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Mitigation measures to prevent delays in Construction Industry using 3D Printing

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Project delays are a significant challenge that can significantly impact construction projects and have been a problem affecting construction projects for more than a century. 3D Printing can reduce the probability of project delays due to its ability to work in inaccessible areas, its greater product customization, minimized waste production, and its ability to print intricate designs. Therefore, given the capabilities of 3D Printing, the research aims to identify the advantages and limitations of 3D Printing Technology. These main causes are delaying the projects and finding a way to mitigate the project delays using 3D Printing Technology. The study used a survey methodology, the literature Review for the recently published papers on 3D Printing and Project Delays. As per this study, the main reason for the project delays are the inappropriate project schedule and labor issues, whereas 3D Printing helps finish the intricate designs, reduces human errors and greater customization makes this technology stand on top. Despite the benefits, this study also identified the barriers to implementing this technology on the construction site: high initial investment and unavailability of standard regulations and codes.

Keywords: Project Delays, 3D Printing, Technology, Additive Manufacturing, Benefits, Challenges.

Introduction

Construction project delays have historically been a critical concern in the construction industry (Morris and Hugh, 1988). Completing projects before the completion date benefits all project stakeholders. However, delayed projects can have consequential impacts on project stakeholders, including the owners and contractors. For the owner, losses can be in the form of delayed project start and loss of revenue, and contractors can also be impacted tangibly and intangibly in the form of the penalty of non-engaged labor, equipment standby charges, fees on disturbing material and equipment timetables, reputation loss and others (Ojoko et al., 2016). Project delays can appear to be an unavoidable event in the delivery of building projects (Ojoko et al., 2016), but it may be efficiently controlled or managed when their causes are carefully recognized and examined. Completing projects as per the schedule can indicate efficiency, at the same time, uncertainties from stakeholders and other contextual factors (such as resources, engagement of other parties, contractual interactions, and others), along with the unpredictable nature of the industry, can impact a project's schedule (Assaf & Al-Hejji, 2006). Further,

the top factors associated with delays were identified as ineffective project planning and scheduling, poor site management, and supervision, poor financial control on-site, and rework due to errors (Aziz, 2013). Using technology in the form of three-dimensional (3D) Printing can alleviate the impacts of some of the factors (such as poor site management and supervision and rework due to errors) that contribute to the delay of a project. 3D Printing, called Rapid prototyping or Additive Manufacturing, is a sophisticated manufacturing technology that can autonomously manufacture complicated form geometries from a 3D computer-aided design model without tooling, dies, or fixtures (Tay et al., 2017). Indications exist that the technology has made inroads into construction sites (Perkins & Skitmore, 2015). However, it is unclear how 3D Printing can contribute to mitigating the delays often cited in the literature.

Therefore, the research determines the questions mentioned in the following:
1. What are the project delays in the construction industry?
2. What are the main causes for the Project delays?
3. What are the advantages and disadvantages of 3D Printing technology?
4. Does the 3D Printing Technology help the projects to mitigate the delays incurred in the project?

Literature review

Weather conditions such as extreme temperatures, precipitation, and high winds were recognized as the most impacting weather conditions on construction (Schuldt et al., 2021). Along with exogenous circumstances, technical and project management considerations such as material shortages, labor supply, equipment failures, ineffective communication between stakeholders, and errors during construction can also potentially cause delays (Hamzah et al., 2011). Further, client and contractor-related factors can also contribute to delays which emanate majorly from delays in interim payment, change orders, poor planning, scheduling, monitoring, feedback, communication and coordination, delay in material availability, inadequate essential materials, and others (Ojoko et al., 2016). According to Al-Momani (2000), the primary reasons for delays in public project development include designers, user changes, weather, site circumstances, late delivery, economic constraints, and a rise in quantity. These characteristics influence the successful delivery of projects within the time frame provided in the agreement (Al-Momani, 2000). As per Assaf and Al-Hejji (2006), owners and consultants recognize that assigning to the lowest bidder is the most common source of delay. However, contractors believe that the most severe reasons for delay are connected to owners. Assaf and Al-Hejji (2006) explained that only one source of delay is shared by all parties: changing orders by the owner during construction. Many factors are shared by the parties involved, such as progress payment delays, improper planning and scheduling by the contractor, poor site management and supervision by the contractor, labor shortages, and financial challenges by the contractor. Both owners and consultants identify labor and contractor-related issues as acute and significant drivers of delay, whereas contractors identify owners and consultants as significant contributors to delays in construction projects is identified by (Assaf & Al-Hejji, 2006). Thus, project delays can be attributed to various controllable and uncontrollable factors which include weather, labor shortages, economic conditions, selection criterion for contractor selection, owner change orders, poor site management supervision, rework because of poor quality of work, and others.

