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An Assessment of Malaysian Contractors' Readiness for 3D Printing Implementation

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Abstract: - Over the years, the construction sector has undergone significant advancements, with 3D printing emerging as one of the most transformative technologies. Despite its potential, adoption in Malaysia remains limited due to a lack of awareness and insufficient knowledge among industry players. This study aims to examine the readiness of Malaysian contractors toward the implementation of 3D printing technologies. Specifically, the objectives are to: (i) identify the benefits of 3D printing technologies for contractors, (ii) analyse the challenges faced by the Malaysian construction industry, and (iii) propose strategies for effective implementation. A total of 150 questionnaires were distributed to contractors classified under G4 to G7 in Klang Valley, as listed on the CIDB website (2023). Out of these, 100 valid responses were collected, representing a 67% response rate. The findings highlight that 3D printing has the potential to revolutionize conventional construction practices by enhancing efficiency, sustainability, and adaptability. However, contractors must address key challenges including technological readiness, cost implications, and regulatory support before large-scale implementation can be realized. The study emphasizes the need for greater industry engagement, training, and strategic planning to ensure successful integration of 3D printing technologies into Malaysia's construction sector.

Keywords: *3D printing, Readiness, Contractor*

1. INTRODUCTION

3D printing or Additive manufacturing (AM) is a process of manufacturing parts by subsequent joining of layers of materials using a 3D model (Baumers, M., Carmignato, S., Leach, 2020). Additive manufacturing (AM) processes use computer-aided design (CAD) models as blueprints to fabricate complex three-dimensional designs layer by layer. According to Low et al., (2017), 3D printing technology is a truly innovative and has emerged as a versatile technology stage. It opens new opportunities and gives hope to many possibilities for companies looking to improve manufacturing efficiency. Recently, there has been a growing interest in construction automation and the applications of 3D printing in construction. According to Duarte et al., (2021) the use of additive manufacturing to obtain compressive structures is already possible and should be considered a starting point to introduce this technology in the industry. Therefore, it is crucial to develop a framework to accomplish these first steps by identifying at first structural shapes that maximize compressive behaviour, and then adaptable construction sequences from such examples. Due to the industry's active involvement in the 3D printing market, the perception of the construction sector may change.

Thus, to improve and facilitate the construction industry's adoption of the innovative 3D printing technology, this study aims to analyse the factors that influenced the acceptance of contractor towards implementing 3D printing technology in Malaysian construction industry.

2. LITERATURE REVIEW

The emergence of 3D printing, also known as additive manufacturing (AM), has sparked considerable interest in the construction sector due to its potential to transform conventional practices. A growing body of literature highlights the significant opportunities associated with the integration of this technology, ranging from cost efficiency to sustainable construction methods. At the same time, numerous technical, economic, and regulatory challenges remain, particularly in contexts such as Malaysia where awareness and adoption are still developing. To better understand the readiness of contractors for this transformation, it is important to examine the benefits, challenges, and strategies associated with 3D printing adoption.

2.1 Benefits of 3D Printing Technologies for Contractors

A 3D solid object can be "printed" from a digital model using additive manufacturing (AM), which involves adding layers of material one at a time. The implementation is crucial since it makes the building's construction approach more practical. 3D printing is quickly discovering new applications because of cost reductions and technological breakthroughs, particularly in short-run manufacturing where personalization is crucial.

a) Speed of Construction

Construction 3D printing can speed up and reduce the duration of the construction process. Construction projects are time-consuming due to many factors. 3D printer integration can solve these problems due to its technological advancement. Thus, with the aid of 3D printing technologies, contractors can benefit in many aspects, as it will reduce the hurdles in the construction process. Besides, numerous logistical processes and preparation duties are eliminated when elements are printed on-site. Both methods require much preparation and logistical effort. With on-site printing of concrete, the raw material is directly moulded into a construction, not requiring wooden moulds as regular concrete would (Kothman & Faber, 2016). Conventional construction will have a deficiency where building parts will get damaged in transit. These damages must be repaired on-site and will require more labour on the contractor's side. With 3D printing technology, the design and visuals of the building can be created in a short amount of time and at a reduced cost (Shahrubudin et al., 2019).

