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# Significance of 3D Printing Risks in Construction Projects

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***Abstract –*** There is a big shift towards 3D printed construction projects in the United Arab Emirates. Although these projects encourage innovation and digital transformation, they are usually riskier than traditional construction projects. The purpose of this paper is to identify and assess the risks in 3D printed construction projects in the UAE. A total of thirty risks were identified from literature. These were then grouped into six categories: 3D printing material, 3D printing equipment, 3D printing design risks, construction site and environment risks, management risks, regulatory and economic risks. A survey was then distributed to construction professionals in the UAE to evaluate the probability of occurrence and impact of each risk, sixty-six responses were collected. the severity of each risk was calculated by multiplying the probability with the impact and relative importance index was used to rank the risks accordingly. The results revealed that the top five severe risks were lack of codes for 3D printing in construction, delays in government approvals, shortage in labour skilled in 3D printed construction, lack of knowledge and information of 3D printed design concepts, changes in 3D construction codes and regulations. This research allows for proper guidance for risk response planning and control in 3D printed construction projects.

***Keywords*:** 3D printing in construction, risks, risk management, construction management.

## 1. Introduction

In recent times, the construction industry has introduced 3D printing as a key element of Industry 4.0 [1]. The growing interest in 3D printing in construction can be attributed to several factors. Notably, 3D printing offers significant advantages over traditional construction methods, including reduced labour requirements, fewer work-related accidents, minimized demolition waste and faster construction [2]. Furthermore, 3D printing plays a vital role in addressing sustainability concerns associated with construction projects [3].

The different techniques of 3D printing fall under five categories: Contour Crafting (CC), Concrete Printing (CP), Selective Binder (cement) Activation (SBA), Selective Paste Intrusion (SPI), and D-Shape [4]. The first two techniques are very similar to each other as they both involve using a nozzle to inject a mixture, that is typically made out of mortar in order to generate the printed component [5]. While the SBA technique involves using a dry mixture of fine aggregate and a cement binder. This binder is applied selectively to the compacted particles, activating it in specific areas and creating a cement paste matrix around the aggregate. Besides, the SPI process includes injecting the binder onto particles to create a paste composed of cement, water, and additives [6]. In contrast, the D-Shape technique employs a printer equipped with multiple inline nozzles to construct large objects. The printer builds these objects layer by layer using sand, with each layer selectively sprayed with a binder. The remaining unsolidified sand around the printed layer acts as temporary support during construction. Typically, a resin binder is used in this technique, which reacts with a hardener component present in the particle bed [4].

Although, this disruptive technology has a lot of benefits that makes it a promising potential to transform the construction industry, there are still several risks around 3D printing. Among these risks is the unreliability of the printing machine that requires costly maintenance [7]. Additionally, the printability feature of some of the construction materials is still under investigation. The lack of proper codes to build, repair and maintain 3D printed construction projects is another added concern [8]. Current literature review is very rich in providing guidelines in identifying and assessing different risks in conventional construction projects. However, there is a clear gap in literature when it comes to the assessment of 3D printing risks in construction projects. Therefore, the main aim of this study is to identify and assess critical risks of 3D printing in construction projects. This research will help pave the way to ensure a smooth transition from traditional construction to 3D printed projects.

## 2. Materials and Methods

The first step was to identify the 3D printing risks in construction projects through literature review. This included journals, articles and books that discuss risks in general and risks related to 3D printing in construction. Thirty risks were identified and used in the survey. The first part of the survey collected general information about the participants. While the second part included two questions for each of the identified thirty risks. One for the probability of occurrence and one for the impact. Both questions had a Liker scale of 1 to 5 where 1 was very low impact/probability and 5 represented very high impact/probability. The surveys were distributed among construction professionals in the UAE with knowledge/experience in 3D printing. The surveys were sent to 200 professionals and sixty-six responses were collected at the end, which correspond to 33% response rate. 51% of the respondents worked in design companies, while 49% worked in contractor companies. Additionally, 65% worked in local companies and 35% worked in international companies.

The relative importance index (RII) was calculated for each risk according to Equation 1. The risks were then ranked based on the calculated RII, this was done for the probability, impact, and severity. Where severity was measured by multiplying the probability and impact of each of the identified risks.

$$RII = \frac{\sum_{i=1}^{5} WiXi}{\sum_{i=1}^{5} Xi} \quad (1)$$

Where,
*Wi*= weight assigned to the $i^{th}$ response
*Xi*= frequency of the $i^{th}$ response
*i*= response category index

## 3. Risk Identification

3D printing risks in construction are grouped into six categories: 3D printing material risks, 3D printing equipment risks, construction site and environment risks, management risks as well as regulatory and environment risks. Figure 1 shows the risk breakdown structure for 3D printed construction projects.

