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ANALYSIS OF FACTORS INFLUENCING 3D CONCRETE PRINTING ADOPTION FOR HOUSING CONSTRUCTION IN INDONESIA

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ABSTRACT: The construction industry is one of the largest industries, yet often perceived as slow to embrace advancements. The most common construction method is the cast-in-situ method, which encounters challenges. In response to these challenges, 3D Concrete Printing (3DCP) emerged as a new method of innovation that relies on extrusion and automation. Currently, the application of 3DCP is limited to constructing structural elements in homes and architectural components. 3DCP offers transformative potential with its automation, reduced waste, and precision, yet its adoption in developing countries remains limited. To enhance the implementation of 3DCP in Indonesia a study was carried out to identify the factors influencing the willingness to adopt 3DCP and assess their level of significance. These influential factors were identified using frameworks such as the Technology Organization Environment (TOE) and the Unified Theory of Acceptance and Use of Technology (UTAUT). The assessment of adoption levels was conducted by engaging with pioneers in 3DCP in Indonesia and contractors associated with the 10 housing development firms in Indonesia who have not yet integrated 3DCP into their practices and analyzed using a Likert scale. The implementation of housing construction in Indonesia is influenced by 9 factors and several strategies and recommendations are needed by the government, 3DCP enthusiasts, and academic institutions. These solutions may be adopted as part of implementation roadmap strategies for further research and implementation in developing countries.

Keywords: 3D Concrete printing, Influencing factors, Housing construction, Indonesia

1. INTRODUCTION

The construction sector is a significant contributor to global economic activity. This sector is also one of the largest industries, but its growth rate must be doubled to meet future demands. There is an urgency to bridge the gap between the construction industry's lagging productivity and its role [1]. Traditional cast-in-situ methods are resource-intensive and environmentally detrimental, accounting for 40% of global energy consumption and greenhouse gas emissions. However, lots of those used resources led to waste [2]. Although numerous studies have explored topics to overcome this challenge, such as the use of concrete, eco-friendly materials, automation, sustainable technology, and strategies to minimize environmental damage, the global impact is still quite inconsequential [3-7].

Globally, construction sector productivity growth averaged 1% a year over the past two decades, compared with 2.8% for the total world economy and 3.6% for manufacturing. However, boosting actions in aspects as shown in Figure 1 has the opportunity to boost construction productivity, where black and white bars show the minimum and maximum potential impact respectively. It is shown that technology plays the most significant aspect, ranging from 14 to 15 percent of productivity increase. In terms of areas of action, regulation has an uncountable percentage of significance since this area acts as the enabler of the implementation of actions. The term technology encompasses the integration of technology in processes, products, and/or management.

Developing countries extend this challenge through the emergence of rapid urbanization and the increasing generation of construction and demolition waste (CDW). In Vietnam, CDW accounts for 10 to 12% of total municipal solid waste, highlighting inefficiencies in waste management and the urgent need for sustainable practices [8]. Globally, there is a significant push towards integrating sustainability into construction practices [9]. This includes adopting prefabrication and modular construction to reduce site disruptions, emissions, and waste [10]. Efforts to incorporate green building practices are also on the rise, aiming to replace traditional steel and concrete with specific applications [11].

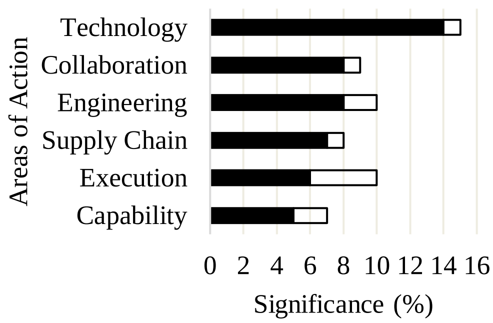

Fig. 1 Potential global productivity improvement from the implementation of best practices

The construction industry has improved a lot over the decades, introducing the incorporation of prefabrication and automation technologies. Among these advancements, 3D Concrete Printing (3DCP) has developed rapidly to become a groundbreaking feature in this space as it provides data-driven, waste-free, and speedy construction. Shifting traditional construction methods to a manufacturing-style production system provides the opportunity for significant productivity growth for several parts of the industry. Beyond its potential, this technology stands at the forefront of the industry's evolution due to its ability to fabricate concrete structures with unique geometries, exceptional precision, no reliance on formwork, minimal environmental damage, and improved productivity [12]. This technology even has attracted a lot of attention from several countries and the emergence of 3DCP has developed research activities in various countries since 2021 [13].

