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IMPLEMENTATION OF 3D-PRINTING TECHNOLOGY IN THE MALAYSIAN CONSTRUCTION INDUSTRY

SIVARAMAN KUPPUSAMY[1,*], TAN YI JIE[2], TAMILSALVI MARI[3,4], SUJATAVANI GUNASAGARAN[3,4], BRUNO LOT TANKO[1]

[1]School of the Built Environment, University of Reading, Malaysia. Kota Ilmu, Persiaran Graduan, Educity, 79200 Iskandar Puteri, Johor
[2] Department of Built Environment, Limerick Institute of Technology, Moylish, Limerick, V94 EC5T, Ireland
[3] School of Architecture, Building and Design, Taylor's University, Taylor's Lakeside Campus, No. 1 Jalan Taylor's, 47500, Subang Jaya, Selangor DE, Malaysia
[4] Liveable Urban Communities Impact Lab, Taylor's University, Taylor's Lakeside Campus, No. 1 Jalan Taylor's, 47500, Subang Jaya, Selangor DE, Malaysia
*Corresponding Author: s.kuppusamy@reading.edu.my

Abstract

The utilisation of 3D printing technology in construction has been previously observed in countries such as China. This research examined the positive and negative impacts of integrating 3D printing technology into the Malaysian construction industry. The study encompasses an overview of construction issues specific to Malaysia, the distinct types, and characteristics of 3D printing technology applicable in construction, and its potential implementation advantages. A questionnaire survey targeted experienced developers and contractors with at least five years of industry experience. The study aimed to gather insights into the positive and negative effects of 3D printing technology. The results demonstrate that construction stakeholders hold diverse views on the impacts of this technology on the industry. Successful implementation of 3D printing technology necessitates a willingness among construction stakeholders to invest in it. However, given that this technology is still in its initial stages, there remain numerous unknown risks and concerns. Therefore, further research is recommended to examine the risks associated with investing in 3D printing technology and its specific applications in construction. This study should allow all relevant construction parties in Malaysia to provide their opinions and shed light on the issue.

Keywords: 3D printing technology, Construction industry, Construction workers, Malaysia.

1. Introduction

For decades, 3D printing technology has been successfully adopted in various industries, such as manufacturing and healthcare. Recently, it has been introduced to the construction industry for building construction [1]. In the construction context, 3D printing technology refers to an automated fabrication process that constructs building structures by layering materials, such as concrete, in a controlled manner using machines or robotics [2]. The technology gained public attention when Chinese company WinSun successfully built ten single-story 3D-printed homes in less than 24 hours.

Construction industry stakeholders believe that 3D printing technology has the potential to address the persistent challenges faced by the industry, including delays, labour shortages, and cost overruns. A notable example occurred in 2015, when WinSun Decoration Design Engineering Co., a Chinese company, utilised 3D printing technology to construct ten houses within 24 hours, costing only $5,000. Given its remarkable advantages, many countries are investing in and promoting the widespread adoption of 3D printing technology [3].

However, in the Malaysian construction industry, the adoption of 3D printing technology still needs to be discovered, as neither the private nor the government sector has taken the initiative. Studies have shown that the Malaysian construction industry tends to be slow and hesitant in adopting innovative technology compared to other countries. This is primarily due to a need for more awareness among construction stakeholders and a reluctance to change traditional approaches [4]. In 2016, the 3D Printing Center of Excellence was established in Malaysia, collaborating with a local research company, Materialise Sdn Bhd, Belgium's leading 3D printing company. The aim is to develop new 3D printing applications and prepare them for the Malaysian marketplace. However, 3D printing technology is relatively new in the Malaysian construction industry, mainly used for prototype development in the medical, design, and manufacturing fields.

The construction industry is often criticised for inefficiency and is considered one of the most problematic industries in many countries, primarily due to the complexity of construction processes [5]. Studies have emphasised persistent declining productivity, cost overruns, and heavy labour requirements in recent decades, indicating that conventional construction approaches have reached their performance limits. Consequently, 3D printing technology has been introduced worldwide as an advanced solution to address these challenges in the construction industry. Construction professionals believe that it has the potential to alleviate some of the industry's burdens. They highlight its ability to support the utilisation of green or recycled materials for waste reduction, enable rapid construction to avoid project delays, reduce labour requirements, and facilitate the production of complex architectural designs and functional integration.