To begin with, previous research has raised significant concerns about the risk of plastic shrinkage and cracking in 3D concrete due to its poor quality [9]. Furthermore, 3D printing materials should have unique characteristics such as printability, buildability, and open time. These special characteristics make 3D printing materials very rare, which leads to shortage in the supply of suitable printable materials [10]. There is also the possibility of material compromise during delivery which could result in unsuitable concrete for printing [11]. Not to mention, that if these materials are not probably handled or stored, it presents a huge risk to the overall success of 3D printed construction projects [12]. As far as the 2D equipment risks are concerned, proper handling of the printer is of high relevance to avoid any damages and/or operator injuries [13]. There is also added the financial risk of transporting and setting up as well as maintaining the 3D printer [14]. Moreover, operators of these 3D printer should be equipped with the proper knowledge and safety protocols to mitigate the risks of human errors, that can otherwise lead to bigger problems and increased financial burdens [15]. The lack of 3D printer suppliers is another added risk. Indeed, the well-known global suppliers are very few, those include CyBe and Apis Cor [16]. Besides, operational hazards and occasional malfunctions pose additional risks to 3D printing in construction projects [17].

Chen et al. [18] stated that cybersecurity breach and hacking is one of the critical risks in 3D printed construction projects. This is mainly due to the fact that almost all of the design information is stored in software. In addition, there is also the risk of lack of sufficient design information about 3D printed construction projects, especially because the field is still relatively new and evolving almost every day [19]. Data interoperability is also another major challenge in 3D printing as all processes are digitalized, which emphasized the need for proper communication and collaborating across the different disciplines [20]. The risks associated with the construction site and environment risks category include the limited availability of skilled labour to deal with robots [21]. It is important to note that the improper management of robots can lead to severe accidents that threaten the safety of the working labour [22]. The complexity and dynamic nature of construction sites make it even harder to implement the use of robots [23].

The high level of unfamiliarity with this new technology makes it hard to produce accurate project budgets and feasibility plans [24]. Incomplete scopes and inaccurate construction schedules are also significant risks in 3D printed construction projects [25]. There is also a lot of uncertainty circling around 3D printing in construction projects, especially because there is a lack of codes and regulations [26]. Finally, product liability is another critical risk in 3D printing, as insurance companies may refuse to provide coverage to such new and unproven technology [6].