Currently, the application of 3DCP is limited to non-structural elements like walls on simple buildings like housing. Indonesia's construction industry, characterized by rapid urbanization, highly populated, and a high demand for affordable housing, presents an ideal case for exploring 3DCP's potential. Thus, Indonesia's experience is also crucial because it concurs with current global conditions, serving as a relevant point of reference for other nations attempting to overcome such problems that their construction sectors face. This study will investigate the factors influencing 3DCP adoption in Indonesia, providing insights that may guide technology integration in similar developing economies, which is Indonesia.

Even though 3DCP supports automation in construction, reduces cost, faster build rates, and a safer working environment, the implementation rate of this technology in Indonesia is a trivial amount compared to other technologies in construction. Challenges such as high upfront capital investment, regulatory liberalization, shortage of qualified manpower, and inadequate infrastructure base impede its implementation [14].

While studies have discussed the 3DCP in various construction applications, there is limited research on its potential to address affordable housing shortages [15]. Indonesia's pressing demand for affordable housing makes this study particularly significant. Unlike prior studies that focus on the technical aspects of 3D Concrete Printing (3DCP) or its applications in developed countries, this research uniquely integrates socio-economic, organizational, and environmental perspectives to analyze adoption in developing countries.

Prior studies also often generalize findings across different conditions. However, research should be done in a specific scope and incorporate diverse stakeholder perspectives, including government agencies, construction firms, and end-users, ensuring a broader understanding of the factors influencing 3DCP adoption. This research also provides insights from both "adopters" and "non-adopters" of 3DCP in Indonesia which addresses the research gap, gaining perspective from contractors who are not yet interested in adopting 3DCP to deeply investigate the reasons they are not interested and what can be done to improve their interest. This study identified localized drivers and barriers, engaged various stakeholders, and proposed actionable solutions that balance economic feasibility and technological advancement in developing countries which may provide a benchmark for other developing countries.

This study further examines the challenges associated with 3DCP adoption in Indonesia, considering economic, regulatory, and technological constraints through a certain methodology to identify and analyze the key factors influencing the adoption of 3DCP. The study then provides a comprehensive assessment of these factors, offering valuable recommendations to facilitate the adoption of 3DCP in developing countries. Finally, the paper concludes by summarizing the significance of the study and its implications for future research and practical implementation.

2. RESEARCH SIGNIFICANCE

This research aims to provide a significant basis for the construction industry improvement in Indonesia and similar developing countries. Through the identification of the factors affecting the preference for 3DCP, there are practical insights that guide builders and policymakers in the adoption of sustainable construction practices leading to improved productivity, reduced waste, and cost-cutting measures. Identification and mitigation of specific obstacles, as regards financial allocation or compatibility will enable developers to come up with focused methods of integrating 3DCP into the existing processes. This action helps in achieving affordable housing goals that are sustainable thus improving life standards for communities.

3. METHOD OF APPROACH

The first step is identifying the factors which are covered by the chosen framework from several selected publications, both external and internal factors. The Unified Theory of Acceptance and Use of Technology (UTAUT) and Technology-Organization-Environment framework (TOE) have been widely applied in innovation and technology adoption studies. UTAUT has flexibility in selecting external variables and could capture the individuals' acceptance behaviors, while TOE considers the technical, organizational, and environmental factors that have a significant influence on technology acceptance and adoption at the organizational level.

Integrating the UTAUT and TOE as a combination of frameworks could combine the advantages of the two models and capture the adoption behaviors at different levels, thus bringing a significant path to provide insights toward an intention of adoption [16].