Consequently, 3D printing technologies will generate significant economic value and benefits worth billions in the coming years. This technology will reshape economies and labour markets, as the use of unskilled labour will be substantially reduced compared to the current situation, particularly in the construction industry. 3D printing technology is poised to become a significant industry trend, as it enhances economic returns and sustainability by reducing production times by up to 70%, labour costs by around 80%, and saving between 30% and 60% of construction waste [6].

This includes initiatives taken by the government of Singapore, which has funded a research centre for 3D printing (3DP) technology to explore its full potential in the construction industry. The aim is to increase competitiveness and productivity to meet the needs of a growing population. 3D printing technology is recognised as a unique adoption in the construction industry and is expected to become a significant industry trend [7].

However, stakeholders in the Malaysian construction industry need to be made aware of this innovative 3DP technology. This goes against the Construction Industry Transformation Programme (CITP) goals, which emphasise promoting advanced technology to enhance productivity and competitiveness. Malaysia continues to rely on problematic traditional construction methods to meet current development needs and compete globally. The adoption of 3DP technology in the Malaysian construction industry has yet to gain traction, as no industry players or professionals have shown interest in exploring this technology. This indicates a lack of awareness among industry players of the benefits of the 3DP technology to the construction industry, such as increased customisation, speed, and reduced labour costs, which could potentially address the problems faced by the Malaysian construction industry [8]. It also signifies a need for more enthusiasm and existing problems in adopting 3DP technology in Malaysia that must be addressed.

The Malaysian construction industry must update its construction methodologies to be globally competitive. Since the 1960s, the industry has yet to experience a significant transformation in technology or construction approaches, and it still heavily relies on traditional methods that excessively depend on foreign labour [9].

In addition, the Malaysian construction industry is facing constant pressure to modernise and undergo reform, primarily due to knowledge of building systems and construction deficiencies. These issues have been consistently raised by stakeholders in the construction sector within Malaysia [10]. Moreover, industry players are hesitant to embrace change and invest in innovative technology, as they incur high costs and unattractive returns associated with adopting novel approaches. This reluctance stems from the belief that established traditional processes are more dependable [4]. Thus, it becomes imperative to assess the suitability of 3D printing technology to transform and upgrade the Malaysian construction industry, aligning it with global standards [11].

This research study examined the pertinent issues concerning the positive and negative impacts of implementing 3D printing technology. Its significance lies in addressing the inherent problems prevailing in the Malaysian construction industry, which result from the ineffective use of traditional methods. By examining both the positive and negative implications of adopting 3D printing technology, the study will provide industry players with a comprehensive understanding of this promising technology and its potential to enhance current construction practices significantly. The findings will serve as a valuable reference point for future researchers exploring 3D printing technology while informing industry players and the Malaysian government in their decision-making processes regarding future investments in this innovative field.

Furthermore, the research aims to develop implementation guidelines for the Malaysian construction industry. These guidelines will provide a framework that empowers industry players to successfully adopt and integrate 3D printing technology, thereby strengthening their practices to match the standards set by developed countries. The outcomes of this study will contribute significantly to the transformation of the Malaysian construction industry, as 3D printing technology can address complex challenges such as heavy reliance on foreign labour, cost overruns, and project delays. By enhancing the overall performance of the Malaysian construction industry, this technology will bolster its competitiveness on a global scale.

2. Factors in Implementing 3-D Printing Technology in Malaysia

Construction innovations have historically responded to external needs, such as client demands, and are inspired by commitments made by other industries [12]. Automation technologies like 3D printing (3DP) have been employed in the construction sector to address various challenges, including safety issues, inflated costs, low productivity, and quality concerns. Over time, substantial advancements have been made in large-scale 3DP technology, with ongoing refinements and developments [13].

2.1. Reduction in reliance on foreign labour

The Malaysian construction industry heavily relies on immigrant labour, with approximately 70 per cent of its workforce comprised of immigrants [14]. This overreliance on foreign labour, particularly from an only source like Indonesia, could be better, as any supply chain disruption can destabilise the Malaysian economy. Furthermore, foreign workers, including undocumented immigrants, affect national security and socio-economic factors. Many of these foreign workers need more skills and contribute to skills formation, relying instead on on-the-job training, which poses challenges for on-site management [15].

