The Implementation of 3D Printing Technology in The Malaysian Construction Industry

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ABSTRACT

The adoption of 3D printing technology has the potential to transform the construction industry by improving project efficiency, reducing costs, and enhancing design flexibility. However, its implementation in the Malaysian construction industry remains limited due to several barriers, including a lack of skilled labour, high initial costs, and limited awareness. This study aims to encourage the implementation of 3D printing technology by identifying its impacts, examining the barriers to its adoption, and proposing practical implementation strategies. A quantitative research approach was adopted, involving a questionnaire survey of 103 Grade G7 contractors in the Klang Valley from a population of 236 contractors, representing a response rate of 43.64%. The collected data were analysed using SPSS Version 29. The findings indicate that respondents recognise the benefits of 3D printing technology, particularly in improving project efficiency (mean = 4.12), reducing construction waste (mean = 3.93), and enhancing design flexibility (mean = 3.79). The main barriers identified were a lack of skilled labour, high initial costs, and limited awareness, all with mean scores above 4.10. Respondents also highlighted training programmes, public awareness campaigns, and government subsidies as key strategies to promote wider adoption.

Keywords: 3D printing technology, construction industry, Malaysia, technology adoption, Grade G7 contractors

INTRODUCTION

The construction industry has long been recognised as one of the most critical sectors for economic development, yet it continues to experience low productivity growth and slow technological adoption (Thanekar et al., 2023). In recent years, 3D printing technology, also known as additive manufacturing or construction 3D printing (C3DP), has emerged as a promising innovation capable of transforming conventional construction practices (Wang et al., 2023). By fabricating building components layer by layer, the technology offers greater design flexibility, improved construction efficiency, cost reduction, and enhanced environmental sustainability (Pessoa & Guimarães, 2020; Wu et al., 2016).

Globally, 3D printing has demonstrated significant benefits. Studies report reductions of 50% to 75% in construction time, 50% to 80% in labour costs, and 30% to 60% in material costs compared with conventional construction methods (Yin et al., 2022). The technology also enables the construction of complex geometries while reducing construction waste and energy consumption (Kamal, 2023; Marijnissen & Zee, 2017).

Despite these advantages, the adoption of 3D printing technology in the Malaysian construction industry remains at an early stage (Chang, 2020). The industry continues to face rising costs, labour shortages, and increasing sustainability demands. However, barriers such as high initial investment, lack of skilled labour, limited awareness among industry stakeholders, and regulatory challenges continue to hinder its implementation (Abdulqader et al., 2025; Charles & Pauzi, 2025). The industry's continued reliance on

conventional construction practices has further slowed technological adoption and productivity growth (Thanekar et al., 2023).

LITERATURE REVIEW

This section reviews the existing literature related to the implementation of 3D printing technology in the construction industry. It discusses the key benefits of 3D printing, the barriers to its adoption, the current state of implementation in the Malaysian construction industry, and the strategies proposed to encourage wider adoption. The review provides the theoretical foundation for the study and supports the development of the research objectives.

Benefits of 3D Printing in Construction

The literature highlights several benefits of 3D printing technology in construction, particularly in improving project efficiency, reducing costs, enhancing design flexibility, and supporting sustainability. One of its most significant advantages is the reduction in construction time, with studies reporting time savings of 50% to 70% compared to conventional methods (Marijnissen & Zee, 2017). For instance, Wu et al. (2016) demonstrated that printing a structural wall required only 65 hours instead of 100 hours, resulting in faster project delivery and reduced site disruption.

Cost efficiency is another major benefit. Through automation, 3D printing can reduce labour costs by 50% to 80%, eliminate conventional formwork, minimise material waste, and lower overall construction costs by 30% to 50% (Marijnissen & Zee, 2017; Wu et al., 2016; Yin et al., 2022). These advantages make the technology particularly suitable for addressing housing and infrastructure demands in developing countries (Chowdhury et al., 2019).

In addition, 3D printing enables greater design flexibility by producing complex geometries and customised building components that are difficult or expensive to construct using traditional methods (Marijnissen & Zee, 2017; Opawole et al., 2022). From an environmental perspective, precise material placement significantly reduces construction waste and energy consumption, supporting more sustainable construction practices (Kamal, 2023; Wu et al., 2016).

Barriers to 3D Printing Adoption

Despite its advantages, the adoption of 3D printing technology remains constrained by several barriers. High initial investment in equipment, materials, and workforce training is consistently identified as the primary obstacle, particularly for small and medium-sized contractors (Charles & Pauzi, 2025; Chowdhury et al., 2019).