b) Freedom of Designing

The capacity to develop structures with complex shapes may be one of the key benefits for most architects. For architects, 3D printing offers a lot of versatility. The digitization of a significant portion of the manufacturing process results in small batches of complicated items that enable high levels of customization at relatively modest additional costs. If one factor were eliminated, a substantially larger percentage of the population could be able to own a home that is uniquely theirs. The precise shape that is created via concrete 3D printing is essentially meaningless in terms of cost. Many people would be able to modify the layout of their homes to suit their individual requirements. This approach enables the architect to develop their original idea without considering potential outcomes because 3D printing technology now makes it possible to create any complex design (Kothman & Faber, 2016).

c) Sustainable Construction

By limiting building waste, 3D printing for construction can minimise pollution by 30% to 60%. For instance, the Chinese Win Sun project used a mixture of industrial wastes, fibreglass, cement, and hardening agent for printing stereolithography. Rapid prototyping, also known as fast, accurate, and repeatable fabrication of elements, was initially achieved using stereolithography (Hager et al., 2016). Rolls of thermoplastic materials, such as ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid), which is a different form of thermoplastic, are used in printers and are frequently utilised in fused deposition modelling (FDM) technology. Fused deposition modelling has developed into the most well-liked and commonly used 3D printing technique worldwide during the last 20 years, according to Hager et al., (2016). However, this technology should be developed with ecological considerations in mind, both for material selection and construction approach (Sakin & Kiroglu, 2017). 3D printing has the potential to revolutionise modern architecture. Contrary to most current methods, which are unsustainable, 3DP will increase construction efficiency while fostering sustainable growth and encouraging the circular economy, for instance by using recycled materials and environmentally friendly materials (Despeisse et al., 2017).

d) Reduced Health and Safety Hazards

By limiting building waste, 3D printing for construction can minimise pollution by 30% to 60%. For instance, the Chinese Win Sun project used a mixture of industrial wastes, fibreglass, cement, and hardening agent for printing stereolithography. Rapid prototyping, also known as fast, accurate, and repeatable fabrication of elements, was initially achieved using stereolithography (Hager et al., 2016). Rolls of thermoplastic materials, such as ABS (Acrylonitrile Butadiene Styrene) or PLA (Polylactic Acid), which is a different form of thermoplastic, are used in printers and are frequently utilised in fused deposition modelling (FDM) technology. Fused deposition modelling has developed into the most well-liked and commonly used 3D printing technique worldwide during the last 20 years, according to Hager et al., (2016). However, this technology should be developed with ecological considerations in mind, both for material selection and construction approach (Sakin & Kiroglu, 2017). 3D printing has the potential to revolutionise modern architecture. Contrary to most current methods, which are unsustainable, 3DP will increase construction efficiency while fostering sustainable growth and encouraging the circular economy, for instance by using recycled materials and environmentally friendly materials (Despeisse et al., 2017).

e) Reduced Health and Safety Hazards

The number of accidents and fatalities involving contractors can be decreased by using 3D printing technology because the printer will handle the riskiest and most dangerous tasks. This advantage arises from the ability of 3D printing to automate the construction process. By minimising the harsh surroundings that on-site personnel are exposed to and by automating some building operations, AM could offer services to the construction sector (Delgado Camacho et al., 2018). The adoption of 3D printing will result in jobs that place a larger focus on technology and move workers to safer environments, such computer programming.