The second step is validating those factors by collecting quantitative and qualitative responses from the stakeholders of contractor companies that have experience in handling housing projects from the 10 best housing developers in Indonesia based on the Indonesia Stock Exchange. The questionnaire serves as the core of the survey where respondents fill out rating questions using a Likert scale ranging from 1 to 9 based on their opinion about the significance of every identified factor towards the intention to adopt 3DCP. These questions are selected based on findings from references and the feasibility of describing qualitative findings from collected quantitative data. The judgment of each scale of the measurement is stated in the questionnaire as in Table 1 to ensure that every respondent has the same view about the score and can provide an objective judgment about the factors.

Table 1. The Likert scale of measurement

Score	Scale	Judgment
1	No Influence	No influence regardless of the condition
3	Slight Influence	Generally not influencing except on forced or a certain condition
5	Moderate Influence	Influencing several conditions
7	Significant Influence	Generally influencing except on forced or certain conditions
9	Extreme Influence	Always influencing regardless of the condition
2,4,6,8	Intermediate Values	Represent compromise between two adjacent judgments

Stakeholders are assumed to have the right and responsibility to represent the companies' decisions. The respondents are divided into two groups, the first group is the respondents who have not implemented 3DCP (R1, R2, R3) and representatives of private-owned contractor firms who qualified as small contractors according to Indonesian National Standard while the second group is the respondents representing the joint-operation company as the pioneer of 3DCP in Indonesia (R4) which is one of the biggest contractors in Indonesia which owned by the country. This separation is based on the company's ownership, qualification, and experience in implementing 3D Concrete Printing as shown in Table 2. Although every respondent has knowledge and insight about 3DCP, separation is still done to minimize the effects of respondent bias. This consideration is done to accommodate the common subjective bias in Indonesia and several other countries, where every individual preference is based on their background and other individuals and/or institutions as their corresponding environment which might affect the way people think, act, and decide.

Table 2. List of respondents' characteristics

Responder	Contractor Size	Owner	3DCP Experience
R1 – CEO	Small	Private	No Experience
R2 – COO	Small	Private	No Experience
R3 – CEO	Small	Private	No Experience
R4 – Senior Officer	Large	Public	Part of the 3DCP Joint Operation

The main criteria for choosing the respondents are those who are currently active in housing construction, have firm knowledge about 3D Concrete Printing, and have an interest in the advancement of construction technology. The respondents included representatives from both state-owned and private-owned contractor firms, specifically chosen based on their experience and standing within the industry with their qualifications and portfolio entrusted by the best developers in Indonesia.

4. RESULTS AND DISCUSSION

4.1 Identification of Factors

The process of identifying factors begins with recognizing the scope of each selected framework, in which assorted factors are eliminated based on findings from publications and relevancies based on respondent judgment.

4.1.1 External factors

According to several publications about TOE, every aspect of technology, organization, and environment has various components that are included in the scope of the framework. Technology adoption is viewed not just as an internal decision but one that is shaped by influences beyond an individual's direct control. Therefore, external factors must be considered. Ignoring these broader influences risks overlooking crucial drivers or barriers that can determine adoption success. The process of selecting the components (factors) for the TOE framework is shown in Table 3.

Based on the findings, factors that are found in less than 50% of the selected references are removed since they are considered not significantly relevant to the aspect. Therefore, factors that are found in less than 4 selected publications are eliminated from questionnaires (T3, O3, E3, E4). Following the elimination of factors enclosed in the TOE framework, external factors are selected which represent influencing the intention to adopt at an organizational level.

Table 3. Factors bounded in the TOE framework are based on several publications.

Factor	[16]	[17]	[18]	[19]	[20]	[21]	[22]	Score
T1	✓	✓	✓	✓	✓	✓	✓	7
T2	✓	✓	✓	✓	✓	✓		6
T3						✓		1
O1	✓	✓	✓	✓		✓	✓	6
O2	✓		✓	✓	✓		✓	5
O3		✓				✓		2
O4	✓	✓	✓	✓		✓		5
E1	✓	✓	✓	✓	✓	✓		6
E2	✓	✓	✓	✓	✓		✓	6
E3							✓	1
E4				✓				1
E5	✓		✓	✓		✓	✓	5

