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Architects' Perspectives on 3D Concrete Printing (3DCP) Technology in Architectural Design

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Abstract

The rapid urbanization and increasing demand for housing in Malaysia have intensified the need for innovative and sustainable construction technologies that enhance architectural design efficiency and flexibility. This study examines architects' perspectives on 3D Concrete Printing (3DCP) technology in architectural design, with particular emphasis on identifying its advantages and understanding professional viewpoints on its design application. As an advanced form of additive manufacturing, 3DCP offers significant architectural benefits, including greater design freedom, reduced material wastage, improved construction precision, and the ability to realize complex forms that are difficult to achieve using conventional construction methods. Despite 3D Concrete Printing's (3DCP) potential for sustainable and customized housing in Malaysia, its integration into architectural practice remains limited due to a critical knowledge gap regarding architects' perceptions of design flexibility and constructability, alongside a lack of localized workflows and technical guidelines. Using a qualitative research approach, this study employs semi-structured interviews with 3 architects to identify the advantages of 3DCP technology and to analyse architects' perspectives on its integration into architectural design practice. In alignment with Research Objective 2 (RO2), the findings reveal that architects perceive 3DCP as a transformative technology that enhances design versatility and enables the customization of complex forms. The study also highlights how 3DCP improves sustainability through reduced material waste and strengthens the integration between digital design tools and physical construction processes. This study contributes to the existing body of knowledge by providing an architectural-oriented understanding of 3DCP, positioning the technology as a design-driven innovation rather than solely a construction technique. The findings aim to assist architects, designers, and built environment professionals in making informed decisions regarding the adoption of 3DCP in future architectural design and housing developments in Malaysia.

1. Introduction

Rapid urbanization, population growth and income disparities among citizens has increased the need to have cheap housing in Malaysia. Due to the ever-growing congestion in the urban centers, the government is under pressure to deliver cost-effective, sustainable, and innovative housing solutions. Although the use of traditional methods of construction has stood the test of time, they tend to restrict the flexibility in architectural design, restrict the capacity of customization, and diminish the digitally enabled innovation (Gamil and Rahman, 2020). Industrialised Building Systems (IBS) have alleviated some of these issues but remain restrictive in accuracy, form flexibility and creativeness in design.

It is against this context that 3D Concrete Printing (3DCP) is already an innovative technology in architectural design. Being a type of additive manufacturing, 3DCP will permit layer-by-layer creation of the concrete infrastructure, enabling architects to experiment with intricate shapes, non-standard forms, and design solutions included inside, and that are challenging in a traditional practice (Lim *et al*., 2021; Khoshnevis *et al*., 2021). On the global level, 3DCP has already shown the possibility to change the role of architects in the decision-making process during designing by increasing the freedom of design, providing a fast prototyping process, and allowing immediate translation of digital models into material structures (Weng *et al*., 2022).

However, in Malaysia, 3DCP is in its infancy, and pilot projects and scholarly research efforts consider local materials and methods of printing (COBOD, 2022; O'Neal, 2020). Nevertheless, the views on the technology expressed by architects, especially the benefits, design opportunities, and role in the architectural practice, are not studied thoroughly. The perception and use of 3DCP by architects in the housing design process are vital in evaluating the viability of this technology and informing professional practice and the future adoption of the technology in the Malaysian built environment (Khoshnevis *et al*., 2021; Weng *et al*., 2022). Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10.0 pt. Here follows further instructions for authors.

Although 3D Concrete Printing (3DCP) has the potential to be expanded more, its use in architectural design practice in Malaysia is still a small area. Though past studies and pilot projects have concentrated much on the efficiency of construction, cost minimization, and material performances, little is known about how architects view 3DCP in terms of flexibility of design, spatial planning, and constructability (Lim *et al*., 2021; Khoshnevis *et al.,* 2021).

The architects have a very important role to play in the initial stages of the development of the project as design decisions are important determinants of the aesthetic and functional deliverables of the housing project. Nonetheless, the inaccessibility of 3DCP-based workflows, ambiguity about design feasibility, and inaccessibility of locally adapted guidelines and best practices are obstacles of integrating the 3DCP into the design process of architects (Weng *et al*., 2022).