Another major challenge is the shortage of skilled personnel with expertise in both robotic technologies and conventional construction practices. Successful implementation requires continuous education, technical training, and organisational readiness to support digital transformation (Shahzad et al., 2022; Tafazzoli et al., 2024).

Limited awareness among industry stakeholders further restricts adoption, as many organisations remain reluctant to replace conventional construction methods despite the proven benefits of 3D printing (Costa et al., 2024). In Malaysia, low awareness has been recognised as one of the key barriers to construction technology adoption (Abdulqader et al., 2025). Furthermore, inadequate regulatory frameworks, including limited guidance on building codes, approvals, and inspection procedures, continue to create uncertainty for industry practitioners (Everett et al., 2022; Kamal, 2023).

3D Printing in the Malaysian Context

Although 3D printing offers considerable potential, its adoption within the Malaysian construction industry remains limited. Rising construction costs, labour shortages, and increasing sustainability requirements have

strengthened the need for digital construction technologies; however, implementation continues to be constrained by technical limitations, financial concerns, and limited industry readiness (Chang, 2020; Charles & Pauzi, 2025).

Previous Malaysian studies consistently identify high initial costs, shortage of skilled manpower, technological limitations, and low awareness as the major barriers to implementation (Abdulqader et al., 2025; Charles & Pauzi, 2025). While the Malaysian government has promoted digital transformation through initiatives such as Building Information Modelling (BIM), challenges relating to technical capability, organisational readiness, financial investment, and regulatory support remain. These experiences provide valuable lessons for accelerating the implementation of 3D printing technology within the construction sector (Abdulqader et al., 2025).

Strategies for Encouraging 3D Printing Adoption

The The literature suggests several strategies to promote the adoption of 3D printing technology in construction. Industry-oriented training programmes are essential for addressing the shortage of skilled personnel and improving technical competency in digital construction technologies (Tafazzoli et al., 2024). Public awareness campaigns can further enhance industry acceptance by demonstrating the practical benefits and successful applications of 3D printing technology (Charles & Pauzi, 2025).

Government financial support, including subsidies and incentives, has also been recognised as an effective mechanism for reducing the high initial investment associated with 3D printing adoption (Charles & Pauzi, 2025; Gangotra et al., 2023). Evidence from China demonstrates that sustained government investment has significantly accelerated technological development and industrial adoption (Yin et al., 2022). Similar policy initiatives could strengthen the implementation of 3D printing technology within the Malaysian construction industry.

METHODOLOGY

This section describes the research methodology adopted to achieve the study objectives, including the research design, population and sampling, data collection, and data analysis techniques.

Research Design

This study adopted a quantitative research approach to investigate the adoption of 3D printing technology in the Malaysian construction industry. A quantitative method was selected because it enables the collection of numerical data from a large sample, allowing statistical analysis and the generalisation of findings (Chowdhury et al., 2019). The research was designed to identify the impacts of 3D printing applications, determine the barriers to implementation, and propose strategies to encourage its adoption. These objectives guided the development of the questionnaire and the data analysis.

Population and Sampling

The target population comprised Grade G7 contractors operating in the Klang Valley. Grade G7 contractors represent the highest contractor classification in Malaysia and are capable of undertaking projects with unlimited contract values. They were selected because of their greater financial capacity, project scale, and potential to adopt innovative technologies.

A list of contractors was obtained from the Construction Industry Development Board (CIDB). Based on this list, questionnaires were distributed to 236 Grade G7 contractors, of which 103 valid responses were received, representing a response rate of 43.64%. This exceeds the average response rate reported for online surveys and is considered adequate for statistical analysis (Chowdhury et al., 2019). Purposive sampling was employed to ensure the respondents possessed relevant experience and represented large-scale contractors within the Klang Valley.

Data Collection

Primary data were collected using a structured questionnaire comprising four sections. Section A gathered respondents' demographic information, including age, gender, occupation, years of experience, and familiarity with 3D printing technology. Section B examined the perceived impacts of 3D printing technology, while Section C identified the barriers to its implementation. Section D assessed the effectiveness of proposed strategies for encouraging adoption. All measurement items employed a five-point Likert scale.

The questionnaire was distributed online via email and WhatsApp to facilitate responses from contractors located across the Klang Valley. Secondary data were obtained from academic journals, government publications, industry reports, and other relevant online resources to support and validate the primary findings.