Given the numerous anticipated and unanticipated parameters that can cause project delays, numerous strategies have been recommended in the literature to alleviate the impacts of the factors on the project's schedule. For example, to counter the impact of weather, three distinct weather modeling strategies for reducing uncertainties in construction have been recommended that include the generation of weather models, construction effect models, and project scheduling models, along with obtaining historical

weather pattern information for using these concepts since it assists in establishing mitigation and adaptation approaches (Schuldt et al., 2021). Weather simulation models should not assume that the weather parameters are constant and can provide input to weather effect models, which in turn provide input to construction schedule models (Schuldt et al., 2021). Rapid construction is possible with 3D Printing. Construction moves along considerably more quickly than it did with earlier technologies. Using 3D Printing technology, construction time may be significantly decreased. For instance, 3D Printing enabled the production of a structural wall in 65 hours as opposed to 100 hours (El-Sayegh et al., 2020). The delivery time for products that require expedited delivery is eliminated by 3D Printing. Thus, this approach enhances production that would otherwise be reduced as a result of late deliverables. (El-Sayegh et al., 2020) In addition to lowering labor expenses, 3D Printing also lowers the time and price of installing and removing formwork.

Along with these technological approaches, 3D Printing can control some of the aspects relating to site management, material, labor, and work quality which can cause delays in a construction project. 3D Printing can also assist in reducing some of the significant issues of a building project, such as construction planning and monitoring, efficient communication, safety, and procurement management, by using BIM, as explained by (Tay et al., 2017). Along with these benefits, several advantages of using 3D Printing have been documented, including decreased waste, design flexibility, and reduced personnel (Wu et al., 2016a). The usage of 3-D Printing in the construction sector is heavily reliant on the accuracy of the Printing tasks, the existence of Printing materials, the budget of the Printing process, and the Printing duration, all of which influence the selection of applicable 3-D Printing technologies as per (Wu et al., 2016). Further, 3D Printing and automation for Building & Construction improvement would be ideal as they can eliminate or reduce human engagement in potentially risky operations, thereby eliminating the risk involved in these dangerous tasks. Thereby indicating that the labor engagement or use of unskilled labor will decrease with increased adoption and implementation of 3D Printing (Tay et al., 2017). Finally, the building design (shape and massing) will no longer be a barrier, and complicated designs can be created within the timeframe (Tay et al., 2017). At the same time, numerous challenges exist for 3D Printing to be used. The current ineptness of automation for truly large-scale fabrication, the severely limited scope of materials that can currently be used in construction, the high price that the industry's pioneers would have to pay in simple things like training, organization, and management, as well as the price of the equipment itself, are all prohibitively for its implementation (Pessoa et al., 2021). According to Wu et al. (2016b) the application of 3-D Printing in the construction sector is still in its infancy, and the life cycle performance of the printed projects is unknown, despite the fact that the usage of BIM may assist in investigating the printed goods at the shape, performance, and assembly levels. The future of additive manufacturing in the construction industry looks interesting, but according to (Camacho et al., 2017), more interdisciplinary research is needed to develop new materials, processes, faster Printing, quality assurance, and mechanical property data before Additive Manufacturing (AM) can reach its full potential in infrastructure construction.