However, by implementing 3D printing (3DP) technology, construction operations and processes can be fully automated, reducing the need for extensive on-site management. As automation takes over the construction process, human involvement becomes secondary, primarily limited to supplying the robotic arm with materials and completing post-construction tasks that are not feasible to automate, such as installing windows and doors [16]. Consequently, the number of labourers required for construction is significantly reduced, effectively addressing the heavy reliance on foreign workers in the Malaysian construction industry. The Singapore government's decision to fund a 3DP technology research centre is an example of using 3DP to mitigate the reliance on foreign workers in construction, as Singapore heavily depends on foreign labour. Furthermore, with the challenge of an ageing population, the government encourages implementing 3D printing technology, a more productive and less labour-intensive.

2.2. Reduction in health and safety accidents in construction sites

According to Warszawski and Navon [17], one of the severe problems that were encountered by the construction industry was the high accident rate at construction sites. Weinstein and Nawara [18] asserted that building automation, like 3D printing (3DP), aimed to enhance the safety standards of construction workers to address the issues above. A global survey conducted by Khoshnevis [19] revealed that the industry caused the deaths of 60,000 workers annually. In Malaysia, the Social Security Organization (SOCSO) reported 656,555 accidents across all industries, with 42,775 accidents in the Malaysian construction industry, accounting for 6.5% of all industrial accidents. On average, this translated to around 350 reported accidents per month.

In recent years, Malaysia has witnessed numerous deaths among foreign workers due to accidents, illnesses, and suicide. These workers often face challenging working conditions, called '3D' conditions - dirty, dangerous, and challenging. The Malaysian Department of Occupational Safety and Health (DOSH) recorded an alarming increase in accidents within the construction industry, including severe and fatal incidents occurring annually.

Increasing automation in the construction process can enhance worker safety by reducing the overall labour requirement and ensuring better-trained workers [20]. 3DP can contribute to safety in several ways. For instance, the layer-by-layer extrusion process in 3DP minimises the chances of workers encountering hazardous materials and chemicals, thus reducing the risks to their skin. It also decreases the incidence of respiratory illnesses by reducing exposure to airborne dust.

Additionally, using full-scale machines in 3DP minimises the need for labour in transportation and coordination, thereby reducing injuries related to construction and transportation activities. 3DP offers a construction method free from waste, noise, dust, and harmful emissions, providing a safer working environment for construction workers and significantly reducing on-site injuries.

2.3. Reduction in construction delay

Construction delays have long persisted in the Malaysian construction industry [21]. A recent report shows that approximately 80% of public sector projects experience delays. In Malaysia, the percentage of projects that face delays during the construction phase is nearly 45.9%, with an additional 17.3% of government contract projects being deemed failures due to delays exceeding three months or abandonment for distinct reasons in 2005.

2.4. Reduction in delay due to low productivity

Despite the Malaysian construction sector being highly competitive, it has faced challenges in terms of productivity compared to other industries, with the GDP per worker being roughly half that of other sectors [22]. Over the years, there has been a need for more progress in productivity and efficiency within the construction industry, indicating a failure on the part of construction stakeholders to adopt innovative technologies that could enhance productivity [23].

One way to address the issue of low productivity is by using 3D printing (3DP) technology, which can streamline complex construction processes. Unlike traditional methods involving breaks for workers or waiting for concrete to cure, 3DP methods operate consistently and uninterrupted, resulting in increased speed. This improved speed directly translates to enhanced efficiency in logistics and management. Furthermore, when integrated with Building Information Modelling (BIM), 3DP can monitor the entire construction process and identify potential assembly or construction issues before the printing phase begins. This significantly reduces the time-consuming construction challenges typically faced in traditional approaches, often requiring multiple stakeholder meetings to resolve issues [24].

A survey by Buswell et al. [25] compared the speed of 3DP with traditional building methods. In traditional methods, each 1-meter height in brickwork necessitates an overnight break for the mortar to cure. Assuming no operational efficiency in labour allocation (continuous work) and disregarding machine setup time, 3DP exhibits an advantage in terms of building time compared to traditional methods due to its ability to operate at a consistent and continuous rate. The study stated that by expediting the construction process, 3DP could improve performance within the Malaysian construction industry by reducing delays.

2.5. Reduction in delay due to the complexity of the design

The separation of the design and construction phases in the construction industry has resulted in architectural designs that often need more consideration for constructability. Designs prepared by architects, especially those with complex curves and geometries, prove to be expensive and challenging to construct using traditional construction methods. These complexities often lead to construction problems on-site and hinder the project's progress, contributing to delays [26].