2.2 Challenges of 3D Implementation in Construction Industry

In 3D printing, there are many issues that need to be resolved before they can be successfully implemented. Technically, the material, machine, and part design are all interdependent, so maintaining correct coordination between these three elements is more important than focusing on improving each one separately (Panda et al., 2018). Thus, despite their enormous promise, there are some issues that must be resolved before they can be successfully used.

a) Risks of Building Information Modelling (BIM)

Depending on how the risks are reduced, Building Information Modelling (BIM) can be effective. There aren't many risks worth mentioning. One of the key tactics for enhancing project performance and effective project delivery is managing BIM projects. To manage project complexity in the construction sector, it is essential to measure BIM cooperation and risk (Ali, K. N., Alhajlah, H. H., & Kassem, 2022).

BIM data must be protected through copyright laws and other legal means because its ownership cannot be established. If the owner, for example, paid for the design, they might feel entitled to ownership. However, if team members contribute confidential information for the project, that data also needs to be protected. As a result, there is no simple solution to the question of data ownership because each project calls for a different solution based on the interests of the participants. The next concern is who will oversee data entry into the model and be responsible for any mistakes. Assuming accountability for maintaining the accuracy of building, information model data entails a high level of risk. Before using BIM technology, it is vital to negotiate and respond to the users' complex indemnity needs. To "fix the problem" with the construction management (CM) company and to acquire the essential skills, persons with lesser BIM competences but a desire to engage in the concept were nevertheless allowed into the project (Disney et al., 2022).

b) Lack of Standardisation in 3D printing

There are no defined construction regulations or requirements for 3D-printed structures. This can raise concerns about the safety and legal ramifications of using 3D printing for construction projects. Each structural component must be printed while adhering to the standards for choosing size, shape, and mechanical qualities in the design, just as traditional reinforced concrete structural components. In 3DPC constructions, the reinforcement system also needs to be standardised (Siddika, A., Mamun, M. A. A., Ferdous, W., Saha, A. K., & Alyousef, 2020). Before being employed in many applications, concrete must adhere to strict criteria. Therefore, 3D concrete printing as a new construction technology needs to reach a specific level of reliability before it can be applied in real-world settings (Panda et al., 2018). It is challenging to transfer information between sectors due to standards developed by the building industry due to intellectual property issues (Shukla et al., 2019).

c) Low Return on Investment

As stated by Afzal et al., (2021), the high upfront expenses necessitate a sizeable financial investment for R&D and application reasons and accepting this risk in a highly competitive market will raise the risk of these expenditures. Small and medium-sized businesses are unable to make system-level technology investments and cannot take advantage of new technological advancements. The main underlying factor in this category is the lack of concrete evidence that implementing robotics will result in a decrease in the cost of asset delivery. According to Pan et al., (2018), the absence of evidence is a significant barrier in the construction business, which is a low-profit and high-risk sector. There aren't any comprehensive and in-depth cost/benefit analyses for adopting robotics.

d) Material Used

Since there is no formwork required here for material deposition, conventional concrete cannot be used directly for 3D printing applications. To print, the material must have enough yield stress to support the successive deposited layers without significantly deforming the bottom layers. In addition, it ought to have strong form retention qualities and be extrudable the main distinction between conventional concrete pumping and 3D printed concrete is that the former involves pouring concrete into a predetermined formwork, whereas the latter does not and the shape of the objects is entirely determined by the rheology of the material and other new properties (Panda et al., 2018).

2.3 Strategies to Implement 3D Printing Among Contractors

In 3D printing, there are many issues that need to be resolved before it can be successfully implemented. Technically, the material, machine, and part design are all interdependent, so maintaining correct coordination between these three elements is more important than focusing on improving each one separately (Panda et al., 2018). Thus, despite their enormous promise, some issues that must be resolved before they can be successfully used.

a) Roles of CIDB

International BIM application has advanced significantly in both developed and developing countries. BIM and 3D printing are closely related since BIM is the primary tool and foundation for 3D printing. Whether BIM was used in a project for design authoring, visualisation, design review, coordination, quantity of documentation, or record model, the objectives were different.