Thus given the importance of reducing human labor, better site, and project coordination, and the ability of 3D Printing to alleviate the potential impacts of factors on project delays, this research determines the main reasons for project delays and investigates whether employing 3D Printing can assist in offsetting some of the variables that are generating construction site delays.

Research Method

Given the research aimed to find out which factors primarily cause delays and to identify what are the ways that can help mitigate it through the usage of 3D Printing, they used a survey method as it has the ability to identify and determine the trends at the point of the study. The research used an online survey

method as most have internet access, a likelihood of prompt responses (Flaherty et al., 1998), and studies within the construction industry have used the method to determine technologies (Langar and Fountain, 2018; McGraw Hill 2015). The general population of the study was US construction industry professionals possessing knowledge of 3D Printing technology and how it can solve the problems associated with project delays. The online instrument was generated in Qualtrics and consisted of both multiple-choice and open-ended questions. The survey consisted of three sections, including a) respondent demographics; b) 3D Printing implementation; c) the role of 3D Printing in helping mitigate the project delays. The survey questions were designed in such a manner that the respondents could complete the study within 10 minutes. After the instrument development, it is shared with professionals through LinkedIn, Email, and as a reminder again sent to professionals after a week. These professionals are targeted as 3D Printing experts. The questionnaire was sent to 20 professionals and received 11 responses. Therefore, the percentage of respondents was 55%.

Results

The majority (40%) of the respondents identified themselves as consultants, followed closely by researchers (30%), as indicated in Figure 1. 36% of others are working in the manufacturing/supply chain/designer business. 40% of respondents are into the form of residential construction, as per Figure 2. The majority of the respondents were in the age group of 25-34 years (Figure 3). 50% of respondents had 1-5 years of experience in the construction industry, and 30% had about 5-10 years of experience in the construction industry (Figure 4). 60% of companies have a company size of less than 100 employees. 10% are into 1,000-1,500 employer companies, and 20% have greater than 2,000 employees (Figure 5). 50% of respondents replied that the revenue of the companies of the respondents is less than $10,000,00 (Figure 6).

