, 2012; Singamneni et al., 2019). Contour crafting is a layered fabrication technology that appears to have great potential for the automated construction of small complete structures that include some of their subcomponents (Khoshnevis, 2004; Lee et al., 2019). It has been developed over many years as a viable building system and creates a smooth surface finish by releasing multiple layers of cement-based paste (Lim, 2012).

All the available technological solutions for 3D printing along with its brief description are summarized in table 3. Although, 3D printing offers many opportunities for the construction industry, but there will also be fresh challenges and demands, such as the need for more digitally savvy engineers, greater use of advanced computational analysis and a new way of thinking for the design and verification of structures, with greater emphasis on inspection and load testing (Buchanan and Gardner, 2019).

3D Printing Technology	Description
Fused deposition modeling (FDM)	Material is deposited layer by layer through an extrusion nozzle mounted on a 6-axis robotic arm. This process allows the production of 3D large-scale complex geometries, without the use of temporary supports (Gosselin et al., 2016; Ghaffar et al., 2018).
Stereolithography Apparatus (SLA)	This technology uses an ultraviolet laser to turn light-sensitive resin (a liquid material that becomes hard when ultraviolet light is shined on it) into solid 3D objects, layer by layer (Stansbury and Idacavage, 2016; Dizon et al., 2018).
Selective Laser Sintering (SLS)	Selective Laser Sintering (SLS) is a type of Powder Bed Fusion (PBF) wherein a bed of powder polymer, resin or metal is targeted partially (sintering) or fully (melting) by a high-power directional heating source such as laser that results to a solidified layer of fused powder (Wang et al., 2016).
Material Jetting	Material jetting technologies offer a higher throughput of products on a larger surface area and less manufacturing complexity compared with other techniques such as vat polymerisation that

	offer similar print resolution (ISO/ASTM 52900, 2015; Dilag et al., 2019).
Binder Jetting	Binder jetting is an Additive Manufacturing process to consolidate powders into net-shapes. a thin layer of powder is spread across the build piston, and the jetted binder droplets interact with the powder particles to form a cross-sectional layer. Once a layer is printed and thermally cured by a heater, a new layer of powder is recoated on top of the printed layer which is then jetted with a binder and stitched to the previous layers (Bai et al., 2019).
Direct Material Laser Sintering (DMLS)	Direct metal laser sintering is one of the most fascinating 3D printing techniques, as it allows to print your own designs in metals such as Aluminum or Titanium. It is more appropriate for metal printing (Rizzuti, 2019).
Selective Laser Melting (SLM)	Selective laser melting (SLM) is a specific 3D printing technique, which utilizes high power-density laser to fully melt and fuse metallic powders to produce near net-shape parts with near full density (up to 99.9% relative density) (Vrancken et al., 2019).
Electron Beam Melting (EBM)	Electron beam melting (EBM) is one of the latest 3D techniques using a computer-controlled electron gun to create fully dense 3D objects directly from metal powder (Singh et al., 2016; Chudinova et al., 2019).
Contour Crafting	Contour Crafting is the first additive fabrication technology developed for automated in-situ construction of custom-designed structures. It could reduce construction costs by cutting down construction time as well as the workforce required for the construction process (Khoshnevis et al., 2016; Kazemian et al., 2019; Wang et al., 2017).

Table 3: Description of Available 3D Printing Technologies

In the current decade, material technology has also attracted the attention of a number of researchers. The research conducted by Lee et al. (2019) on the trends in 3D printing technology for construction has considered the research materials from the past 20 years (1997-2018) and concluded that concrete was the most frequently used material in 3D printing in construction. Lim et al. (2011) argued that high-performance building materials such as concrete are preferred because of the consistently high level of material control required during printing in 3D printing processes. Since the 3D printing process doesn't use the formwork, the general concrete is not suitable to be used in 3D printing. It is important that the slump of the concrete is reduced to zero to avoid deformation at the time of lamination (Kang et al., 2015). Similarly, metal and alloy are also reported to be one of the best materials for 3D printing. A review study conducted by Ngo et al. (2018) reported that the number of companies selling AM systems went from 49 in 2014 to 97 in 2016. They also noted that using metal and alloy in 3D printing makes the manufacturing process of complex geometries that required special connections easier compared to conventional manufacturing methods. Other materials that have significantly used in 3D printing include polymers, ceramics and composites (Mühler et al., 2015; Kuo et al., 2016; Wen et al., 2017).