Data Analysis

The collected data were analysed using the Statistical Package for Social Sciences (SPSS) Version 29. Descriptive statistics, including frequency, percentage, and mean score analyses, were used to summarise respondents' demographic profiles and evaluate their perceptions of the impacts, barriers, and strategies related to 3D printing technology. The analysis was performed according to the three research objectives to identify the perceived impacts of 3D printing, determine the major implementation barriers, and rank the proposed strategies for encouraging its adoption.

RESULTS AND ANALYSIS

This chapter presents the findings collected through the questionnaire survey. A total of 236 questionnaires were distributed to Grade G7 contractors in the Klang Valley, and 103 valid responses were received, giving a response rate of 43.64%, which is above the average response rate typically reported for online surveys. The results are presented in three parts, namely the perceived impact of 3D printing technology, the barriers to its implementation, and the suggested solutions for encouraging adoption.

Perceived Impact of 3D Printing Technology

This section presents the perceived impact of 3D printing technology on project efficiency, design flexibility, construction waste, and potential cost reduction. Respondents rated each item on a five-point scale, ranging from very unsignificant to very significant.

Table 1: Perceived impact of 3D printing technology on project efficiency, design flexibility, and construction waste

Item	Very unsignificant	Unsignificant	Neutral	Significant	Very significant	Mean
Effect on project efficiency	0 (0%)	20 (19.4%)	5 (4.9%)	21 (20.4%)	57 (55.3%)	4.12
Design flexibility	20 (19.4%)	0 (0%)	5 (4.9%)	35 (34.0%)	43 (41.7%)	3.79
Reducing construction waste	0 (0%)	20 (19.4%)	5 (4.9%)	40 (38.8%)	38 (36.9%)	3.93

Table 1 shows that project efficiency recorded the highest mean score (4.12) among the three impact items. A total of 57 respondents (55.3%) rated the effect as very significant, and 21 respondents (20.4%) rated it as significant, so 75.7% of respondents view 3D printing as having a strong positive effect on project efficiency. This finding is consistent with the literature, which reports that 3D printing can reduce construction time by 50% to 70% (Marijnissen & Zee, 2017).

Reducing construction waste recorded the second highest mean score (3.93). A total of 40 respondents (38.8%) rated the effect as significant and 38 respondents (36.9%) rated it as very significant, so 75.7% of respondents recognise the waste reduction benefit of 3D printing. This finding supports the literature, which reports that 3D printed construction produces only about 30% of the waste typical of conventional projects (Kamal, 2023).

Design flexibility recorded the lowest mean score among the three items (3.79), although it remains a positive rating overall. A total of 43 respondents (41.7%) rated the effect as very significant and 35 respondents (34.0%) rated it as significant, giving a combined 75.7%. However, 20 respondents (19.4%) rated design flexibility as very unsignificant, which suggests that a notable minority of respondents do not yet associate 3D printing with greater design freedom, possibly because most current applications in Malaysia remain limited to simple structural components rather than complex architectural forms.

Table 2: Perceived level of cost reduction from 3D printing technology

Level of cost reduction	Frequency	Percentage (%)
None	2	1.9
1%-10%	26	25.2
11%-30%	43	41.7
31%-50%	26	25.2
Above 50%	6	5.8
Total	**103**	**100.0**

Table 2 shows respondents' estimates of the cost reduction that 3D printing can offer. The largest group of respondents, 43 respondents (41.7%), estimated a moderate cost reduction of 11% to 30%. Meanwhile, 26 respondents (25.2%) estimated a smaller reduction of 1% to 10%, and another 26 respondents (25.2%) estimated a larger reduction of 31% to 50%. Only 6 respondents (5.8%) estimated a reduction above 50%, and 2 respondents (1.9%) estimated no effect at all. Cumulatively, 68.9% of respondents believe the cost reduction is up to 30%, and 94.2% believe it is up to 50%. This finding is broadly consistent with expert estimates in the literature, which report that 3D building printing can save 30% to 50% of total construction cost (Yin et al., 2022).

Barriers to 3D Printing Implementation

This section presents the barriers that respondents perceive as limiting the implementation of 3D printing technology in the Malaysian construction industry. Respondents rated their level of agreement with five barrier statements on a five-point scale, ranging from very disagree to very agree.