However, 3D printing technology solves this issue [27]. It can construct complex geometries that are difficult or impossible to assemble using conventional construction methods. Additionally, using advanced 3D printing technologies, as highlighted by Mellor [28], allows for producing highly customised products with intricate geometries in a shorter time. This increase in construction speed, even for complex designs, reduces the likelihood of delays occurring during construction.

2.6. Reduction in construction waste generation

The construction industry significantly contributes to harmful emissions, generating considerable solid waste [26]. These wastes can be in the form of liquids, solids, gases, and even radioactive materials. The issue of construction waste generation has become a pressing concern in Malaysia, with illegal dumping of construction waste being a significant problem [29]. However, 3D printing (3DP) technology offers a potential solution by significantly reducing waste generation by a factor of 10 [20]. Construction machines designed explicitly for 3DP, such as Contour Crafting, can be fully electric, resulting in emission-free operation. Moreover, the precise additive fabrication process controlled by computers in 3DP minimises material waste, potentially leading to little or even zero waste production.

Another aspect of waste reduction in 3DP lies in eliminating formwork and mould-making, as the printing process constructs the building to the required size [3]. Additionally, using recycled waste materials is possible in 3D printing technology, which further reduces waste. An example is China-based company WinSun, which uses a mega-printer and blends cement with recycled waste materials to construct houses [30].

The efficiency of the 3DP method also translates into shorter construction periods than traditional construction methods. This increased speed of construction positively impacts logistics, management, and the transportation system, which in turn has environmental benefits [26]. As explained by Lim et al. [16], waste reduction can be achieved through the adoption of 3DP, as there is a reduced need for personnel on-site, resulting in fewer vehicles being driven to and from the construction site. This reduction in vehicle usage helps decrease gas emissions. Overall, there is significant potential for waste reduction by implementing 3DP technology.

2.7. Reduction in construction cost overrun

Cost overrun is a prevalent issue in Malaysia's construction industry and is considered normal. It refers to a situation in which the actual budget for a construction project exceeds the initial estimated budget. One of the factors contributing to cost overrun is the complexity of the design, which often leads to higher costs than initially estimated and encounters construction problems on-site. This is supported by Buswell [31], which states that design uniformity is crucial for creating constructible buildings and reducing costs. However, 3D printing (3DP) technology can significantly reduce the cost of designing and constructing complex buildings or shapes that would be costly with traditional construction methods. 3DP can minimise material waste by eliminating the need for formworks and moulds [3]. The building is printed as designed in the computer software, and a computer controls every construction process.

According to Hughes [20], a sizeable portion of cost savings in 3DP comes from reducing labour and time requirements. 3DP machines operate efficiently during construction, and cost savings can be achieved by decreasing the construction timeline, which helps mitigate cost overrun [32]. By reducing the dependence on labour, 3DP also reduces the risk of injuries, which is presumed to decrease unexpected miscellaneous construction costs by up to 30%. Furthermore, reducing the need for extensive site supervision can minimise cost overrun, as poor site supervision is often linked to cost overrun issues.

2.8. Scope of the Research

The scope of this research focused on the practicability of 3D printing technology in the housing construction area within the Malaysian construction industry, excluding roads and infrastructure. In the scope of this research, '3D printing technology' was treated as a collective term encompassing all types of 3D printing technology, including Contour Crafting, D-Shape Technology, and Concrete Printing. These technologies were all based on additive manufacturing and had distinct characteristics and applications.

The 3D printing technologies use a layering process, where materials are printed layer by layer, with variations in the thickness of the layers among the distinct types. Contour Crafting involved a crane-mounted system for on-site and in-situ applications. D-Shape and concrete printing, on the other hand, were gantry/framework-based technologies primarily used in off-site manufacturing processes. However, there was no reason both methods could not be used in an in-situ context [3]. This made Contour Crafting technology more practical for adoption in large construction projects.

In this research, it was essential to establish boundaries to differentiate 3D printing technology in the construction industry from the general context of 3D printing. Therefore, the philosophical standpoint adopted was that 3D printing technology was a process that used an additive, layer-based manufacturing technique to construct intricate geometric shapes without the need for formwork. Building components were designed as volumetric objects using 3D modelling software (CAD) and then sliced into a series of two-dimensional layers. The data was transferred to a printing machine to print the structural components layer by layer. To ensure the inclusion of essential studies on 3D printing, the research used several search terms, as recommended by [28].