The next section provides an insight into the organizational factors that could influence the 3D printing in construction.

3.2 Organization:

There are several organizational factors that impact companies' aim to adopt new systems and approaches (Hsiao et al., 2009; Brooks et al., 2014). The organizational factor can be referred to several organizational circumstances including organizational willingness, that grant the basis of support or barrier from the perspective of senior officials. Many studies have established that management commitment in organizations plays a significant role to achieve the desired goal (Umar and Egbu, 2018; Umar and Wamuziri, 2017). The most important factor in 3D implementation and adaptation in construction is, therefore, could be the 'management commitment'. The progress towards 3D implementation and adaptation at the organizational level would thus reveal that either the management is seriously committed to achieving this or not. The fully committed management will ensure that they considered all the factors associated with

3D printing when they plan to adopt and implement such technology. Such committed management normally starts with the training requirement well before the execution of such projects which involves new technology. Iacovou et al., (1995) in their research study, analyzed organizational readiness on technology implementation and concluded that it is important to examine whether or not organizations are furnished with enough technical or financial resources. The availability of enough technical resources reflects a solid technical base, while financial resources indicate an organization's capital foundation available for technology investment by companies (Sealy, 2012). This resource-based angle confirms that an organization's 3D printing adaptation and implementation can be viewed as a type of systematic investment that can result in the generation of new manufacturing capacities that could further expand business potentials (Mellor et al., 2014; Cohen, 2014). Similarly, the research conducted by many researchers concludes that managerial barriers have a role in the implementation of new technology (Liu and Sun, 2011; Lin, 2009).

One of the fundamental arguments stated by Mellor et al., (2014) for 3D technology implementation lives in shifting tasks and jobs, which result about changes in operational procedure and formation. In such a situation, effective management of the managerial barriers also contributes to the successful implementation of 3D printing in the organization. Similarly, Cooper et al. (1990) discussed that in this matter the support from the top management of the organization is an important factor for the successful implementation of the new technological instrument in the organization. Such support is directly connected to the strategic objectives, manufacturing process, research and strategy of the organization (Mellor et al., 2014). The top management's support during technology implementation is viewed as important by Chang et al., (2007) with the argument that such support ensures the coordination among all organizational units which further helps to achieve the implementation in a successful manner. The above discussion clearly reveals that there are a number of factors that could affect the adaptation of 3D printing in construction. All these factors fall under the preview of the organization.

3.3 Environment:

Environmental factors that could influence the 3D printing implementation in construction can be categorized into competitive pressure, expectations from market tendency, business partners, and government support. The research conducted by Jeyaraj et al., (2006) concluded that competitive pressure generally refers to the factor that positively influences the technology adoption. Many other researchers are in the view that such influence delivers even stronger power when the implementation contributes directly to market competition (Wang et al., 2010; Chong et al., 2009; Zhu et al., 2006; Nelson et al., 2005). When the industry is confronted with competitive pressure, some organizations are inclined to adopt 3D printing in order to improve inventory, supply chain visibility, accurate data collection, and operational efficiency (Conner et al., 2015; Wang et al., 2010). Similarly, the expectations of market tendencies also influence the process of 3D technology implementation. Zhu et al. (2006) in their research mentioned that it is important to understand the trade-offs in the implementation of a new manufacturing approach. Similarly, inadequate technical assets also incur some crucial hurdles for 3D printing implementation in organizations (Quan et al., 2015; Mani et al., 2014; Mellor et al., 2014; Ford, 2014). Some of these factors of 3D printing are also linked with its relative immaturity in development, and top management needs to take them in consideration when deciding on this particular technology implementation in the organization.