Another issue is that there are no laws governing 3D printing in construction. It would be challenging to apply the technology in a way to adhere to all the construction norms and guidelines since there are no established regulations for the use of 3D printing in construction (Ali et al., 2022). This is the point at which the Malaysian Public Work Department (PWD) should have received an act and regulations regulating 3D printing from CIDB, the country's regulatory body. To successfully improve BIM deployment, it is crucial to have a willingness and dedication to the technology. To increase construction performance and achieve global competitiveness, every sector of the construction industry should be accountable for cooperating (Othman et al., 2021).

b) Roles of Developer and Supplier

In addition to ICT, many engineering consulting companies have independent research and development (R&D) departments that oversee both introducing and advancing existing technology. They typically work closely with project engineers to commercialise cutting-edge methods and technologies. In the ideal situation, these R&D departments have adequate funding and work in tandem with creative ICT departments to acquire cutting-edge equipment and systems that can be tested in real-world commercial settings. Project management must consider the production and assembly phases of the construction process from the beginning of the design process in a new building process for the paradigm shift to occur. The design process ought to be viewed as a cooperative effort by architects, engineers, and builders. If the true potential of additive construction is to be realised, all these factors need to be much more integrated into a single design process (Olsson et al., 2019). Contractors must collaborate closely with developers to provide the greatest options for building methods that provide the best value for the project's budget when integrating new technologies like 3D printing.

c) Awareness through Technology Exhibition

Technology Exhibitions are public markets where vendors set up shop to offer their things and customers come to learn more. Customers may learn about new technology during the exhibitions or receive updated information about technology they are already familiar with. The researcher was able to examine how vendors sell their technologies and observe vendor-customer interactions "in the wild" by taking part in these exhibitions. This provided the researcher with the context and knowledge needed to form the adoption framework. By employing this technique, 3DPC can gain widespread recognition among industry players everywhere, particularly in Malaysia. Interviews with knowledgeable individuals were conducted to provide the framework with more depth based on facts that may not be immediately obvious from seeing the TEs (Sepasgozar & Davis, 2018). The combination of data resources from exhibitions and interviews adds significant originality to this exploratory study and enables triangulation of the findings to strengthen the validity of the research.

3. RESEARCH METHODOLOGY

3.1 Quantitative Design Method

The research required the identification of the benefits, challenges, and strategies of 3D adoption Malaysia construction industry from the perspectives of the contractors to gather their opinions for further analysis. The most appropriate approach to directly address the research issues was determined to be descriptive research. According to its definition, descriptive research focuses more on what happened than on how or why it happened, correctly and methodically describing the characteristics of a particular population or area of interest (Nassaji, 2015).

The "observed phenomenon" in this research is the benefits, challenges, and strategies of 3D applications in construction, whereas descriptive research tends to employ questionnaires to conduct research to characterise the variability in different phenomena. Since these professionals are most likely to be involved in 3D adoption, the characteristics of the sample that was chosen to receive the questionnaire are among the contractor G4 to G7. The Klang Valley area were chosen in the study because they have a sizable population and a high building output for a variety of reasons, such as geography, administration, etc. The survey was given to 150 participants.