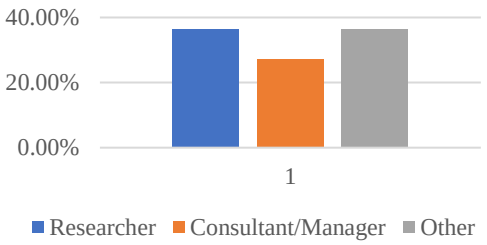

Figure 1: Role of Respondents

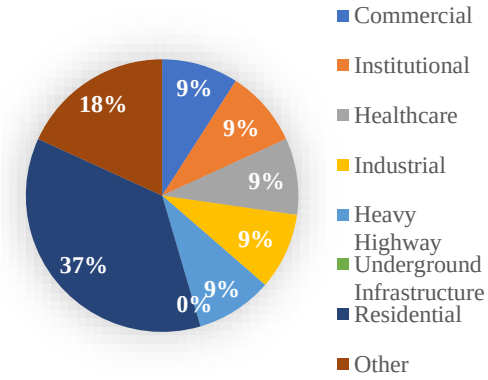

Figure 2: Form of construction

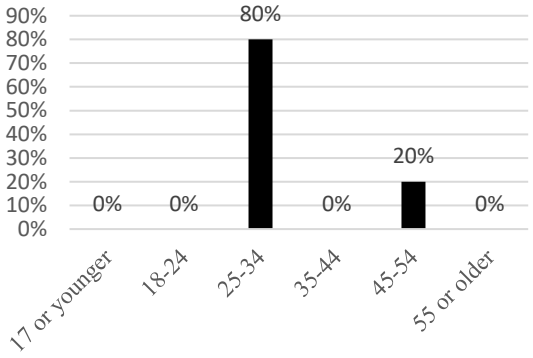

Figure 3: Age of the Respondent

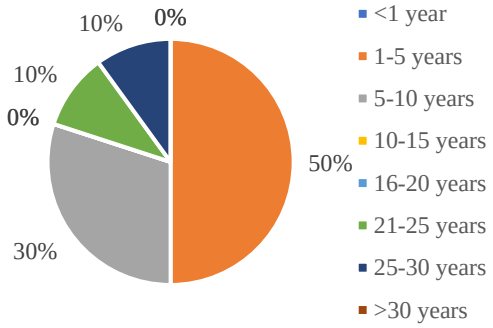

Figure 4: Respondent work Experience

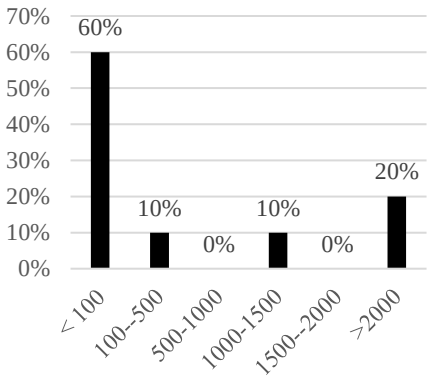

Figure 5: Employees in Company

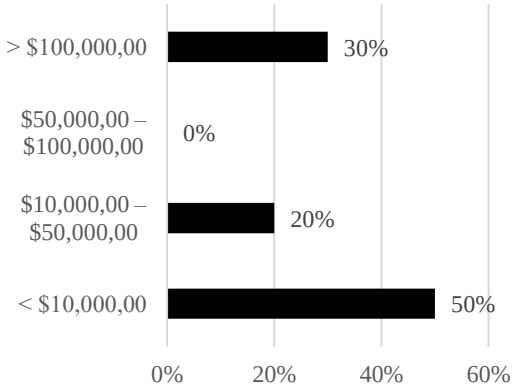

Figure 6: Company size based on revenue

Project Delays

Per the survey respondents, the main reason for project delays included labor shortages, project complexity, inadequate planning, and inappropriate project scheduling (Figure 7).

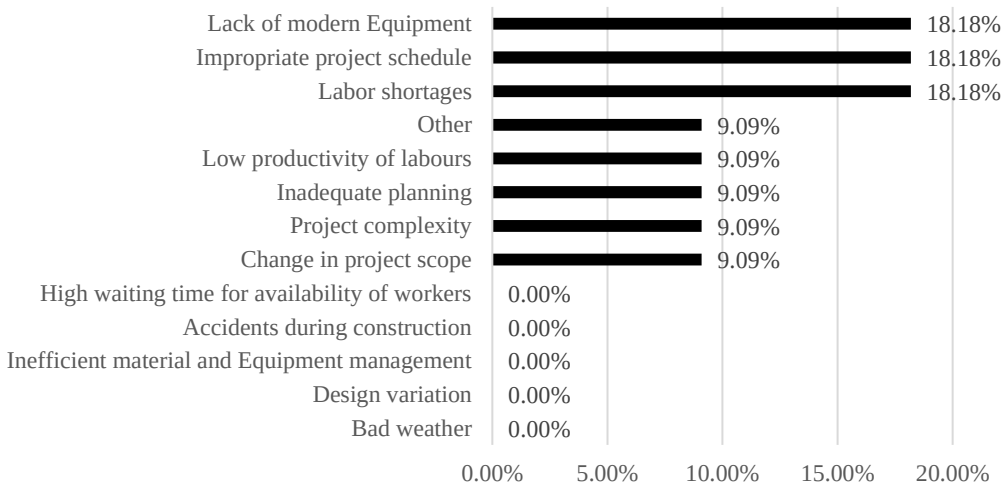

Figure 7: Main cause for the Project Delays

Additive Manufacturing

The majority of the respondents (80%) haven't implemented 3D Printing. Currently, 3D Printing applications are in the initial stage and getting implemented gradually. It also consists of barriers such as high initial investment and training required. As per the respondents, design complexity was one of the most significant advantages of using 3D Printing (Figure 8). The equipment's initial investment was identified as the significant barrier to its implementation (Figure 9).