It is also a fact that environmental factors pass their effect through a connection with technological revolution by the reality that they depend on each other. One of the examples is the effect of business associates outside the organization. Business associates particularly play an important role in whether new approaches can transport their ultimate contribution, especially when a large number of business associates use such approaches in production (Mohr and Khan, 2015; Iacovou et al., 1995). The connection of the different business associates is therefore important in the whole cycle of 3D implementation. First, a business associate expands the technology to customers through its machine dealers. Secondly, these customers pursue to introduce the technology to their personal business associates, which afterwards distribute it to their own dealers and customers (Mashhadi et al., 2015; Mellor et al., 2014). The discussion reveals that 3D printing technology implementation and adaptation can be influenced by the readiness of an organization's business associates.

Similarly, government-support also contributes to the victorious implementation and adaptation of new technologies. Many researchers categorize government technological support into technological infrastructure, quality of the workforce, training plan, and the adequate provision of technological workers (Conner et al., 2015; Ford, 2014). For instance, the Taiwan government boosts 3D printing implementation through the improvement of 3D printing materials which helps organizations to carry their own enhancement and transfer to 3D printing.

The factors discussed above play an important role to develop an environment and can, therefore, be helpful in the implementation of 3D printing in construction. The next section discusses the cost factor.

3.4 Cost:

The cost also appears to be an important element to understand the success of 3D printing in construction. The research conducted by Tay et al., (2017) noted that the cost-benefits of 3D printing were among the major research interests in the period from 1997 to 2016. The cost of 3D printing can be calculated on the basis of several components that include the fixed cost of printing materials, utilization cost and maintenance of the printing equipment. Furthermore, 3D printing application in construction is directly associated with a variety of investment forms that include investment in hardware, software and system integration (Yeh and Chen, 2018; Baumers et al., 2016; Thomas, 2015; Heath, 2015; Allen, 2006Ruffo et al., 2007).

Based on the various and large characteristics of cost, construction companies may recognize a substantial amount of costs associated to this type of project. The cost of 3D printing was considered by Yeh and Chen (2018) to be the most important factor that significantly affects the success of 3D printing technology. It is therefore important to consider certain elements of cost for 3D printing, including machine cost, material cost, and labor cost in relation to adopting and implementing 3D printing technology in construction. Different studies on the first 3D printed office inaugurated in 2016, which was built in China and then shipped to Dubai is estimated to have had 80% reduced construction costs, 60% lower labour costs and produced 60% less waste than a comparable conventional office building (WEF, 2016). This project was mainly supported by the government of the United Arab Emirates, thus the cost could be reduced due to government support and subsidies.

There are however a number of studies that reflect justifications for a reduced cost through 3D printing. For instance, Bak (2003) considered the application of 3D printing with conventional construction and noted that since 3D printing technology can reduce waste because it uses less material than conventional construction methods. Using less materials and generating less waste is a sign of cost competitiveness. Similarly, the process of 3D printing is automated; the manpower required during construction can be reduced. In addition, environmental preparation and construction times can be significantly reduced (Buswell et al., 2006; Lee et al., 2019). In fact some of the 3D printing companies claiming that they can construct a house of more than 230 sqm in only 20 hours (ICFhome, 2019). There is a great opportunity for construction organizations to step in to adopt and implement 3D printing technology and get the benefits of the reduce cost of construction.

The next section aims to provide a conclusion of the paper.