This gap in knowledge can be used to support the idea of conducting research to understand how architects see 3DCP, their opinions about its benefits, possible limitations, and applicability to housing construction in Malaysia. It is important to fill this gap so that architects can use 3DCP as a design-based technology to encourage innovation, high customization, and sustainable housing solutions.This study is dedicated to 3D Concrete Printing (3DCP) use in the housing design in Johor Bahru, the fast-developing urban city with its population of over 900,000 people as of 2023. The study focuses particularly on the attitude of professional architects who have worked on small-scale and medium residential construction works including single to double-storey terrace or semi-detached houses, but not high-rise and commercial works. The study examines the perceptions of practicing architects concerning the application of 3DCP as a way of attaining design flexibility and geometric complexity and integrated digital processes through semi-structured interviews with the professionals. In addition, a qualitative comparison with the traditional and Industrialised Building System (IBS) practice is given to outline unique architectural benefits, oriented to the design-based results but not on the construction work or cost indicators.

2. Literature Review

2.1 Introduction

3D Concrete Printing (3DCP) is the groundbreaking change in the architectural practice allowing obtaining complex geometries and non-standard forms that cannot be created using traditional methods and Industrialised Building Systems (IBS) (Yabaniguel and Gulec Ozer, 2025; Kamar *et al.,* 2009). Although the adoption of the technology in Malaysia is still immature, the presence of fiber-reinforced research by UTHM and pilot projects in Sarawak show that the technology is viable to provide sustainable and cost-effective housing (O'Neal, 2020; COBOD, 2022). Architects still play a key role in this shift, and using BIM and digital processes, they can bridge the gap between design creativity and structural printibility, but mainstream integration is still

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currently hampered by technical limitations and absence of holistic local regulatory machinery (Weng et al., 2022; Lim et al., 2021).

2.2 Definition and Principles of 3DCP

3D Concrete Printing (3DCP) is an additive method of manufacturing, an additive process where specialized mixtures of concrete are deposited based on digital designs with unmatched freedom to architects to make complex, non-standard forms at the cost of conventional formwork (Yabanigul & Gulec Ozer, 2025). By directly translating CAD or BIM models into physical construction, 3DCP links the digital conceptualization and construction stages and enables the simultaneous optimization of aesthetics and structural performance (Lim et al., 2021; Gebel et al., 2023).

Its main idea is premised on digital fabrication, where 3D designs are sliced into layers that are robots engaged to execute the design, which allows forming of adaptive building forms that are applicable to the urban setting of Malaysia (COBOD, 2023). In this workflow, the role of the architect becomes more technical and partnering where the architect is expected to optimize the design to meet print limitations, chooses materials and plans print paths. In either case using either a gantry or robotic-arm system, the architect makes sure that the digital intent is accurately reproduced in both the dimensional accuracy and quality control in the printing and curing stages.

2.3 Implementation of 3DCP in other Countries

The international practice of 3DCP emphasizes various applications of architects in the forefront of technological integration in the variable regulatory and economic environments. Netherlands (Project Milestone): The first entirely printed residential development in Europe with architects having the use of complex modular geometries and unique aesthetic fronts using 3DCP. This project indicates the significance of the initial cooperation between architects and regulatory authorities to make sure that innovative designs are structurally feasible and up-to-date (Bos *et al*., 2016).

United Arab Emirates (Dubai 3D Printing Strategy 2030): The top-down government plan of Dubai is to have 25 percent of new constructions 3D printed by 2030. Here, architects play a central role in envisioning the future, high-performance designs in the so-called regulatory sandboxes, where designers can explore new forms and structural layouts (Alaloul *et al*., 2020).

USA (ICON Affordable Housing) In both Texas and Mexico, ICON applies mobile 3D printers to show how the architect can design disaster-resilient and fast-deployable structures. These projects are concerned with the optimization of space and the transformation of digital models to conform to the restrictions of on-site mobile printing systems and local building codes (ICON, 2022).