- Additive Manufacturing
- Concrete Printing
- Rapid Prototyping

The study primarily targeted the construction stakeholders in Malaysia who were financially sound to invest in the technology and could provide valuable suggestions. These stakeholders included registered housing developers and registered building contractors (CIDB: Grade G2-G7; Category B-Building Construction)/ (PKK: Class A-E; category Building Works). Respondents were selected from the top and middle management levels, as they could offer reliable opinions and represent their companies in decision-making processes. They were also familiar with the Malaysian construction industry. Only well-established companies with more than five years of experience in the construction industry and financial stability were included in the research. This ensured that the participants were knowledgeable about 3D printing technology.

2.9. Research limitations

Several limitations have been identified in this study. One main area for improvement is the potential lack of cooperation from respondents when answering the questionnaire. Additionally, the survey relies on self-reported perceptions of the respondents regarding 3D printing technology, which introduces subjectivity into the data collection process.

Another limitation is that 3D printing technology is still in its infancy and relatively unpopular in the Malaysian construction industry. As a result, some respondents may need to be more familiar with this technology and need help answering specific questions in the questionnaire. Furthermore, the sample size of this study is considered small, as it is limited to 85 respondents selected from the top and middle management levels of qualified developers and building contractors. Given that Malaysia has over 10,000 registered housing developers and contractors, the findings are unlikely to be representative of the applicability of 3D printing technology in the industry. Additionally, the stakeholder survey does not include government departments, private organisations, or professional practices such as architectural or quantity surveying consultation firms, which could provide professional opinions on implementing 3D printing technology in the Malaysian construction industry.

Moreover, there needs to be more information or literature specifically focused on 3D printing technology in the construction industry context. Since 3D printing technology has not been extensively implemented in the Malaysian construction industry, the available information is primarily sourced from other countries. The research incorporates literature from various countries and Malaysia's limited body of knowledge. This can be seen as a limitation of the study, as the scarcity of literature may not effectively represent the issues and concerns regarding implementing 3D printing in the Malaysian construction industry.

3. Methodology

This study employed a quantitative questionnaire survey method to collect data from construction stakeholders, including developers and contractors.

3.1. Survey research

Questionnaires were distributed to the respondents using hand delivery and online survey software. The questionnaire was designed to gather demographic information from the respondents, which was used to establish their organisational profiles concerning financial capabilities and experience.

To assess the impact of implementing 3D printing (3DP) in the Malaysian construction industry, questions were formulated using a 5-Point Likert-type scale. The research questions aimed to capture the effects of implementing 3DP. To ensure the quality of the collected data and the questionnaire’s effectiveness, a pretesting phase was conducted with 10 respondents. This allowed for assessing the validity of the data collection instruments.

Certain modifications were made to the questionnaire based on the feedback received during the pretesting phase. For example, keywords such as "Positive Effect" and "Negative Effect" were bolded to help respondents quickly understand the nature of the questions. These adjustments were made to improve the clarity and effectiveness of the questionnaire.

3.2. Sampling design and data analysis strategy

Probability sampling was used in this research as it allowed for accurate statistical inferences. Specifically, simple random sampling was adopted for its ease of use and time-saving nature. This involved randomly selecting a sample from Malaysia's large population of registered developers and contractors. Every respondent in the population had an equal chance of being chosen, ensuring a representative sample.

The targeted population for this research consisted of registered developers and contractors in Malaysia who had over 10 years of experience in the construction industry. All respondents were required to have attained tertiary education and hold senior management positions within their respective companies. Additionally, they needed at least 4 years of working experience and sufficient knowledge of the construction industry's issues related to the hindering effects and driving factors of implementing 3DP technology.

The population size for this research was 85 respondents. While multiple respondents from the same company were allowed, a limit to 3 respondents per organisation was imposed to prevent the results from being skewed by a single organisation.

Statistical Package for the Social Sciences (SPSS) software version 25.0 was employed to facilitate efficient data analysis. The data was presented using frequency distribution, mean, and standard deviation.

4. Findings and Discussion

4.1. Demographic profile of the research sample

The following results provide an overview of the demographic profile of the respondents, including the types of organisations they belong to, the paid-up capital of their companies, the year of establishment, and their individual working experience.