T1: Compatibility | T2: Benefit for company | T3: Observability | O1: Business strategy | O2: Budget allocation |O3: Company size | O4: Professionals availability | E1: Competitor condition | E2: Market demand | E3: Risk management | E4: Performance gap | E5: Government regulations

4.1.2 Internal factors

Venkatesh [23] proposed the UTAUT framework which aims to capture user intentions to use an information system and subsequent usage behavior. This framework was proposed years ago but is still being used in recent research. Table 4 shows the core factors in UTAUT at the individual level. These internal considerations illuminate the subjective processes that lead an individual to react toward an innovation. Accounting for these factors can provide insights into how users form intentions and how they perceive its relevance to their tasks.

Table 4. Factors encompassed in the UTAUT framework

Factors		Definition
PE	Performance Expectancy	The degree to which a person believes that using a system would enhance their job performance
EE	Effort Expectancy	The degree a person believes would be relatively free of effort (easy to adapt)
SI	Social Influence	The person's perception that others' opinions matter the most
FC	Facilitating Conditions	The perceptions of constraints on resource and technology facilities that support the adoption

4.2 Responses from Questionnaire

The first respondent group who had not implemented 3DCP and the representative from the PTPP-Autoconz joint operation as the pioneers of 3DCP housing construction in Indonesia responded to the questionnaire differently. As an approach to objectively collect quantitative data, the score of the first group of respondents is separately averaged as shown in Table 5.

Table 5. Scores for each factor given by responders

Code	R1	R2	R3	Average	R4
T1	7	4	9	6.67	9
T2	1	1	2	1.33	9
O1	3	3	3	3.00	8
O2	9	3	5	5.67	8
O4	2	1	1	1.33	7
E1	3	3	1	2.33	8
E2	9	9	7	8.33	9
E5	7	7	9	7.67	9
PE	7	7	5	6.33	8
EE	7	5	6	6.00	8
SI	5	7	6	6.00	7
FC	5	3	5	4.33	8

Note: Factors encompassed in TOE which are less relevant based on publications were eliminated (T3, O3, E3, E4).

4.3 Selection of Factors

According to stakeholders' responses to the factors, several factors are considered less significant. Some factors might be close to not influencing the intention to adopt 3DCP, especially those with a score of below 3, which means below slight influence. The judgment of a factor that has a diminutive score is not necessarily considered an influencing factor.

4.3.1 Significance of factors

The significance of each factor can be calculated by taking out the ratio of the average score of each group towards the maximum score of 9. This calculation is done to accommodate the potential bias of using a numerical scale, in which the perception of the scale might be different between individuals who use this research. Calculating the significance of factors clarifies which variables truly influence adoption and separates them from those with minor impact. This ensures that resources and interventions can be directed toward the most pivotal elements, increasing the likelihood of successful adoption.

First, the responses from the first group of respondents who have not implemented the 3DCP in their projects but have the knowledge are ranked from the highest score to the lowest score based on the responses gathered from the questionnaire as shown in Table 6. It is assumed that every respondent in this group has equal knowledge, scope, qualification, and experience so averaging the response will be used as an approach. Therefore, their judgments can be averaged and there will be a smaller bias among the samples in this group of respondents.

Table 6. Significance of factors according to responders R1, R2, and R3

Rank	Factors	Score	Significance
1	E2	8.33	92.59%
2	E5	7.67	85.19%
3	T1	6.67	74.07%
4	PE	6.33	70.37%
5	EE	6.00	66.67%
5	SI	6.00	66.67%
7	O2	5.67	62.96%
8	FC	4.33	48.15%
9	O1	3.00	33.33%
11	E1	2.33	25.93%
12	T2	1.33	14.81%
12	O4	1.33	14.81%

Note: The definition of each code is similar to Table 3

Second, the responses from the second group of respondents who are the pioneers of 3DCP implementation in Indonesia are ranked from the highest score to the lowest score based on the responses gathered from the questionnaire as shown in Table 7.