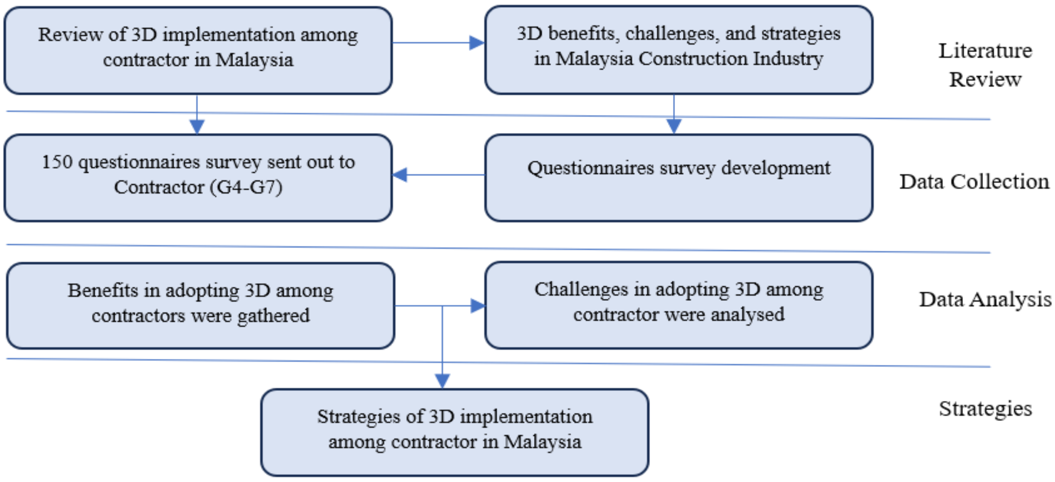

Fig. 1 Research Methodology

4. RESULTS AND DISCUSSIONS

This section presents and interprets the findings of the study, focusing on the readiness of Malaysian contractors to adopt 3D printing technologies. The results are derived from survey data collected among contractors, with emphasis on identifying the key challenges they face and the strategies that may facilitate adoption. By analysing the responses, the discussion highlights both the practical barriers such as cost, material limitations, and lack of awareness and the potential enablers, including government policies, industry collaboration, and capacity building. The interpretation of these findings provides valuable insights into how the construction sector can prepare for the integration of 3D printing as a mainstream practice.

4.1 The Challenges of Implementing 3D Printing among Contractors

Table 1 The Challenges of 3D implementation

Items	Ranking	Mean Value	Standard Deviation
High additional cost in Research & Development of 3D printing technologies	1	4.28	0.73
Materials used in 3D printing which requires extra cost	2	4.19	0.76
Maintaining consistent quality throughout the construction process	3	4.18	0.78
Long term durability issues of 3D printing buildings	4	4.17	0.75
Lack of awareness in terms of exposure and education of 3D printing	5	4.16	0.75
Risks of building information modelling such as human error will affect quality of project	6	4.13	0.78
Lack of skill labour and expertise which will affect the quality of construction	7	4.12	0.75
Lack of clear guidelines and standards in 3D printing leads to legal issues and safety of the project	8	3.99	0.74

Table 1 shows an analysis of the challenges of 3D implementation in the construction industry. The highest value of the mean is 4.28 (SD 0.73) for the high additional cost of Research and Development (R&D) of 3D printing technologies. The high cost of the technology's implementation in construction robotics is because the automation technologies are so expensive (Yamani Bin Yahya et al., 2019). The statement where materials used in 3D printing require extra cost has the second highest mean value of 4.19 (SD 0.76). Paul et al., (2018) mentioned that for printing, the material must possess sufficient yield stress to hold the subsequent deposited layers without any major deformation of the bottom layers. Simultaneously, it should be extrudable with good shape retention properties. Maintaining consistent quality throughout the construction process, with a mean value of 4.18 (SD 0.78). This is supported by the statement from De Schutter et al., (2018) that structural design will have to consider the layered structure, requiring new design models for shear loading.

These are the three lowest values of the mean. The risks of building information modelling, such as human error, will affect the quality of the project, with a mean value of 4.13 (SD 0.78). It is supported by (Regona et al., 2022). Nevertheless, construction robotics can take a significant amount of time to set up and need constant monitoring by skilled workers. The lack of skilled labour and expertise that will affect the quality of construction is the second-last ranking, with the value of the mean being 4.12 (SD 0.75). This challenge is supported by Maki et al. (2022), there is a limited number of personnel who have complete knowledge and understanding of all the methodologies of 3D printing. The lowest value of mean 3.99 (SD 0.74) is the lack of clear guidelines and standards in 3D printing, which leads to legal issues and the safety of the project. These companies have no framework to follow, and there is no guidance on implementing these technologies on sites (Xin et al., 2022).