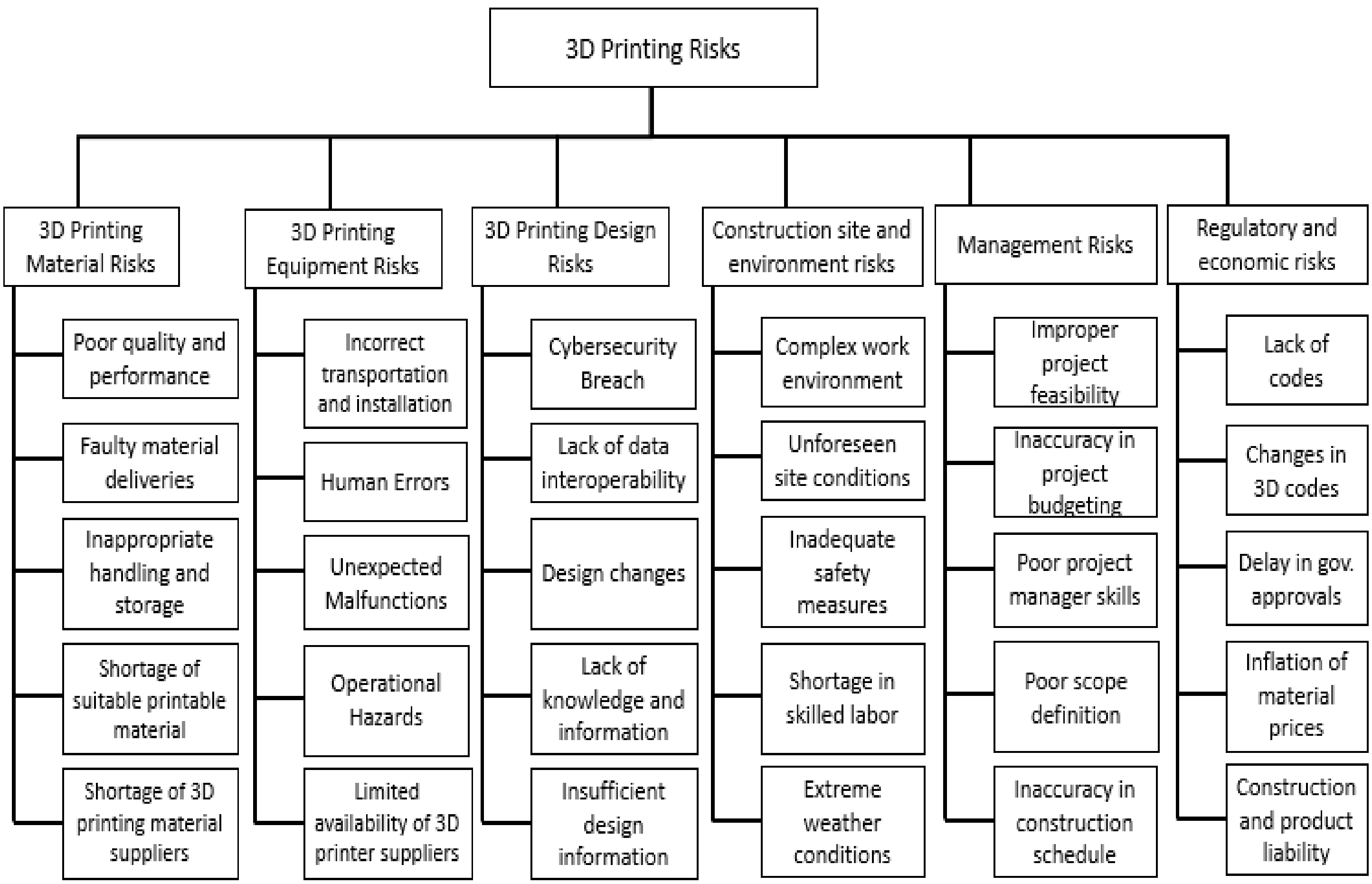


Fig. 1: Risk breakdown Structure for 3D printing in construction projects

## 4. Results

The relative importance index (RII) was calculated for each risk based on probability impact and severity. These risks were then ranked according to their RII values. The results are presented in table 1. The top 10 risks, based on severity are presented in table 2.

Table 1: Overall Risk Significance.

| Factor | Description | Probability | | Impact | | Severity | |
|---|---|---|---|---|---|---|---|
| | | RII | Rank | RII | Rank | RII | Rank |
| 1 | Poor quality and performance of 3D printing materials | 2.89 | 26 | 3.51 | 11 | 10.41 | 26 |
| 2 | Faulty material deliveries | 3.00 | 23 | 3.54 | 10 | 11.03 | 20 |
| 3 | Inappropriate handling and storage of 3D printing materials | 3.05 | 21 | 3.32 | 21 | 10.84 | 23 |
| 4 | Shortage of suitable printable material | 2.95 | 24 | 3.38 | 19 | 10.7 | 25 |
| 5 | Shortage of 3D printing material supplies | 3.41 | 6 | 3.59 | 6 | 12.81 | 9 |
| 6 | Incorrect transportation and installation of 3D printing equipment | 2.78 | 28 | 3.32 | 21 | 10 | 28 |
| 7 | Human errors | 2.84 | 27 | 3.11 | 28 | 10.16 | 27 |
| 8 | Unexpected malfunctions | 3.30 | 12 | 3.49 | 12 | 12.11 | 14 |
| 9 | Operational hazards | 2.43 | 29 | 2.81 | 29 | 7.54 | 29 |
| 10 | Limited availability of 3D construction printer suppliers | 3.35 | 11 | 3.46 | 15 | 12.38 | 12 |
| 11 | Cybersecurity breach | 2.22 | 30 | 2.81 | 29 | 7 | 30 |
| 12 | Lack of design interoperability | 3.03 | 22 | 3.19 | 25 | 10.78 | 24 |
| 13 | Design changes | 3.30 | 12 | 3.49 | 12 | 12.44 | 10 |
| 14 | Lack of knowledge and information of 3D printed design concepts | 3.65 | 4 | 3.57 | 8 | 13.78 | 4 |
| 15 | Insufficient or incorrect design information | 3.41 | 6 | 3.68 | 3 | 13.51 | 6 |
| 16 | Complex work environment | 3.16 | 18 | 3.14 | 27 | 10.97 | 21 |
| 17 | Unforeseen site conditions | 3.19 | 16 | 3.35 | 20 | 11.68 | 17 |
| 18 | Inadequate safety measures | 2.95 | 24 | 3.19 | 25 | 10.92 | 22 |
| 19 | Shortage in labour skilled in 3D printed construction | 3.68 | 3 | 3.59 | 6 | 13.89 | 3 |
| 20 | Extreme weather conditions | 3.19 | 16 | 3.24 | 24 | 11.32 | 18 |
| 21 | Improper project feasibility | 3.11 | 20 | 3.41 | 17 | 11.24 | 19 |
| 22 | Inaccuracy in project budgeting | 3.41 | 6 | 3.65 | 5 | 12.95 | 7 |
| 23 | Poor project manager skills related to 3D printed construction | 3.41 | 6 | 3.57 | 8 | 12.89 | 8 |
| 24 | Poor scope definition of 3D printed construction | 3.30 | 12 | 3.41 | 17 | 12.22 | 13 |
| 25 | Inaccuracy in construction schedule | 3.27 | 15 | 3.27 | 23 | 11.92 | 15 |
| 26 | Lack of codes for 3D printing in construction | 4.05 | 1 | 3.97 | 2 | 16.76 | 1 |
| 27 | Changes in 3D construction codes and regulations | 3.43 | 5 | 3.68 | 3 | 13.73 | 5 |
| 28 | Delay in government approvals | 3.86 | 2 | 4.03 | 1 | 16.3 | 2 |
| 29 | Inflation of material prices | 3.16 | 18 | 3.46 | 15 | 11.73 | 16 |
| 30 | Construction and product liability | 3.38 | 10 | 3.49 | 12 | 12.41 | 11 |