Table 7. Significance of factors according to responders R4

Rank	Factors	Score	Significance
1	T1	9.00	100%
1	E1	9.00	100%
1	O2	9.00	100%
1	EE	9.00	100%
5	E2	8.00	88.89%
5	PE	8.00	88.89%
5	T2	8.00	88.89%
5	FC	8.00	88.89%
5	O4	8.00	88.89%
5	O1	8.00	88.89%
12	E5	7.00	77.78%
12	SI	7.00	77.78%

Note: The definition of each code is similar to Table 3

4.3.2 Bias and variations of respondents' judgment

Generally, state-owned and privately owned construction enterprises have different perspectives and characteristics. State-owned enterprises view a project with various constraints, such as national budget drafts, government timelines, and governmental reign of the presidency where amendments of policies frequently occur. However, private-owned firms tend to have a profit-oriented perspective due to the scope of the project which is usually smaller.

Furthermore, bigger construction firms tend to have a more positive view towards investment in technology and sustainability while smaller firms which usually find challenges in cost and cashflow stability consider investing in sustainable technology not worth the long-term financial benefit for the company.

Moreover, larger companies generally have numerous workers and professionals where workloads are manageable, but coordination might be more complex. Therefore, adopting a system with easier coordination and less manpower would benefit well since it cut off human error proportion significantly and reduce labor costs. On the other hand, smaller companies with fewer teams and projects believe that new technology does not have to benefit them significantly. A new system might be considerable if it does not give any drawbacks to the current system, especially in terms of cost, time, and quality.

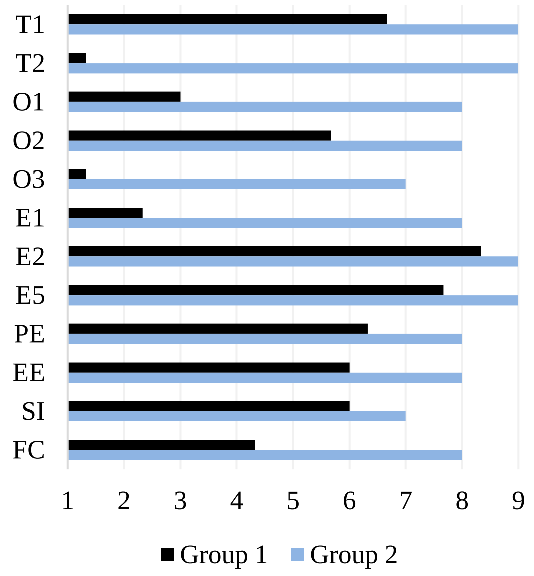

Fig. 2 Significance of factors as rated by two groups of respondents

Several factors have a small influence on the intention to adopt 3DCP as shown in Figure 2. For instance, the utmost unforeseen finding is the fact that benefits that are brought to the company by utilizing 3DCP do not influence the first group of contractors to adopt 3DCP regardless of the condition. The encompassed benefit in this research consists of every aspect of constraint in construction (cost, time, quality, safety, and environment). They asserted that any adoption of innovation must not bring drawbacks, but do not have to bring benefits. This finding extends the existing literature about challenges to widespread 3DCP adoption [24] which emphasizes that the challenges of extensive adoption of 3DCP are mainly on mechanical properties issues, such as strength, thermal, and acoustic performance.

Qualitatively, in terms of risk perception, the pioneers of 3DCP who have successfully implemented 3DCP, the pioneers have likely mitigated many of the risks (e.g., technical failures, training challenges) associated with the technology. This reduces their perception of risk and increases their willingness to embrace further advancements. In contrast, non-adopters who are currently lacking experience may amplify the perceived risks, such as high investment costs, lack of skilled labor, or compatibility issues with existing workflows. This heightened risk aversion creates a barrier to acceptance. This risk also aligns with external pressures, where state-owned enterprises are often under greater pressure from governments and stakeholders to adopt sustainable and innovative practices. This external push motivates them to explore and invest in technologies like 3DCP. However, private firms are generally driven by market forces and client demands. If clients are not requesting 3DCP or if the market does not actively reward innovation, these firms have little incentive to adopt the technology.

