THE IMPACTS OF DIGITAL FABRICATION ON THE CONSTRUCTION INDUSTRY: A SYSTEMATIC REVIEW

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ABSTRACT: *The building industry is a major consumer of natural resources and a large contributor to environmental degradation, leading to a need to rethink current building practices. Digital fabrication (Dfab) technologies, which transform design and engineering data into physical products, are gaining traction in the Architecture, Engineering and Construction (AEC) industry. This study aimed to evaluate the implications of digital fabrication in the construction industry, by identifying the current Dfab applications and the hindrances that are limiting its implementation. The research questions addressed were why Dfab is essential in the construction sector, the current state-of-the-art of Dfab in the construction industry, and how Dfab is improving the construction industry. Through a systematic literature review, the findings proposed that Dfab can revolutionize the construction sector, enabling freeform architecture, reducing construction costs, cutting material waste, and increasing worker safety. Nevertheless, further research is needed to overcome obstacles such as high costs and the lack of digital skills in the construction industry.*

KEYWORDS: *Digital fabrication, Construction industry, Project management, Digital technology, Systematic review.*

1. INTRODUCTION

The building industry is recognized as a large consumer of natural resources and a significant contributor to environmental impacts and is considered an inefficient manufacturing process (Wu, Wang and Wang, 2016). It is still working to improve the situation and boost overall productivity, but there are obstacles to overcome (García de Soto *et al.,* 2018). To address environmental challenges, there is a need to rethink conventional building models and techniques due to the predicted increase in global population in the coming decades (Naboni, Breseghello and Kaunic, 2019). To promote sustainability, the architectural profession needs to develop fully automated production forms and processes (Tuvayanond and Prasittisopin, 2023).

The ability to create objects directly from design information is causing a transformation in many fields of design and production (Agustí-Juan and Habert, 2017). The key to fostering high-quality industry growth is creating and applying digital transformation (Yuan *et al.,* 2022). The use of digital fabrication (Dfab) technologies is rapidly increasing in the Architecture, Engineering and Construction (AEC) industry (Graser, Kahlert and Hall, 2021). The "third industrial revolution," also known as digital fabrication, is anticipated to revolutionize the construction sector by allowing freeform architecture, lowering construction costs, reducing material waste, and raising worker safety (Wangler *et al.,* 2016). Dfab refers to a construction process that utilizes digital code to control manufacturing devices and processes, allowing for the seamless conversion of design and engineering data into physical products (Graser, Kahlert and Hall, 2021). Dfab is an automated fabrication method that uses data to enhance efficiency and productivity (Ng and Hall, 2021).The technology began developing more than 25 years ago, but its rapid development started later (Žujović *et al.,* 2022). The use of Digital design and fabrication technologies have created methods and processes for producing more complex and customised architectural solutions while still utilising standard building materials over the last two decades (Carvalho and Sousa, 2014). Integrating design and construction is essential for new technologies such as digital fabrication, and a specialised design management strategy is required to overcome integration barriers (Ng, Graser and Hall, 2023). Digital technology allows for better control, increased construction efficiency, the removal of the need for conventional formwork, and the ability to customise building materials during the construction process compared to traditional methods (Yuan *et al.,* 2022). The use of computational design and robotic fabrication together has the potential to bring about significant advancements in the form and structure of architecture (Agustí-Juan and Habert, 2017).

Digital fabrication necessitates a redesign of the design process. Thus, there is a need for a better understanding of digital systems in areas such as technical development, technological systems, organisational contexts, contractual provisions, and business models (Ng *et al.,* 2022). However, the use of additive Dfab in large-scale construction is still in its early stages and requires overcoming challenges in changing traditional construction processes and roles of those involved in the project (García de Soto *et al.,* 2018).

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A BIM platform is not essential for Dfab design in small-scale projects, as long as there is integration of process, information, and organisation (Ng, Graser and Hall, 2023). BIM is a cutting-edge digital system that promotes innovation and enhances project values through information integration in construction projects, which also involves changes in design management and overall best practices (Ng, Graser and Hall, 2023). Different non-destructive methodologies to capture complex shapes have been developed through the use of photographs, video-recording, laser sensors and LED light projections, demonstrating the significant advantages in speed and accuracy that these digital methods can offer compared to conventional analogue processes (Lorenzo and Mimendi, 2020). Many countries have plans to increase the proportion of construction activities carried out off-site (Kim, Cuong and Shim, 2022). However, the effectiveness of DFAB is determined by the inclusion of fabrication information and organization in the design process, which can be challenging to achieve in traditional delivery models such as Design-Bid-Build (Ng and Hall, 2021).