2.4 Comparison of Construction Methods

Architecturally, the 3DCP provides workflow with a paradigm shift, as a replacement of the purely manual trades sequentiality with an accurate robotic extrusion. In contrast to conventional approaches or IBS, where timber frameworks and modular repetitive designs limit the realisation of intricate BIM models, 3DCP enables the direct physicalisation of the complex BIM models (Gebel et al., 2023). Table 1 demonstrates that 3DCP is much faster (small units require 24-72 hours), needed less labor (only 3-5 workers), and had low material waste (less than 3 percent), whereas design flexibility (freeform and curved structures) was high (Tay *et al*., 2020; Ghaffar *et al*., 2018).

2.5 Critical Challenges to 3DCP Integration in the Malaysian Context

The implementation of the 3D Concrete printing (3DCP) in the Malaysian architectural environment is now hindered by an intricate combination of technical and systemic obstacles. First, the effect of the tropical environmental factors, namely, high humidity and ambient temperatures, on the rheological characteristics of concrete contributes to a fact that the structural accuracy and aesthetic integrity of complex designs are under a threat (Tu *et al*., 2023). Moreover, the huge initial capital outlay and logistical issues in terms of the accessibility of sites still discourage architectural experimentation (Malik *et al.,* 2022). The most important aspect is that there is still a professional skills gap on parametric modeling and structural simulation among local practitioners. It is augmented by the fact that there is no specialized building code in the Uniform Building By-Laws (UBBL), which adds a gap in regulatory clarity and increases professional liability throughout the design approval procedure (Siddiqui *et al*., 2023; El-Sayegh *et al*., 2020).

2.6 Architectural Potential: Design Innovation and Versatility

In contrast, 3DCP introduces a new design worldview as it provides architects with an opportunity to combine aesthetic complexity and functional performance without the classical limitations of formwork (Wu *et al.,* 2016). Technology enables an economic framework of Complexity for Free, where vastly customized, biophilic, or topological optimized structures can be produced without the expense premium of custom, conventional construction. 3DCP facilitates the achievement of mass customization and the exploitation of low carbon cementitious mixtures, by facilitating the precise deposition of materials. This enables architects to seek high-performance building envelopes that are consistent with Malaysian national frameworks of sustainability and green building requirements (Yeon *et al*., 2020).

3. Research Methodology

3.1 Research Design

This study adopts a qualitative research design to investigate the feasibility and implications of 3D Concrete Printing (3DCP) in addressing housing development challenges in Malaysia. Qualitative methods were selected for their ability to capture rich, context-specific insights that are not easily measurable through quantitative approaches (Rahman *et al.,* 2022). This method allows the researcher to capture how architects and other industry experts perceive, respond to, and engage with the potential application of 3DCP in the local housing sector.

Furthermore, the research design utilizes semi-structured interviews as a primary data collection method to obtain in-depth insights into architectural workflows and design considerations (Rahman *et al.,* 2022).

3.2 Data Collection Methods

The data collection for this study is conducted through a qualitative approach focused exclusively on gathering primary data from practicing architects to capture their professional perspectives on 3D Concrete Printing (3DCP). This is achieved through semi-structured interviews designed to explore the specific impact of 3DCP on architectural workflows, design flexibility, and the integration of Building Information Modelling (BIM) within the Malaysian context. By targeting architects as the sole participant group, the study ensures a deep, specialized analysis of how this technology influences the creative and technical decision-making process at the design stage.

3.3 Data Analysis Method

The qualitative data gathered from the semi-structured interviews and case study reviews will be analyzed using thematic analysis to identify, organize, and report recurring patterns within the architects' responses. This process begins with the transcription of all interview recordings, followed by a thorough immersion in the data to establish a high level of familiarization. The researcher will then conduct an initial coding process, labeling specific segments of the text that relate to design flexibility, technical limitations, and professional adaptation (Braun & Clarke, 2006; Creswell & Poth, 2018). These codes will be systematically categorized into broader themes that capture the essence of the architects' perspectives toward 3D Concrete Printing (3DCP) in Malaysia. To ensure the reliability and validity of the findings, data triangulation will be employed by comparing the interview insights with established industry reports and case study outcomes, ensuring that the final analysis provides a coherent and credible interpretation of the technology's architectural implications. All recorded qualitative data is transcribed for thematic analysis to identify the core opportunities and challenges unique to the architectural profession.