The divergence in judgments stems from a combination of experiential, organizational, and contextual factors. Pioneers have the advantage of practical insights and a forward-looking approach, while non-adopters are hindered by resource constraints, risk aversion, and a lack of direct exposure to technology.

4.3.3 Selection of factors based on respondents' judgment

Calculation of significance is done to determine the priorities to design a plan of actualizing 3DCP construction as an approach towards sustainable construction through automation which led to the increment of productivity in the construction industry. Therefore, neglecting factors that are considered less significant might be an approach to planning an efficient implementation strategy.

According to the pioneer of 3DCP housing construction in Indonesia, all assorted factors are generally influencing the adoption and implementation of 3DCP with four factors having an extreme influence, which are compatibility, competitor, budget allocation, and effort expectancy.

On the other hand, according to contractors who have not implemented 3DCP, some factors are considered less than slightly influencing which are close to having no influence regardless of the conditions. Therefore, nine factors are considered influencing the intention of contractors who have not implemented 3DCP to adopt this technology for housing projects in Indonesia as shown in Table 8. These factors provide perspectives from both contractors who have not implemented 3DCP and ones who have experienced it which minimizes the bias due to company size, ownership, and experience.

Table 8. Influencing factors

Code	Factor	Definition
E2	Market Demand	Availability of customers who are considering using 3DCP
E5	Government Regulations	Limitations and standards, set by the government which
T1	Compatibility	Availability of infrastructures (hardware and software)
PE	Performance Expectancy	People's expectation towards enhanced job performance (efficiency, productivity, effectivity)
EE	Effort Expectancy	People's expectation of the easiness of implementation
SI	Social Influence	Motivation and support from important individuals
O2	Budget Allocation	Investment cost and budget allocation suitability toward company projection
FC	Facilitating Conditions	Availability of resources, references, and training to assist the learning process
O1	Business Strategy	Suitability to the company's business strategy

Note: Factors are ranked from highest to lowest significance

These ranking of factors are identified through a structured methodology. However, these findings may vary across different regions. Countries with distinct individual behavior, policies, technological compatibility, and contractor behavior may face different challenges or opportunities. Factors such as cybersecurity, digital integration, and government incentives could play a greater role in highly industrialized markets in developed countries.

4.4 Future Advancement

Currently, Indonesia faces an assortment of challenges that impede 3D Concrete Printing (3DCP) very adoption, including a low-cost labor market and a relatively unskilled/uneducated workforce that prefers traditional construction techniques. This results in the current labor force not coping with automated systems due to their lack of proficiency which makes it expensive to introduce advanced technologies such as 3DCP. Another factor is that Indonesia is geographically located in the Pacific

Ring of Fire making it susceptible to natural disasters which makes it necessary to adopt construction methods that focus on the resilience of structures.

Furthermore, a set of implementation strategies can be designed based on the assorted factors. These strategies are strongly recommended to be planned by the government and 3DCP enthusiasts. In terms of technology, providing software/hardware for contractor use must take priority over providing benefits and creating a new trend in construction technology. Furthermore, research and development in reducing costs is needed to create 3DCP modification that suits the company's funding and investment allocation plans.

The government is recommended to prioritize the development of regulations and incentives that can promote the adoption of 3DCP by offering financial assistance to technological investments and supporting construction companies with training initiatives. Additionally, enhancing digital literacy and technical training programs for construction workers will bridge the skills gap, making 3DCP a more feasible and widely accepted solution for the Indonesian construction industry. Moreover, there is a substantial need for a regulator who can provide exposure to various housing developers as a market regarding the benefits of 3DCP. Addressing material optimization and reinforcing 3D-printed structures to meet seismic resistance standards will be critical for ensuring long-term viability in earthquake-prone regions which need to be regulated. In addition, this is a call for all small-scale construction firms to ensure they enter into collaborative agreements with technology providers to enable them to access the required tools and expertise for implementing 3DCP. Therefore, collaboration between academia, industry, and government stakeholders will be crucial in transforming 3DCP from an emerging technology into a mainstream construction method that redefines the future of urban development worldwide.