4.2 The Strategies of 3D Printing Implementation among Contractors

Table 2 Strategies of adopting 3D implementation among Contractors

Items	Ranking	Mean Value	Standard Deviation
Technology exhibitions in terms of campaigns and exhibitions to give exposure about 3D printing	1	4.17	0.79
Government providing subsidies to those who implement 3D printing technologies	2	4.15	0.71
Government under CIDB to enforcing laws about 3D printing technologies	3	4.11	0.76
Up roaring about cost benefits from implementing 3D printing	4	4.11	0.76
Collaboration between R&D team and ICT team to maintaining and developing 3D printing technologies	5	4.10	0.82
Emphasizing Building Information Modelling (BIM) among construction players	6	4.09	0.84
More developers use 3D printing as an affordable option compares to conventional method	7	4.01	0.71
Programs of apprenticeship and training given to the construction players	8	3.95	0.80

Table 2 shows the analysis of the strategies to implement 3D printing among contractors. The highest value of the mean is 4.17 (SD 0.79) for technology exhibitions in terms of campaigns and exhibitions to give exposure to 3D printing. This strategy is supported by a statement from Olsson et al., (2019) which cites collaboration within the construction sector as a key success factor for the implementation of 3D printing, along with R&D funding. The statement where the government provides subsidies to those who implement 3D printing technologies has the second highest mean value of 4.15 (SD 0.71). The government under CIDB enforcing laws about 3D printing technologies came in third with a mean value of 4.11 (SD 0.76). At the early stage of implementation, the government's enforcement of BIM as a driver for construction projects is necessary.

These are the three lowest values of the mean. emphasising Building Information Modelling (BIM) among construction players with a mean value of 4.09 (SD 0.84). BIM represents a comprehensive data source by providing a high amount of precise information (Borrmann et al., 2018). More developers use 3D printing as an affordable option compared to conventional methods; the second-last ranking with the value of the mean is 4.01 (SD 0.71). Ibrahim et al., (2019) mentioned that although the initial cost of BIM is quite higher than that of a CAD platform, over the long haul, expanded profitability could be conceivably accomplished by BIM. The lowest value of mean 3.95 (SD 0.80) is the programme of apprenticeship and training given to the construction players.

5. Conclusion

The findings of this study underscore the transformative potential of 3D printing in reshaping the Malaysian construction industry. By critically examining its benefits, challenges, and strategies, it becomes clear that while the technology offers significant opportunities such as faster project delivery, design flexibility, sustainability, and improved occupational safety its successful integration is hindered by substantial barriers. These include high upfront investment costs, material limitations, the absence of standardisation and regulatory frameworks, as well as a lack of awareness and technical expertise among contractors.

To fully harness the advantages of 3D printing, industry stakeholders must adopt proactive strategies. Government bodies, particularly the CIDB and the Public Works Department, play a crucial role in establishing policies, standards, and incentives that can accelerate adoption. Likewise, collaboration between developers, suppliers, and contractors is essential to create an integrated ecosystem where new technologies can be tested, refined, and scaled. Awareness campaigns, professional training, and knowledge-sharing platforms such as technology exhibitions and apprenticeships further serve as catalysts for building industry-wide readiness.

Ultimately, the readiness of Malaysian contractors to embrace 3D printing depends not only on overcoming technical and financial challenges but also on fostering a cultural shift towards innovation and sustainability. If implemented strategically, 3D printing has the potential to revolutionise conventional construction practices, enhance productivity, reduce environmental impact, and improve global competitiveness. Future research should expand beyond contractor readiness to include client perspectives, long-term cost–benefit analyses, and case studies of pilot projects to provide richer empirical evidence. In doing so, the construction sector can move towards a more efficient, sustainable, and technologically advanced future.

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