4. Results and Discussion

This section presents the findings obtained from the semi-structured interviews conducted with architects to explore their perspectives on the implementation of 3D Concrete Printing (3DCP) technology in architectural design. The study adopted a qualitative research approach, with data collected through written responses and interview notes. Content analysis was employed to analyse the data systematically, allowing key themes and patterns to be identified in relation to the research objectives.

4.1 Respondent Background

Table 1 presents the background of the respondents involved in this study. All three respondents are professional architects with experience in architectural design and construction-related projects. Respondents R1 and R2 each have more than fifteen years of professional experience, while Respondent R3 has approximately eight years of experience in the industry. Their involvement in architectural practice provides

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them with sufficient exposure to both conventional construction methods and emerging technologies such as 3D Concrete Printing (3DCP).

The respondents' professional experience enhances the credibility of the findings, as their insights are derived from practical involvement in design development, construction coordination, and collaboration with other built environment professionals. This ensures that the perspectives gathered are relevant and reliable for addressing the research objectives of this study.

Table 1 *Respondent's Background*

Respondent	Role	Professional Background	Years of Experience
R1	Architect	Architectural Practice	More than 15 years
R2	Architect	Architectural Practice	More than 15 years
R3	Architect	Architectural Practice	More than 15 years

4.2 Advantages of 3D Concrete Printing (3DCP) technology in architectural design.

The 3D Concrete Printing (3DCP) has a few benefits over traditional and industrialised construction techniques and especially in architectural design. It can be used to give it more design flexibility, less reliance on labour, quicker construction, and more complex, customised forms. Table 2 provides a summary of how 3DCP was found to have design advantages by the respondent.

Table 2 *Design Advantages of 3DCP*

Design Advantage Factors	**R1**	**R2**	**R3**	**Total**
Reduced Labour Dependency	/	/	/	3/3
Design Flexibility in Form and Geometry	/	/	/	3/3
Ability to Create Complex and Organic Forms	/	/	/	3/3
Architectural Creativity and Customisation	/	/	/	3/3
Reduced Formwork Requirement	/	/	/	3/3
Integration of Architectural and Structural Forms	/	/	/	3/3
Material Optimisation Through Digital Design	X	/	/	2/3
Suitability for Affordable Housing Design	/	/	/	3/3

Table 2 shows the design advantages of 3D Concrete Printing identified by the respondents. All respondents agreed that 3DCP offers greater design flexibility, enhanced creativity, and reduced labour dependency compared to conventional and IBS construction methods. The findings indicate strong consensus on the potential of 3DCP to enable complex architectural forms and customised housing solutions, although material optimisation was highlighted by only two respondents.

(a) Reduce Labour Dependency

All respondents indicated that 3D Concrete Printing (3DCP) reduces labour dependency compared to conventional construction methods. R1 highlighted that traditional construction relies heavily on manual labour, whereas 3DCP automates key construction activities.

"Compared to conventional construction, 3D concrete printing requires fewer workers on site. IBS is economical for repetitive elements, but 3DCP gives more freedom in product design." (R1)

This reduction in labour dependency was also associated with faster wall construction, as emphasised by R3.

(b) Design Flexibility in Form and Geometry

All respondents agreed that 3DCP enhances design flexibility in architectural form and geometry. The ability to produce curved and organic forms without conventional formwork was identified as a key advantage.

"From an architectural point of view, 3D concrete printing allows more freedom in terms of form and geometry. Curves and organic shapes can be designed without worrying too much about formwork." (R3)

However, R1 cautioned that design flexibility remains influenced by material limitations, as concrete is the primary printing material.

"The flexibility is there, but because the material is limited to concrete, the design can become repetitive if not carefully explored." (R1)

(c) Ability to Create Complex and Organic Forms

The respondents indicated that 3DCP enables the production of complex and organic forms without the cost implications commonly associated with conventional construction methods.