4.5 Future Applications of the Study

Future research areas could involve in-depth studies over time that examine the long-term effects of 3DCP adoption on building efficiency and sustainability and also studies done across various places that appraise different techniques used for their implementation, such as the PESTLE framework. The findings of this study not only address critical challenges in Indonesia's construction sector but also establish a model that can serve as a valuable example for other developing countries. Indonesia's socio-economic and regulatory landscape reflects common barriers faced by nations with similar conditions, such as high population growth, urbanization, and resource constraints.

Future studies could explore time-based (longitudinal) analysis to assess the long-term impact of 3DCP adoption on risk, cost efficiency, sustainability, and affordability for housing. Comparative studies between developed and developing countries could also offer valuable insights into how different regulatory frameworks, technological ecosystems, market dynamics, and the characters of the individuals influence the scalability of 3DCP.

5. CONCLUSION

Indonesia, as well as other developing countries, has lots of potential for innovation. Nowadays, achieving sustainable construction through automation is within the bounds of possibility by understanding the influence of several factors on the intention of adoption. Formulating the implementation strategies will be effective by considering the influencing factors which are market demand, regulation, compatibility, expectancy, social influence, budget allocation, facilitating conditions, and business strategy. These solutions may be adopted as part of implementation roadmap strategies for further research and implementation for developing countries.

As the construction industry stands at the crossroads of innovation and necessity, the adoption of 3DCP represents more than just a technological shift. 3DCP serves as a transformative leap toward a more sustainable, efficient, and resilient future. This study identifies the key factors influencing 3DCP adoption in Indonesia to provide the fundamental base for strategic implementation in developing economies that face similar challenges. Obstacles are indelible, but the potential benefits of automation, waste reduction, and design flexibility should overcome the hesitations due to traditional practices. By embracing this paradigm shift, the industry can unlock new possibilities in housing development for a smarter and more sustainable urban environments that meet the demands of a rapidly evolving world.

6. REFERENCES

[1] Mischke J., Stokvis K., and Vermeltfoort K., Delivering on Construction Productivity is No Longer Optional. McKinsey & Company, 2024, pp. 1-15.

[2] Masters G. M. and Randolph J., Energy for Sustainability: Foundations for Technology, Planning, Policy, 2nd ed. Island Press, Washington DC, USA, 2019, pp. 1-637.

[3] Nguyen H., Adachi Y., Kizuki T., Maeba H., and Inazumi S., Integration of Information and Communication Technology (ICT) into Cement Deep Mixing Method, International Journal of GEOMATE, Vol. 19, Issue 74, 2020, pp. 194-200.

[4] Tkach, E., Serova, R., Stassilovich, E., Imanov, Y., Bogoyavlenskaya, T., and Khan, M., Modified