4.1.1. Types of Organisations

The summary result of the respondents' organisation is shown in Table 1. A total of 85 survey responses were obtained, collected via email and in person. The table above illustrates that more organisations were categorised as Contractors than Developers. As indicated in Table 1, out of the total questionnaire response rate, 37 respondents represented Developer firms, accounting for 43.5 %t. In contrast, Contractor firms contributed 48 respondents, making up 56.5 % of the collected questionnaires. There was an uneven distribution of respondents between the two types of organisations, with a difference of 11 respondents. The variation in organisational types among the respondents may have influenced the survey results. Nonetheless, the difference was minor, suggesting that the findings remain valid and representative.

Table 1. The type of organisation of the respondents.

Organisation	Frequency	%
Developer	37	43.5
Contractor	48	56.5
Total	85	100

4.1.2. Paid up capital of the organisation of the respondent

The summarised results of the respondents' organisation's paid-up capital are presented in Table 2.

All 85 respondents' organisations have a paid-up capital exceeding RM1 million, accounting for 100 % of the total. This finding suggests that all respondents are from financially stable organisations, indicating their ability to provide reliable opinions on the practicability of 3D Printing Technology.

Table 2. Paid up capital of the organisation of the respondents.

Capital	Frequency (N)	%
More Than RM1 Million	85	100

4.1.3. Year of establishment of the organisation of the respondent

Table 3 summarises the respondents' organisation's year of establishment. Findings showed that 34 organisations had been established for over 20 years but less than 40 years, accounting for 40% of the total questionnaires. Additionally, 51 organisations have been established for over 20 years but less than 40 years. This result indicates that most of the respondent organisations have considerable experience in the industry. The longer an organisation has been established in the industry, the more experience it possesses, allowing it to provide valuable insights into the practicability of 3D Printing technology. Their experience reflects the growth of the Construction Industry in Malaysia over the years.

Table 3. Year of establishment of the organisation of the respondents.

Year Established	Frequency	%
Less Than 20 Years	34	40
More Than 20 But Less Than 40 Years	51	60
Total	85	100

4.1.4. Respondents' working experience in the construction industry

To ensure the results' reliability, the respondents' working experience was crucial as it allowed them to understand the industry-related questions deeply. The findings in Table 4 indicate that every respondent had at least 5 years of working experience in the construction industry, affirming the qualification of all respondents in this survey. Specifically, 41 respondents had a working experience of more than 5 years but less than 10 years, while 44 respondents had more than 10 years of experience in the construction industry. The fact that all respondents had a minimum of 5 years of experience adds to the trustworthiness of the obtained results.

Table 4. Respondents' working experience in the construction industry.

Working Experience	Frequency	%
More than 5 Years but Less Than 10 Years	41	48.2
More than 10 Years	44	51.8
Total	85	100

4.2. The Consequence of Implementation of 3DP in the Malaysian construction industry

This data corresponds to the research question of this paper, which aims to identify the potential benefits (positive effects) and challenges (negative effects) of implementing 3D printing technology in the Malaysian construction industry.

4.2.1. Positive effects will be potential benefits of 3DP in Malaysia's construction industry

The summarised results of the combined views of respondents (Developers and Contractors) on the potential benefits (positive effects) of 3D printing technology in the Malaysian construction industry are presented in Table 5. A lower mean value indicates that respondents agree more with the positive effects of implementing 3D printing technology in the Malaysian construction industry. The mean values for each positive effect range from 1-3 (strongly agree-somewhat agree) with minor variations in the mean values.

Table 5. Positive effects of 3DP technology implementation.

	Frequency (N)	Mean	Std. Deviation
Reduce Construction Waste	85	1.4471	0.764
Reduced The Number of Foreign Worl Needed	85	1.7059	0.784
Increase Safety on Construction Site	85	1.7765	1.016
Speed Up Construction on Process	85	2.2588	0.965
Cost Saving to Avoid Cost Overrun	85	2.8353	1.089

4.2.1.1. Reduced Construction Waste

Reduced construction waste was one of the top positive effects of implementing 3D printing technology in the Malaysian construction industry, with the lowest mean value of (M=1.45, SD=0.76). This indicates that respondents generally agreed that 3D printing technology has the potential to reduce construction waste when implemented in the industry. The consensus among respondents may be attributed to their perception that 3D printing enables precise material usage and the ability to print structures in the required shape through computer control.