"With conventional methods, complex forms usually mean higher cost because of formwork. In 3DCP, complex geometry does not necessarily increase construction cost." (R3)

(d) Architectural Creativity and Customisation

All respondents agreed that 3DCP supports architectural creativity and design customisation. R2 highlighted that the technology enables a shift away from standardised building layouts.

"3D concrete printing allows architects to move from standardised buildings to more site-specific and customised designs. It gives more freedom to respond to context and user needs." (R2)

Nevertheless, R1 noted that architectural creativity must comply with structural requirements.

"Creativity is possible, but it must work within the limitations of load-bearing wall concepts, unlike conventional beam and column structures." (R1)

(e) Reduced Formwork Requirement

All respondents identified the reduction in formwork as a major advantage of 3DCP.

"With conventional methods, complex forms usually mean higher cost because of formwork. In 3DCP, complex geometry does not necessarily increase construction cost." (R3)

(f) Integration of Architectural and Structural Forms

The respondents agreed that 3DCP enables the integration of architectural and structural elements, particularly through load-bearing wall systems.

"Yes, walls function as both architectural and load-bearing structural elements." (R1)

(g) Material Optimisation Through Digital Design

Material optimisation was primarily highlighted by R2 and R3, who noted that digital and parametric design tools allow material usage to be optimised while maintaining structural integrity. As stated by R2,

"With proper digital modelling, material usage can be optimised, which improves efficiency and reduces waste."(R2)

In contrast, R1 did not emphasise material optimisation, as the respondent viewed current 3D Concrete Printing applications as being primarily constrained by material limitations and load-bearing wall systems, where structural feasibility and compliance were prioritised over optimisation-driven material reduction.

"Material optimisation is not my main concern at this stage because 3D concrete printing is still limited to concrete and a load-bearing wall system. The priority is ensuring structural stability and compliance rather than reducing material usage through complex digital optimisation." (R1)

(h) Suitability for Affordable Housing Design

All respondents agreed that 3DCP has potential for affordable housing applications, primarily due to labour reduction and construction speed.

"Yes, reduced labour and construction time make 3DCP suitable for affordable housing." (R3)

"Yes, 3DCP has potential for affordable housing if cost efficiency is achieved." (R1)

(i) Summary

In summary, the findings indicate that 3D Concrete Printing offers advantages in reducing labour dependency, enhancing design flexibility, supporting architectural creativity, and improving construction efficiency. However, material limitations and structural requirements remain important considerations in its application.

4.3 Architects' perspectives on the application of 3DCP technology in Architectural Design.

Architects have been instrumental in application of 3D Concrete Printing (3DCP) in building projects. Their opinions offer feedback on the workflow integration, design issues, cooperation needs, and how the technology can be used in affordable housing. The points of view of the respondents are summarised in Table 3.

Table 3 *Architect Perspective on the application of 3DCP technology in Architectural Design*

Aspect	R1	R2	R3	Total
Early Integration in Design Workflow	/	/	/	3/3
Use of Digital and Parametric Modelling	X	/	/	2/3
Close Collaboration with Structural Engineers	/	/	/	3/3
Reliance on Load-Bearing Wall System	/	/	/	3/3
Challenges in Translating Design to Printable Form	/	/	/	3/3
Limited Material and Reinforcement Options	/	/	/	3/3
Lack of Clear Regulatory Guidelines	/	/	/	3/3
High Initial Cost and Technology Investment	X	/	/	2/3
Willingness to Adopt Based on Cost Efficiency	/	/	/	3/3
Future Potential for Affordable Housing	/	/	/	3/3
Architects' Role in Advancing 3DCP Adoption	/	/	/	3/3

This section addresses Research Objective 2, which focuses on how 3DCP integrates into architectural design workflows, the challenges faced during implementation, collaboration with consultants, constraints affecting adoption, and future strategies for wider implementation in Malaysia.

(a) Early Integration in the Design Workflow

All respondents agreed that 3DCP must be integrated from the early design stage to ensure feasibility and efficiency. This reflects a shift from a conventional linear workflow to a more integrated design–construction process.