Table 3: Barriers to the implementation of 3D printing technology

Item	Very disagree	Disagree	Neutral	Agree	Very agree	Mean
Lack of skilled labour	0 (0%)	20 (19.4%)	5 (4.9%)	21 (20.4%)	57 (55.3%)	4.12
High initial cost	0 (0%)	20 (19.4%)	5 (4.9%)	56 (54.4%)	22 (21.4%)	4.13

Lack of awareness	0 (0%)	20 (19.4%)	5 (4.9%)	20 (19.4%)	58 (56.3%)	4.13
Challenges in obtaining regulatory approval	0 (0%)	20 (19.4%)	5 (4.9%)	55 (53.4%)	23 (22.3%)	3.79
Availability of suitable materials	20 (19.4%)	0 (0%)	5 (4.9%)	20 (19.4%)	58 (56.3%)	3.58

Table 3 shows that lack of skilled labour and high initial cost are perceived as the most pressing barriers, with mean scores of 4.12 and 4.13 respectively. For lack of skilled labour, 57 respondents (55.3%) very agree and 21 respondents (20.4%) agree, so 75.7% of respondents view the shortage of skilled workers as a significant obstacle. This finding is consistent with the literature, which reports that 3D printing requires workers who are skilled in both robotic technology and traditional civil engineering tasks (Shahzad et al., 2022; Tafazzoli et al., 2024).

For high initial cost, 56 respondents (54.4%) agree and 22 respondents (21.4%) very agree, so 75.8% of respondents consider the cost of equipment, materials, and training a critical obstacle to adoption. This finding aligns with prior research identifying financial concerns as a top barrier to technology uptake in construction (Chowdhury et al., 2019).

Lack of awareness also recorded a high mean score (4.13). A total of 58 respondents (56.3%) very agree and 20 respondents (19.4%) agree that awareness remains a barrier, giving a combined 75.7%. This finding suggests that even though most respondents are personally familiar with 3D printing, they perceive a wider awareness gap across the industry and the broader construction community (Abdulqader et al., 2025).

Difficulty in obtaining regulatory approval recorded a mean score of 3.79. A total of 55 respondents (53.4%) agree and 23 respondents (22.3%) very agree that regulatory approval is a challenge, giving a combined 75.7%, while 20 respondents (19.4%) disagree and 5 respondents (4.9%) remain neutral. This result reflects the absence of clear building codes, permits, and inspection procedures specifically for 3D printed structures in Malaysia, and it is consistent with the literature on regulatory gaps in construction 3D printing (Everett et al., 2022; Kamal, 2023).

Availability of suitable materials recorded the lowest mean score among the five barriers (3.58). While 58 respondents (56.3%) very agree and 20 respondents (19.4%) agree that material availability is a concern, 20 respondents (19.4%) very disagree, which is a notably higher level of disagreement than for the other barriers. This pattern suggests that opinion is more divided on this issue, with some respondents perceiving sufficient access to suitable 3D printing materials while others do not.

Suggested Solutions and Strategies

This section presents the strategies that respondents consider effective for encouraging the implementation of 3D printing technology. Respondents rated the effectiveness of five solutions on a five-point scale, ranging from very ineffective to very effective.

Table 4: Suggested solutions to encourage the implementation of 3D printing technology

Item	Very ineffective	Ineffective	Neutral	Effective	Very effective	Mean
Government subsidies	0 (0%)	20 (19.4%)	5 (4.9%)	20 (19.4%)	58 (56.3%)	4.13

Training programs	20 (19.4%)	0 (0%)	5 (4.9%)	55 (53.4%)	23 (22.3%)	3.59
Collaboration between construction companies	20 (19.4%)	0 (0%)	5 (4.9%)	55 (53.4%)	23 (22.3%)	3.59
Public awareness campaigns	0 (0%)	20 (19.4%)	5 (4.9%)	20 (19.4%)	58 (56.3%)	4.13
Establishment of local 3D printing facilities	0 (0%)	20 (19.4%)	5 (4.9%)	21 (20.4%)	57 (55.3%)	4.12

Table 4 shows that government subsidies and public awareness campaigns are viewed as the most effective solutions, both recording a mean score of 4.13. For government subsidies, 58 respondents (56.3%) rated the strategy as very effective and 20 respondents (19.4%) rated it as effective, giving a combined 75.7%. This finding supports the use of financial incentives to offset the high initial cost identified as a major barrier in Section 4.4, and it is consistent with international experience, where government investment has accelerated 3D printing adoption in other countries (Yin et al., 2022).