4.2.1.2. Reduced the number of foreign workers needed

The reduction in the number of foreign workers needed scored the second lowest mean value (M=1.71, SD=0.78), ranking it second among the positive effects. The implementation of 3D printing technology is known for its automation capabilities, which can lead to a decrease in the overall workforce required. In the Malaysian construction industry, a significant amount of the labour force includes workers from foreign countries like Bangladesh and Nepal, reducing the dependency on blue-collar labour to reducing the number of foreign workers needed for construction projects; this likely explains why respondents agreed that one potential benefit of 3D printing technology is reducing the number of foreign workers in the construction industry.

4.2.1.3. Increase safety on the construction site

Increasing safety on the construction site ranked third among the positive effects of implementing 3D printing technology in the Malaysian construction industry (M=1.78, SD=1.01). Respondents agreed that the adoption of 3D printing technology could bring potential benefits to the industry, most likely because they perceive that a reduction in the number of workers needed on the construction site using 3D printing technology would also lead to a corresponding decrease in the probability of workers getting injured. Additionally, some risky or critical tasks traditionally performed by human workers can be taken over by automated 3D printers, further enhancing safety on the construction site.

4.2.1.4. Speeding up the construction process

Speeding up the construction process scored the second highest (M=2.26, SD=0.97) among the positive effects of implementing 3D printing technology. Respondents only somewhat agreed (mean value between agree and somewhat agree) that 3D printing technology could accelerate construction. While it is believed that automated 3D printers can speed up construction due to their continuous operation, the respondents did not strongly agree with this statement. Respondents may perceive that 3D printing may not efficiently expedite the construction process, as it may involve high complexity and input from professionals. Additionally, construction delays are often attributed to slow decision-making by construction parties, which is not solely dependent on construction activities.

4.2.1.5. Cost saving to avoid cost overrun

Cost saving to avoid cost overrun ranked last among the positive effects, with the highest mean value of (M=2.83, SD=1.09). Respondents somewhat agreed that implementing 3D printing technology can lead to cost savings. This may be due to the respondents' belief that any mistakes made during the data input stage of the 3D printing process could increase construction costs. Furthermore, cost overrun issues in construction projects are often attributed to incorrect estimations by professionals, price fluctuations, and changes in design rather than solely being caused by the slow construction process of traditional approaches. Therefore, it is rational to assume that 3D printing technology may not definitively address the problem of cost overruns in the construction industry.

4.2.2. Negative effects hindering the implementation of 3DP in Malaysia's construction industry

The summary results of the combined views of respondents (Developers and Contractors) on the negative effects hindering the implementation of 3D printing in the Malaysian construction industry are presented in Table 6. The lower the mean value, the more agreeable the respondents are with the negative effects that hinder the implementation of 3D printing in the industry. Table 6 shows the analyses of the respondents' opinions on the negative effects of implementing 3D printing technology in the Malaysian construction industry based on the computed mean values. Table 6 shows that the mean values for each negative effect range from 1 to 4 (strongly agree to somewhat disagree), with variations in the mean values observed.

4.2.2.1. Increased project upfront cost

With the lowest mean value of (M=1.19, SD=0.39), increased project upfront cost ranked first among the negative effects of implementation, indicating that respondents strongly agreed that using 3DP would increase the project upfront cost. The respondents' opinion that implementing 3DP may increase the project's upfront costs was likely influenced by their perception that construction 3D printers were expensive machines, which would result in higher initial project costs.

4.2.2.2. Contractual problems

The negative effect of contractual problems arising scored a mean value of (M=2.14, SD=1.09), ranking it second among the five negative effects (as shown in Table 6). This indicates that respondents agreed that implementing 3DP may lead to contractual problems. The agreement on this issue may stem from that 3DP is an innovative technology, and contract amendments must be established to accommodate its use. More clarity in contractual obligations between construction stakeholders and implementing 3DP technology could lead to contractual problems.

Table 6. Negative effects that hinder the implementation of 3DP in Malaysia's construction industry in ascending order of means value.

Rank	Negative effects	Frequency (N)	Mean	Std. Deviation
1	Increased Project Upfront Cost	85	1.18	0.393
2	Contractual Issues	85	2.14	1.093
3	Increased Cost of Technical Staff Training Technical Staff	85	2.69	1.08
4	Issues in _Materials Handling on Site	85	2.83	1.122
5	Loss of Jobs for General workers	85	3.45	1.229

4.2.2.3. Increased cost of training of technical staff

The increase in training expenses for technical staff was ranked third, with a mean value of (M=2.69, SD=1.08). The findings suggest that respondents disagreed that implementing 3DP could escalate training costs for technical personnel. This agreement indicates respondents acknowledged the need for skilled technical staff to ensure smooth and secure operations with innovative technology like 3DP. Nevertheless, this agreement was only marginal, potentially due to the perception that the training costs for technical staff were relatively minor compared to other expenses, such as the acquisition cost of the 3D printer.