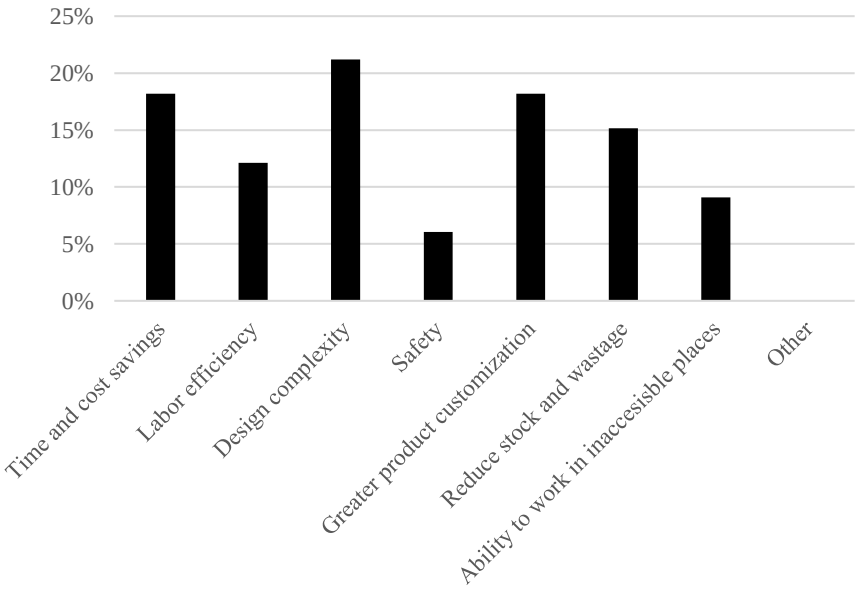

Figure 8: Advantages of 3D Printing

According to the survey, the limitation of 3D Printing is the initial investment, as the equipment is expensive (Figure 9). The respondents also identified that the extent of customization that can be done using 3D Printing is also effective, as shown in (Figure 10).