Project management and delivery models have shifted fundamentally due to the digitization of project information (Hall, Whyte and Lessing, 2020). The uniqueness of each construction work is due to its immobility, customization of both construction works and processes, and interdisciplinarity (Bischof, Mata-Falcón and Kaufmann, 2022). DFAB techniques combine automated subtractive, formative, or additive building methods with computational design approaches (García de Soto *et al.,* 2018). An alternative to costly and inefficient manufacturing practices was proposed through automation in construction and architecture (Tuvayanond and Prasittisopin, 2023). The limits of architectural design and production may be expanded by digital fabrication techniques (Agustí-Juan and Habert, 2017). Dfab adoption faces not only technical challenges, but also organizational and process barriers, as it involves multiple research disciplines and professions such as architects, materials scientists, roboticists, structural engineers, manufacturers, and trade contractors (Graser, Kahlert and Hall, 2021). However, there is a desire to investigate alternative methods of creating formworks using digital fabrication technology (Carvalho and Sousa, 2014).

In recent years, the intersection between digital fabrication techniques and cementitious materials has become significant (Wangler *et al.,* 2016). Digital fabrication with concrete is a newly developed and wide-ranging field that can potentially reduce environmental impact and promote industrialization in construction while meeting various construction requirements (Bischof, Mata-Falcón, & Kaufmann, 2022). Modern product creation has shifted to rely heavily on 3D printing (Agustí-Juan & Habert, 2017). Digital fabrication has been applied to the production of formworks using concrete, a significant application of this technology (Wangler *et al.,* 2016). However, in free-form, digital fabrication using concrete, accurately predicting the material's mechanical properties in its fresh state is crucial to ensure control over element deformations and overall stability during the printing process (Esposito *et al.,* 2021). Bucklin et al. (2023) describe a new construction method called the Mono-Material Wood Wall (MMWW), which employs subtractive manufacturing with digital control to enhance the functionality of wood and eliminate the need for other materials, thereby improving sustainability compared to traditional construction techniques. The impact of the fast-growing demand and regeneration rate of renewable building materials on the environment in the long term is yet to be determined despite the industry's shift towards them (Bitting *et al.,* 2022). However, using non-traditional renewable materials and developing suitable design and construction processes will be necessary for large-scale construction (Lorenzo & Mimendi, 2020).

According to Graser, Kahlert, & Hall (2021), it is crucial to reduce the time it takes to introduce new Dfab technologies to the market to speed up adoption, but this has been challenging. To successfully implement digital fabrication in the construction industry, better integration of fabrication-related information and organization into the design process is needed despite its growing emergence (Ng & Hall, 2021). Correspondingly, an increasing number of studies investigate the industry needs and strategies for adopting digital fabrication (Ng *et al.,* 2022). It is essential to research the environmental advantages of digital fabrication in architecture and construction, as it is still a developing technology, to make necessary adjustments in the early stages (Agustí-Juan and Habert, 2017). Despite extensive literature outlining its challenges, limited attention has been given to strategies employed in projects to successfully implement Dfab. The construction industry is currently focusing its research efforts on robotic fabrication, collaborative work between humans and robots, and prefabricated technologies as part of smart construction (Yuan *et al.,* 2022).

Given this, the current study determines the impact of digital fabrication on the construction industry. The study seeks to answer the following research questions:

1. Why is digital fabrication important in construction industry?
2. What is the state-of-the-art of digital fabrication related to construction industry?

3. How is digital fabrication improving the construction industry?

2. RESEARCH DESIGN AND METHODOLOGY

The analysis performed in this study identified the main research themes and categorized them based on the impacts of digital fabrication (Dfab) in the construction industry. The results may benefit other researchers as they summarise recent advancements, patterns, and potential research and innovation opportunities in the AEC sector. Based on the selected research philosophy, this study adopts a qualitative research strategy with an inductive approach. In qualitative research papers, the methods section emphasizes transparency of the methods used, such as the reasons, processes, and individuals involved in their implementation, to provide a deeper understanding and facilitate discussion of how they may have affected material's mechanical properties (Busetto, Wick and Gumbinger, 2020).

This study used the systematic literature review (SLR) method, that minimizes bias by exhaustively searching relevant studies through a systematic, transparent, and reproducible process (Chung, Lee and Kim, 2021). This study utilized the keyword search method and the snowball method to gather relevant information. In order to gather more information and discover papers that may have been overlooked, the keyword search and the snowballing technique were combined. To initiate the development of this study, the primary task was to identify the relevant keyword for retrieving research articles from academic databases. The following summary provides an outline of the process involved in this stage.

Researchers utilized the Scopus database, benefiting from its advanced search features, including filters for authors, affiliations, publication years, and document types, facilitating the discovery of pertinent and up-to-date research in specific fields. In the initial search for relevant literature, researchers employed the keyword string "[digital AND fabrication AND construction AND industry]" and obtained 300 documents. Subsequently, they applied specific restrictions, including open access availability, subject area in engineering, English language, and exact keywords "Digital Fabrication" or "Construction Industry," resulting in the retrieval of 47 documents directly related to their research topic.