Aerated Concrete Based on Man-Made Waste, International Journal of GEOMATE, Vol. 23, Issue 97, 2022, pp. 131-138.
[5] Hidayat F., Arifin A., Farrosi M. A. A., Soemardi B. W., Pradoto R. G. K., Puri E. R., Technology Landscape for Surveying and Mapping in Construction Industry, International Journal of Integrated Engineering, Vol. 14, Issue 9, 2022, pp. 74-80.
[6] Pradoto R. G. K., Soemardi B. W., Gazali A., Sunarjo H. N., Putri A. T., Purba R. P., Mahardika I., An Overview of Technology Landscape in Construction Materials for the Indonesian Construction Industry, Jurnal Teknik Sipil ITB, Vol. 30, Issue 3, 2023, pp. 351-358.
[7] Pradoto R. G. K., Soemardi B. W., Gazali A., Putri A. T., Purba R. P., Mahardika I., Development of Concrete Material Technology in the Context of Supply-Demand based on Geographical Aspects, IOP Conference Series: Earth and Environmental Science, Vol. 1065, Issue 1, 2022, pp. 1-11.
[8] Tuan N. V., Kien T. T., Huyen T. T. H., Nga T. T. V., Giang N. H., Dung N. T., Isobe Y., Ishigaki T., and Kawamoto K., Current Status of Construction and Demolition Waste Management in Vietnam: Challenges and Opportunities, International Journal of GEOMATE, Vol. 15, Issue 52, 2018, pp. 23-29.
[9] Armstrong G., Max K., Gilge C., and Vora S., Familiar Challenges - New Approaches, KPMG, 2023, pp. 2-37.
[10] Aijaz H., Joshi A., Meisels M., Hardin K., and Wellener P., 2023 Engineering and Construction Industry Outlook, Deloitte, 2022, pp. 2-9.
[11] Blanco J. L., Rockhill D., Sanghvi A., and Torres A., From Start-up to Scale-up: Accelerating Growth in Construction Technology, McKinsey & Company, 2023, pp. 1-12.
[12] Rehman A. U., Kim I. G., and Kim J.H., Towards full Automation in 3D Concrete Printing Construction: Development of an Automated and Inline Sensor-printer Integrated Instrument for In-situ Assessment of Structural Build-up and Quality of Concrete, Developments in the Built Environment, Vol. 17, 2024, pp. 1-18.
[13] Habibi A., Buswell R., Osmani M., and Aziminezhad M., Sustainability Principles in 3D Concrete Printing: Analysing Trends, Classifying Strategies, and Future Directions, Journal of Building Engineering, Vol. 98, 2024, pp. 1-19.
[14] Al-Tamimi A. K., Alqamish H. H., Khaldoune A., Alhaidary H., and Shirvanimoghaddam K., Framework of 3D Concrete Printing Potential and Challenges, Buildings, Vol. 13, Issue 3, 827, 2023, pp. 1-27.
[15] Alami A. H., Olabi A. G., Ayoub M., Aljaghoub H., Alasad S., and Abdelkareem M. A., 3D Concrete Printing: Recent Progress, Applications, Challenges, and Role in Achieving Sustainable Development Goals, Buildings, Vol 13, Issue 4, 924, 2023, pp.1-20
[16] Qin X., Shi Y., Lyu K., and Mo Y., Using a TAM-TOE Model to Explore Factors of Building Information Modelling (BIM) Adoption in The Construction Industry, Journal of Civil Engineering and Management, Vol. 26, Issue 3, 2020, pp. 259-277.
[17] Awa H. O. and Ojiabo O. U., A Model of Adoption Determinants of ERP within T-O-E Framework, Information Technology and People, Vol. 29, Issue 4, 2016, pp. 901-930.
[18] Li M., Investigation of the Severity of Modular Construction Adoption Barriers with Large-Scale Group Decision Making in an Organization from Internal and External Stakeholder Perspectives, CMES - Computer Modeling in Engineering and Sciences, Vol. 137, Issue 3, 2023, pp. 2465-2493.
[19] Hatoum M. B. And Nassereddine H., Determining Decision-Making Factors for Technology Adoption in the Construction Industry, 2024, pp. 1-33.
[20] Zhang J., Zhang M., Ballesteros-Pérez P., and Philbin S. P., A New Perspective to Evaluate the Antecedent Path of Adoption of Digital Technologies in Major Projects of Construction Industry: A Case Study in China, Developments in the Built Environment, Vol. 14, 2023, pp. 1-16.
[21] Nguyen T. H., Le X. C., and Vu T. H. L., An Extended Technology-Organization-Environment (TOE) Framework for Online Retailing Utilization in Digital Transformation: Empirical evidence from Vietnam, Journal of Open Innovation: Technology, Market, and Complexity, Vol. 8, Issue 4, 2022, pp. 1-22.
[22] Katebi A., Homami P., and Najmeddin M., Acceptance Model of Precast Concrete Components in Building Construction Based on Technology Acceptance Model (TAM) and Technology, Organization, and Environment (TOE) Framework, Journal of Building Engineering, Vol. 45, 2022, pp. 1-5.
[23] Venkatesh V., Morris M. G., Davis G. B., and Davis F. D., User Acceptance of Information Technology: Toward a Unified View, MIS Quarterly, 2003, pp. 425-478.
[24] Kaliyavaradhan S. K., Ps A., and Rajendran N., Top Challenges to Widespread 3D Concrete Printing (3DCP) Adoption–A Review. European Journal of Environmental and Civil Engineering, Vol. 28, Issue 2, 2024, pp. 300-328.