"For 3D concrete printing to work effectively, it must be embedded into the workflow from the early design stage, not treated as a construction add-on." (R2)

(b) Use of Digital and Parametric Modelling

Respondents highlighted the importance of digital and parametric modelling in supporting 3DCP implementation. Digital tools were identified as essential in translating architectural intent into printable forms and reducing design changes during construction.

"Design development needs to be digital and parametric so that the forms are ready for printing without major changes during construction." (R3)

While R2 and R3 strongly emphasised the role of digital and parametric modelling in improving design efficiency and print readiness, R1 expressed a more cautious view, indicating that digital modelling alone does not fully address the fundamental material and structural constraints associated with current 3D Concrete Printing applications.

"Digital modelling helps in translating the design into a printable form, but it does not solve the limitations caused by concrete material and load-bearing wall systems. Even with parametric tools, the design outcome can still be restricted." (R1)

(c) Close Collaboration with Structural Engineers

All respondents emphasised the need for close collaboration with structural engineers in 3DCP projects. This is primarily due to the structural role of printed elements and the absence of conventional beam-and-column systems.

"The structural engineer must be involved from the beginning because most 3DCP buildings do not use beams and columns. The walls carry the load." (R1)

(d) Reliance on Load-Bearing Wall Systems

Respondents agreed that 3DCP buildings rely heavily on load-bearing wall systems. This structural approach directly influences architectural layout and design decisions.

The reliance on load-bearing walls increases the importance of early structural coordination during the design stage.

(e) Challenges in Translating Design to Printable Form

All respondents identified challenges in translating architectural designs into printable forms. These challenges include printing constraints, material behaviour, and detailing limitations.

"Architects need to balance design intention with print constraints such as overhangs, spans, curing time, and build volume." (R3)

"Detailing and quality control are still challenging because the technology is relatively new and standards are not fully established." (R2)

(f) Limited Material and Reinforcement Options

Respondents highlighted limitations related to material choices and reinforcement methods in current 3DCP applications. These limitations restrict design freedom and structural strategies.

"Printer size, speed, and site logistics still limit the scale and freedom of design." (R3)

(g) Lack of Clear Regulatory Guidelines

All respondents identified the absence of clear regulatory guidelines and approval frameworks as a major barrier to 3DCP adoption in Malaysia.

"The main limitation is not the design potential, but the lack of clear standards, approvals, and professional responsibility frameworks." (R2)

(h) High Initial Cost and Technology Investment

In contrast to R2 and R3, R1 expressed a more cautious position, indicating that high initial costs and technology investment represent a significant barrier rather than a manageable challenge. This view is closely linked to R1's emphasis on cost efficiency and economic feasibility as key determinants in deciding whether 3D Concrete Printing should be proposed or adopted in housing projects.

"The adoption of 3D concrete printing will depend heavily on whether it can be cost-efficient compared to conventional and IBS construction. High investment costs make it difficult to justify its use at the current stage." (R1)

(i) Willingness to Adopt Based on Cost Efficiency

All respondents agreed that willingness to adopt 3DCP increases when the technology demonstrates clear cost and time advantages.

"Architects will adopt 3DCP when it clearly delivers faster and cheaper housing compared to conventional methods." (R3)

(j) Future Potential for Affordable Housing

Respondents unanimously agreed that 3DCP has strong potential for affordable housing development, provided cost efficiency and scalability are achieved.

This aligns with earlier findings related to labour reduction and construction speed.

(k) Architects' Role in Advancing 3DCP Adoption

All respondents identified architects as key actors in advancing the adoption of 3DCP through proactive design, coordination, and engagement with authorities.

"Architects should play a proactive role by designing print-ready buildings and working closely with engineers and authorities to push the technology forward." (R1)

"3DCP becomes mainstream when it moves from experimental projects to a regulated and cost-effective construction system." (R2)

(l) Summary

In summary, the findings under Research Objective 2 indicate that effective adoption of 3DCP in architectural practice requires early design integration, strong digital capability, close interdisciplinary collaboration, and clear regulatory support. While cost, material, and technical constraints remain, respondents viewed 3DCP as a viable future construction method, particularly for affordable housing in Malaysia.