4. Conclusion:

It is expected that the construction industry will be growing on further considering the fact that it has to play the main role to meet some of the basic requirements of humanity. With this expected growth, the challenges associated with the construction industry will also be growing in the future. It is important for the construction industry to adopt the latest innovative trends so that it could meet the expectations effectively. One of such innovative trend is 3D printing which has already been adopted in some industries; the progress in construction is comparatively slow. This article, therefore, explored the factors that could be helpful in the successful implementation of 3D printing in construction. Although the topic has already been discussed in a number of researches, however, construction was not in focus in many cases. This article, therefore, considered the existing literature in order to accomplish these factors. Four main databases including Web of Science, Pro-Quest, Scopus and Science Direct were considered to extract the main research from 2000 to 2019 related to 3D printing by using specific keywords. A total of 137 articles were downloaded. Finally, after the screening process, 43 articles were selected to complete this study. Although the database resulted in a large number of factors, however, they were grouped into four categories of a) Technological factors, b) Organizational factors, c) Environmental factors, and d) Cost factors. The Technology factor can be divided into a number of sub-factors including technology infrastructure, technology integration, information system and the advantages that arise from new technology applications. Technology advancement and adaptation are important for the victorious implementation of 3D printing in construction. Similarly, an important factor that contributes to organizational factor is the willingness of the organization to adopt and implement 3D printing. The organizational factor is further highly influenced by the top management support and managerial barriers. In addition, factors such as competitive pressure, expectations from market tendencies, business associates, and government policies and support together establish the environmental factor which is one of the proven factors that could influence the 3D printing implementation in construction. In relation to the cost factor, materials cost, machine cost, and workers are important sub-factors. Apart from these sub-factors, hardware, software, and system integration costs also contribute to the overall cost of 3D printing and thus need to be taken into consideration. Construction organizations will be reluctant to adopt 3D printing if the cost of manufacturing through 3D printing would be higher than the traditional methods. As a general understanding, the cost of 3D printing would be one of the most important factors for construction organizations as a deciding factor. As discussed earlier, the research methodology adopted to accomplish the aims and objectives of this research was qualitative in nature, in which a systematic review approach was adopted. Time and other resources did not permit to investigate the views of construction industry professionals, particularly, those who are working on 3D printing projects globally. Such research could be highly benefitted from the inputs of such individuals. This appears as one of the main limitations of this research. Finally, it is needed to be kept in mind that construction industries in different regions have their own characteristics which are highly influenced by local economic conditions, thus the importance or ranking of the factors described in this article could vary from region to region and need to be further investigated. Overall, the construction industry has it vital role to meet the global human requirement and deliver the housing and infrastructure projects on time and in sustainable manners. 3D printing is one of the technologies that will help the construction industry to meet this expectation and to contribute towards the achievement of UN Sustainable Development Goals.

Appendix I:

Factors Influencing 3D Printing in Construction

Keywords	Period	Inclusion Criteria	Exclusion Criteria	Database	Total Downloaded Articles/ Reports	Total Articles/ Reports/ Tools After Criteria	Classification Criteria:
Additive Manufacturing, 3D Printing in Construction, 3D Printing Success Factors, 3D Printing Adoption Criteria, Cost Reduction, Technology adoption, RFID, Organizational readiness, critical factors, Technology-	January, 2000 to June, 2019	Publications and Reports on 3D Printing in Construction or the Publications and Reports demonstrate that it importance in relation to 3D printing in construction	Publications and Reports where the keywords are not in the title, abstract or in the keywords Publications and Reports which fails to reflect a relationship or application with / in construction	Web of Science Pro Quest Scopus Science Direct	137	Total Articles = 43 **Technology (15 items):** Quan et al. (2015); Petrick and Simpson (2013); Berman (2012); Lin (2009); Liu and Sun (2011); Zhu et al. (2010); Pearce et al. (2010); Mellor et al. (2014); Despeisse and Ford (2015); Thomas (2016); Ford (2014); Khoshnevis (2004); Singamneni et al. (2019); Armillotta (2019);	**Technology:** Technology infrastructure, Technology integration, Relative advantages of technology

organization-environment (TOE), rapid manufacturing (RM),			Articles and Reports in a non-English language			Sanjayan et al. (2019).	

						Organization (13 items): Sealy (2012); Cohen (2014); Mellor et al. (2014); Chang et al. (2007); Liu and Sun (2011); Lin (2009); Hsiao et al. (2009); Bharadwaj (2000); Wu et al. (2018); Yeh et al. (2018); Balasubramanian et al. (2017); Ben-Ner and Siemsen (2017); Rayna and Striukova (2016).	**Organization:** Organizational readiness, Management support, Managerial obstacles
						Environment (9 items): Jeyaraj et al. (2006); Wang et al. (2010); Conner et al. (2015); Mani et al. (2014); Mohr and Khan (2015); Mashhadi et al. (2015); Chong et al. (2009); Nelson et al. (2005); Conner et al. (2015).	**Environment:** Competitive pressure, Expectations of market trends, Trading partners, Government policy

						Cost (6 items): Tay et al., (2017); Yeh and Chen (2018); Baumers et al. (2016); Heath (2015); Ruffo et al. (2007); Allen (2006).	

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