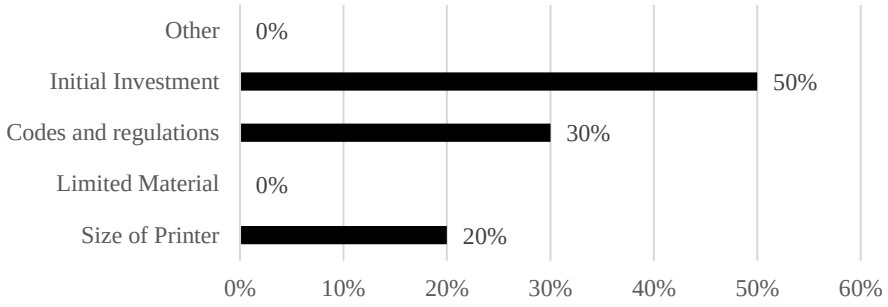

Figure 9: Barrier to Implementation of 3D Printing

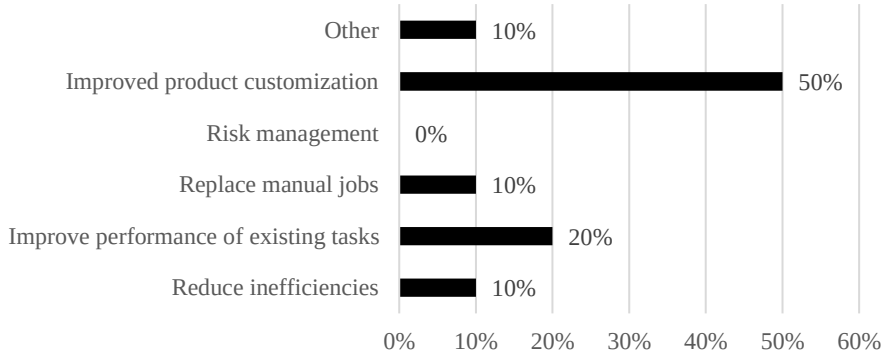

Figure 10: Effectiveness of 3D Printing

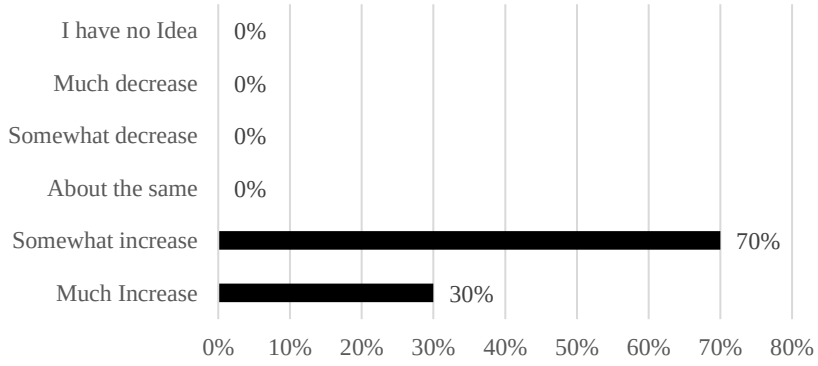

Figure 11: Future forecast of 3D Printing

The future forecast of 3D Printing, as per the survey shown in Figure 11, is 70% mentioned somewhat increase, and 30% mentioned much increase. For the question of whether the delay can be mitigated or

not, more than 50% have mentioned probably and definitely yes that delay can be mitigated using 3D Printing in construction projects (Figure 12).

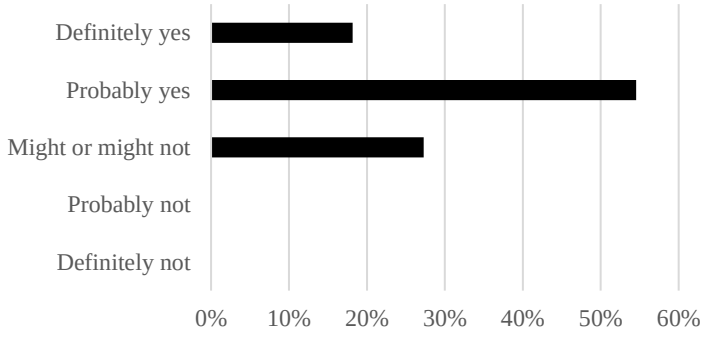

Figure 12: Delay mitigation through 3D Printing

Summary and conclusion

3D Printing is one of the emerging technologies in the construction industry. The construction industry will undergo a transformation due to 3D Printing. Construction might become more productive and sustainable with the help of Industry 4.0 advancements and 3D Printing. Project delays can occur due to various reasons, but some of the reasons, like labor shortage, Project complexity, and delay due to human errors, can be mitigated of some sort with 3D Printing. 3D Printing is good at customizing the designs, whatever we like, and helping to finish the intricate designs that are complicated to do manually or with current procedures and providing us with a prototype that is shown digitally in 3D. Though this has all these advantages, it also contains some of the limitations that stop the adoption of this technology, such as the high initial investment, No proper standard codes, and regulations. The delay mitigation can be done using this 3D Printing technology. However, there must be further research on providing standard codes and regulations. If these limitations can be overcome, this 3D Printing will serve the world with its applications in the construction industry.

Future studies

This research can be extended by standardizing the codes and regulations required for more knowledge on using 3D Printing. Research is needed on this technology and whether it can be integrated with BIM software to improve its applications. Research can also be done on introducing multiple nozzles and safety monitoring systems to enhance the safety of using this technology on-site.

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