4.4 Discussion

This section discusses the findings of this study in relation to the established research objectives. The discussion evaluates the advantages of 3D Concrete Printing (3DCP) technology in architectural design and analyses architects' perspectives on its application by comparing the interview results with existing literature. This section aims to provide a clearer understanding of how 3DCP contributes to architectural design practices and the key considerations influencing its adoption.

4.4.1 Discussion for Research Objective 1

Research Objective 1 was to determine the benefits of the 3D Concrete Printing (3DCP) technology in building design. The results show that 3DCP offers a high degree of design freedom through the possibility of creating complex and tailored geometries without having to use standard formwork. This enables architects to directly convert digital design models to actual buildings, which increases architectural creativity and design freedom (Buswell *et al.,* 2018; Lim *et al*., 2012).

The other important benefit, which has been noticed, is the decrease in the labour dependence and the time of construction. The 3DCP is automated and reduces the manual labour on site and the velocity of construction, especially the wall systems. This increased efficiency also allows delivering projects faster and saving possible costs in comparison with traditional construction technologies (Ghaffar *et al*., 2018; Tay *et al.,* 2017).

Further, the findings demonstrate the appropriateness of 3DCP to affordable housing development as it has the capacity to facilitate customisation of its design without causing a huge markup in the construction process.

The unification of architectural and structural features of the printed components contributes to the increase of material efficiency and the optimisation of construction. The mentioned benefits prove that 3DCP can be a promising and progressive technology in architectural practice in the future (Bos *et al*., 2016; Buswell *et al.,* 2018).

4.4.2 Discussion for Research Objective 2

The results indicate that the second research objective was achieved in the form of determining the main variables that influence the use of 3D Concrete Printing (3DCP) in architectural design. The respondents stressed the need to be integrated early in the design process, to use digital and parametric models, and to work closely with structural engineers. These aspects allow effectively converting sophisticated designs into printing formats and increase design flexibility and creativity (Takva *et al*., 2024; Lim *et al*., 2021; Wu *et al*., 2016).

The opportunities of 3DCP in affordable housing were also mentioned by the respondents, including a decreased level of labour reliance, quicker construction, and the possibility of creating tailored units. But constraints like material choice, reinforcement technique, and cost issues are also significant constraints. Such results resonate with previous studies that show that the material behaviour, design geometry, and buildability play a significant role in determining the feasibility of 3DCP applications in housing projects (Takva et al., 2024; Bos *et al.,* 2016).

Lastly, the research also indicates the need to work together between architects, engineers, and regulatory bodies to maximise the potential of 3DCP. The collaboration of digital tools and organized working processes, as well as strategic stakeholder engagement, is essential to realize the benefits of 3DCP in practice (Lim *et al*., 2021; Bos *et al.,* 2016).

5. Conclusion

In conclusion, this study has successfully achieved its research objectives by identifying both the transformative advantages and the critical challenges of 3D Concrete Printing (3DCP) adoption within the Malaysian context. The findings reveal that 3DCP offers unprecedented design flexibility and the execution of complex geometries without traditional formwork, allowing for a seamless integration of architectural and structural functions. However, the study also highlights significant barriers, such as technical material constraints in tropical climates, high equipment costs, and the current absence of regulatory codes in the Uniform Building By-Laws (UBBL). To overcome these obstacles, the research proposes strategic interventions, including the formulation of national standards, the implementation of government-backed pilot projects, and the modernization of architectural training to include digital construction skills. Ultimately, this research provides a vital roadmap for architects and stakeholders to effectively navigate the complexities of 3DCP, fostering more innovative and efficient housing solutions in Malaysia.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Azifuzaiddin bin Asmadinata, Norliana binti Sarpin,;* ***data collection:*** *Azifuzaiddin bin Asmadinata;* ***analysis and interpretation of results:*** *Azifuzaiddin bin Asmadinata, Norliana binti Sarpin;* ***draft manuscript preparation:*** *Azifuzaiddin bin Asmadinata, Norliana binti Sarpin, Sulzakimin bin Mohamed, Haryati binti Shafii, Roshartini binti Omar.. All authors reviewed the results and approved the final version of the manuscript.*

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