Table 2: Ten most severe risks in 3D printed Construction projects.

| Risk | RII | Rank | Category |
|---|---|---|---|
| Lack of codes for 3D printing in construction | 16.76 | 1 | Regulatory and economic risks |
| Delay in government approvals | 16.3 | 2 | Regulatory and economic risks |
| Shortage in labour skilled in 3D printed construction | 13.89 | 3 | Construction site and environment risks |

| | | | |
|---|---|---|---|
| Lack of knowledge and information of 3D printed design concepts | 13.78 | 4 | 3D printing design risks |
| Changes in 3D construction codes and regulations | 13.73 | 5 | Regulatory and economic risks |
| Insufficient or incorrect design information | 13.51 | 6 | 3D printing design risks |
| Inaccuracy in project budgeting | 12.95 | 7 | Management risks |
| Poor project manager skills related to 3D printed construction | 12.89 | 8 | Management risks |
| Shortage of 3D printing material supplies | 12.8 | 9 | 3D printing material risks |
| Design changes | 12.44 | 10 | 3D printing design risks |

## 5. Discussions

The results show that 3 out of the top 10 severe 3D printing risks belong to the regulatory and economic risks. Also, 3 of the top 10 belong to 3D printing design risks. 2 belong to management risks, one belongs to 3D printing material risks, and one belongs to construction site and environment risks. The severity of these risks stems from the novelty of the 3D printing technology in the UAE, where there are no established codes and regulations yet. Lack of information related to design and management related issues in 3D printing as well as lack of experience are all risks that have been stressed upon in this research due to the newness of this technology and the presence of many ambiguities around it. It is worth noting that these results are extremely different from a recent study done by Hassani [27] where the author assessed the different risks n a traditional construction project in the UAE and the results concluded that that three most significant risks were cultural diversity, external risks and economic risks. Indeed, the importance of design-related risks have also been emphasized by Sakin and Kiroglu [13], where the authors stated that CAD tools are not yet developed enough to explore the full potential of 3D printed design. Also, new design concept needs to be introduced to meet the requirements of 3D printing.

In addition, two of the management risks are also in the top 10 such as inaccuracy in project budgeting and poor project manager skills related to 3D printed construction. This is mainly due to the fact that there are a lot of unfamiliar costs in 3D printed construction projects, which makes it hard to accurately estimate the budget of the project, especially when managers are still accustomed to the familiar conditions of conventional construction projects [28]. The results also revealed that shortage of 3D printing material supplies scored 9$^{th}$ place in the top ten sever risks of 3D printing in construction projects. Perhaps, this could be attributed to the fact that 3D printing materials are not readily available in the local market and might need to be imported which makes 3D printed projects riskier due to increased cost and time [29].

## 6. Conclusions

The UAE has been promoting the shift towards innovation and digital transformation in the construction industry such as 3D printing. Mainly due to the various benefits that this technology offers which include time and cost reduction, improved productivity, and sustainability boost. However, 3D printing is affiliated a lot of risks and still has a long way to become a mainstream. The need to identify and assess these risks is of paramount importance. This would provide an opportunity to develop risk response and control strategies that are essential for successful project risk management. Thirty risks were identified through literature review and used to develop a survey to measure the probability and impact of each one of these risks. The top five risks were: lack of codes for 3D printing in construction, delays in government approvals, shortage in labour skilled in 3D printed construction, lack of knowledge and information of 3D printed design concepts, changes in 3D construction codes and regulations. Among the main recommendations that would help make the transition from traditional construction project into 3D printed projects a smooth one is the development of proper codes and regulations by leading professional associations as well as intense labour and engineers training to ensure that they become more familiar with this emerging technology. Infusing 3D printing education in universities is also critical to produce a generation that understand the basic concepts behind this disruptive technology.

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