4.2.2.4. Issues with materials handling on site

Negative effects of troubled on-site material handling ranked fourth among the negative effects, with the second-highest mean value of (M=2.84, SD=1.12). The mean value was close to 3.00 (somewhat agreed), with only a 0.1592 difference from the mean value of the increased cost of training for technical staff. Therefore, respondents agreed that problems of troubled on-site material handling may have arisen after implementing 3DP technology. Respondents somewhat agreed that implementing 3DP may lead to issues of on-site material handling because they were not familiar with the operation of the 3D Printer.

4.2.2.5. Loss of jobs for general workers

The problem of general workers facing job loss received the highest mean value of (M=3.45, SD=1.23), ranking last among the negative effects of implementing 3DP. The results indicate that respondents disagreed (with mean values ranging from somewhat disagree to disagree) with the idea that implementing 3DP would lead to general workers losing their jobs. As previously discussed, 3DP is an automated technology that reduces the required workforce, potentially triggering job loss. However, the results show that respondents disagreed with this notion. This is likely because respondents believed that specific tasks in the construction process cannot be replaced by 3D printers, such as the placement of materials, which still requires the presence of general workers in the construction industry. Nonetheless, the standard deviation of 1.23 is the highest among the five negative effects, indicating that respondents' opinions were inconsistent. While some respondents agreed with the statement, others disagreed.

4.3 Discussion

The primary objective of this research is to explore the positive effects of 3D printing technology as a potential solution to the problems faced by the traditional construction approaches adopted in the Malaysian construction industry. The literature review highlights the current issues in construction, including heavy reliance on foreign labour, high accident rates on construction sites, significant construction waste, and cost overruns.

Based on the findings, construction stakeholders believe implementing 3DP can have several positive effects. The most apparent positive effect identified is the reduction of construction waste, which can address the issue of excessive waste generated during construction. Additionally, stakeholders perceive that 3DP can help decrease the reliance on foreign workers, improve safety on construction sites, and expedite the construction process, as supported by the literature review. However, stakeholders only somewhat agreed that 3DP can effectively tackle the problem of cost overruns in the construction industry. While research suggests that significant cost savings can be achieved through labour and time reductions with 3DP, as stated by [20], stakeholders have different perspectives and doubt the technology's ability to address cost overruns effectively.

The respondents strongly agreed that the main factor that challenges the implementation of 3D printing is s the increased upfront cost of projects. Concerns about contractual issues follow this, the elevated cost of training technical staff, and troubles with on-site material handling. Interestingly, respondents least agree that the problem of general workers facing job losses is a negative effect, potentially due to the industry's excessive dependence on foreign labour.

5. Conclusion

In conclusion, the survey findings indicated that construction stakeholders perceived the most significant potential benefit or positive effect of implementing 3D printing technology as reducing construction waste. This perception stemmed from the enormous amount of construction waste generated in traditional Malaysian construction methods, which incurred significant expenses for disposal. Disposing of construction waste posed contractual, environmental, and legal challenges. The next identified positive benefit was the non-reliance or reduction in the number of foreign workers needed. Currently, the government has implemented policies to control and reduce illegal foreign construction workers, as legalising and contracting workers from overseas has become an economic and political concern in Malaysia. Increasing safety on construction sites was also a positive benefit, as it could help address construction safety and health issues, particularly near-miss accidents, and unreported deaths in Malaysia.

Utilising technology to speed up the construction process was seen as a positive benefit in the Malaysian construction industry, as time directly impacts costs, and reducing construction time can result in savings for developers and contractors. However, in the opinion of construction stakeholders, 3D printing was not deemed an effective tool for addressing cost overruns in the current Malaysian construction industry. Many respondents identified cost and contractual issues as the main obstacles to implementing 3D printing technology in the Malaysian construction industry. This impediment may be attributed to rising construction costs and increasing contractual disputes between developers and contractors. One potential solution suggested was for the government to encourage the implementation of 3D printing technology in government projects by using specific government contracts or providing subsidies and tax breaks to private developers or contractors venturing into 3D printing technology in Malaysia.

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