For public awareness campaigns, 58 respondents (56.3%) rated the strategy as very effective and 20 respondents (19.4%) rated it as effective, giving the same combined 75.7%. This result is consistent with the barrier analysis in Section 4.4, where lack of awareness was identified as a significant obstacle, and it supports the use of demonstration projects and outreach activities to build understanding of 3D printing among industry stakeholders (Charles & Pauzi, 2025).

The establishment of local 3D printing facilities recorded a mean score of 4.12, close to the two solutions above. A total of 57 respondents (55.3%) rated this strategy as very effective and 21 respondents (20.4%) rated it as effective, giving a combined 75.7%. This suggests that respondents see value in developing local production capacity and supply chains for 3D printing materials and equipment, rather than relying solely on imported technology.

Training programs and collaboration between construction companies recorded lower mean scores of 3.59 each, though both remain on the positive side of the scale. For training programs, 55 respondents (53.4%) rated the strategy as effective and 23 respondents (22.3%) rated it as very effective, giving a combined 75.7%, while 20 respondents (19.4%) rated it as very ineffective. A similar pattern appears for collaboration between construction companies, with 55 respondents (53.4%) rating it as effective and 23 respondents (22.3%) rating it as very effective. The comparatively lower mean scores for these two items suggest that, while respondents value training and inter-company collaboration, they consider direct financial and awareness-based interventions to be more immediately effective in encouraging adoption.

Summary of Findings

Overall, the results show that Grade G7 contractors in the Klang Valley are largely familiar with 3D printing technology and recognise its benefits, particularly in improving project efficiency and reducing construction waste. At the same time, the industry faces persistent barriers, most notably the shortage of skilled labour, the high initial cost of equipment and training, and a continuing awareness gap.

Respondents consistently favour government subsidies, public awareness campaigns, and the establishment of local 3D printing facilities as the most effective strategies for encouraging wider adoption, while training programs and inter-company collaboration are viewed as moderately effective supporting measures.

DISCUSSION

The findings of this study provide insight into the state of 3D printing technology adoption in the Malaysian construction industry. The high level of familiarity among Grade G7 contractors, at 75.7%, suggests that information about 3D printing technology has already reached key decision makers in large construction companies. This awareness is an important foundation for adoption, since understanding of technology benefits is a prerequisite for investment decisions.

The alignment between respondents' perceived impact of 3D printing and the benefits documented in international literature (Marijnissen & Zee, 2017; Pessoa & Guimarães, 2020; Wu et al., 2016) indicates that Malaysian contractors are well informed about global developments in construction technology. The mean score for project efficiency (4.12) closely matches the strength of the benefit reported in the literature, where 3D printing is shown to reduce production time by 50% to 70% (Marijnissen & Zee, 2017). This awareness of international best practice positions Malaysian contractors to adapt 3D printing technology for local conditions and requirements.

The identification of lack of skilled labour, high initial cost, and lack of awareness as the three most pressing barriers, each with a mean score above 4.10, is consistent with findings from other studies on technology adoption in construction (Abdulqader et al., 2025; Charles & Pauzi, 2025; Tafazzoli et al., 2024). These barriers are interconnected. For example, the skills gap contributes to high implementation cost, since companies must invest in training or compete for scarce technical expertise. Similarly, lack of awareness can perpetuate the skills gap by reducing demand for training programs and educational opportunities.

CONCLUSION

This study set out to identify the impact of 3D printing technology on the Malaysian construction industry, to determine the barriers to its implementation, and to suggest strategies to encourage its adoption. Based on a survey of 103 Grade G7 contractors in the Klang Valley, the findings show that most respondents are already familiar with 3D printing technology, and they recognise its positive impact on project efficiency, design flexibility, and the reduction of construction waste.

At the same time, the study confirms that lack of skilled labour, high initial cost, and lack of awareness remain the most significant barriers to wider adoption, each recording a mean score above 4.10 on a five-point scale. Respondents view government subsidies, public awareness campaigns, and the establishment of local 3D printing facilities as the most effective strategies for overcoming these barriers, while training programs and collaboration between construction companies are seen as valuable but comparatively longer-term measures.

These findings suggest that encouraging 3D printing adoption in the Malaysian construction industry requires coordinated action from government, industry associations, and technology providers. Financial incentives can reduce the cost barrier, awareness campaigns can close the information gap, and structured training can build the skilled workforce needed to sustain adoption over time. Future research that extends beyond Grade G7 contractors, and that incorporates qualitative and longitudinal methods, would further strengthen the evidence base for encouraging 3D printing adoption across the wider Malaysian construction industry.

REFERENCES

1. Abdulqader, M., Alias, A. H. B., Haron, N. A., & Zuhri, M. Y. M. (2025). Advancing BIM adoption in Malaysia's construction industry: Overcoming barriers and enhancing operations and facility management. International Journal of Sustainable Development and Planning, 20(9), 3673-3690. https://doi.org/10.18280/ijsdp.200904
2. Chang, Y. N. (2020). Lack of adoption of 3D printing in Malaysia construction industry. https://eprints.tarc.edu.my/15543/
3. Charles, S. D., & Pauzi, N. N. M. (2025). Barriers and strategies in the management of 3D printed house technology in Malaysia. AIP Conference Proceedings, 3322, 30007. https://doi.org/10.1063/5.0292050

4. Chowdhury, T., Adafin, J., & Wilkinson, S. (2019). Review of digital technologies to improve productivity of New Zealand construction industry. Journal of Information Technology in Construction, 24, 569-587. https://doi.org/10.36680/j.itcon.2019.032
5. Costa, M., Carrara, J. M., Stefano, E. de, Rodriguez, T. T., Freitag, A. E. B., Barreto, J. C., & Pereira, J. C. (2024). Technological innovation in civil construction. Revista de Gestão Social e Ambiental, 18(11). https://doi.org/10.24857/rgsa.v18n11-087
6. Everett, B., Soto, J. E., Bakhshi, P., & Pourmokhtarian, A. (2022). Exploring 3D printing potentials for sustainable, resilient, and affordable housing. 296-306. https://doi.org/10.3311/ccc2022-038
7. Gangotra, A., Gado, E. D., & Lewis, J. I. (2023). 3D printing has untapped potential for climate mitigation in the cement sector. Communications Engineering, 2(1). https://doi.org/10.1038/s44172-023-00054-7
8. Kamal, M. A. (2023). Analyzing the competency of 3D printing technology in architectural, interior and product design. E3S Web of Conferences, 410, 4014. https://doi.org/10.1051/e3sconf/202341004014
9. Marijnissen, M. P. A. M., & Zee, A. van der. (2017). 3D concrete printing in architecture: A research on the potential benefits of 3D concrete printing in architecture. eCAADe Proceedings. https://doi.org/10.52842/conf.ecaade.2017.2.299
10. Opawole, A., Olojede, B. O., & Kajimo-Shakantu, K. (2022). Assessment of the adoption of 3D printing technology for construction delivery: A case study of Lagos State, Nigeria. Journal of Sustainable Construction Materials and Technologies, 184-197. https://doi.org/10.47481/jscmt.1182607
11. Pessoa, S., & Guimarães, A. S. (2020). The 3D printing challenge in buildings. E3S Web of Conferences, 172, 19005. https://doi.org/10.1051/e3sconf/202017219005
12. Shahzad, Q., Umair, M., & Waqar, S. (2022). Bibliographic analysis on 3D printing in the building and construction industry: Printing systems, material properties, challenges, and future trends. Journal of Sustainable Construction Materials and Technologies, 198-220. https://doi.org/10.47481/jscmt.1182627
13. Tafazzoli, M., Naeijian, F., & Naqvi, S. F. N. (2024). 3D printing in highway construction, opportunities and challenges. In IntechOpen eBooks. IntechOpen. https://doi.org/10.5772/intechopen.1005529
14. Thanekar, S., Dahiwile, Y., Sriram, V., Patil, P., Shivanwar, K., & Vispute, G. (2023). Comparative studies of 3D printing with conventional system in load bearing structure. International Journal for Research in Applied Science and Engineering Technology, 11(1), 1730-1734. https://doi.org/10.22214/ijraset.2023.48493
15. Wang, Q.-C., Yu, S.-N., Chen, Z., Weng, Y., Xue, J., & Liu, X. (2023). Promoting additive construction in fast-developing areas: An analysis of policies and stakeholder perspectives. Developments in the Built Environment, 16, 100271. https://doi.org/10.1016/j.dibe.2023.100271
16. Wu, P., Wang, J., & Wang, X. (2016). A critical review of the use of 3-D printing in the construction industry. Automation in Construction, 68, 21-31. https://doi.org/10.1016/j.autcon.2016.04.005
17. Yin, J., Suo, Y., Lv, T., Ma, K., Wang, X., & Zhang, Z. (2022). Application of 3D printing technology in the construction industry and its development prospects. Atlantis Highlights in Intelligent Systems. https://doi.org/10.2991/ahis.k.220601.002