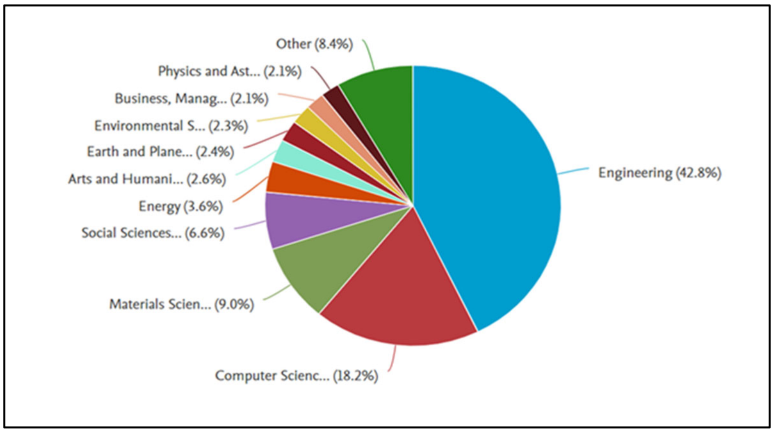

Figure 1: The distribution of documents by subject area before applying any restrictions to the search results in Scopus

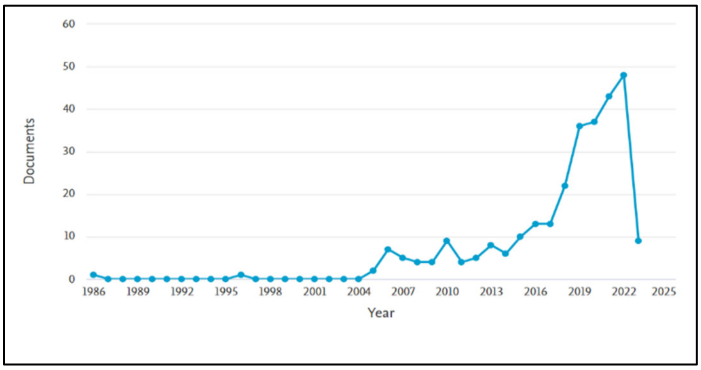

Figure 2: The distribution of documents by year before applying any restrictions to the search results in Scopus

The main objective of this section was to evaluate the appropriateness of the selected resources rather than the procedure itself. To determine eligibility, the study utilized an inclusion and exclusion approach, ensuring that only publications directly related to emerging digital fabrication in the construction industry were included. A benefit of these resources is that they contain highly relevant information pertaining to the study's topic. The researchers based their document selection on criteria that focused on the relevance of content to "Data Analysis and Management" in the most recent publications within the "Construction" field, specifically related to the use of "Digital Fabrication" in construction. Through an examination of titles, abstracts, and full texts, irrelevant documents were excluded, resulting in the selection of 27 articles that met these criteria.

The chosen resources were subject to content analysis, with most being journal articles providing comprehensive insights into digital fabrication in construction. While some sources were not directly construction-related, they still contributed to understanding the emerging digital technology. The selected studies utilized diverse qualitative or quantitative research methods, ensuring varied findings that enhance the credibility of this study concerning the research questions. Finally, the last step involved identifying the primary themes associated with the research questions.

3. DATA ANALYSIS AND MANAGEMENT

These documents' titles, abstracts, and full texts were examined to remove any irrelevant ones, resulting in 27 newly selected articles that are relevant to the study as shown in table1.

Table1: 27 newly selected articles that are relevant to the study

	Tittle	Year	Country	Source
1	Designing for Digital Fabrication: An Empirical Study of Industry Needs, Perceived Benefits, and Strategies for Adoption	2021	Switzerland	Journal of Management in Engineering
2	DFAB HOUSE: implications of a building-scale demonstrator for adoption of digital fabrication in AEC	2021	Switzerland	Construction Management and Economics
3	Digital fabrication, BIM and early contractor involvement in design in construction projects: a comparative case study	2023	Switzerland	Architectural Engineering and Design Management
4	Environmental assessment of multi-functional building elements constructed with digital fabrication techniques	2019	Switzerland	The International Journal of Life Cycle Assessment
5	Feasibility study of large-scale mass customization 3D printing framework system with a case study on Nanjing Happy Valley East Gate	2022	China	Frontiers of Architectural Research
6	Mirror-breaking strategies to enable digital manufacturing in Silicon Valley construction firms: a comparative case study	2020	Switzerland	CONSTRUCTION MANAGEMENT AND ECONOMICS
7	Multi-scale design and fabrication of the Trabeculae Pavilion	2019	Denmark	Additive Manufacturing
8	Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall	2018	United Arab Emirates	Automation in Construction

9	Teaching Target Value Design for Digital Fabrication in an Online Game: Overview and Case Study	2021	Switzerland	29th Annual Conference of the International Group for Lean Construction
10	Design for Manufacture and Assembly of Digital Fabrication and Additive Manufacturing in Construction: A Review	2023	Thailand	Buildings
11	3D Printing Technologies in Architectural Design and Construction: A Systematic Literature Review	2022	Serbia	Buildings
12	Challenges and Opportunities in Scaling up Architectural Applications of Mycelium-Based Materials with Digital Fabrication	2022	Switzerland	Biomimetics
13	A critical review of the use of 3-D printing in the construction industry	2016	Australia	Automation in Construction
14	Digital Concrete: Opportunities and Challenges	2016	Switzerland	RILEM Technical Letters
15	Digital Fabrication Technology in Concrete Architecture	2014	Portugal	32nd International Conference on Education and research in Computer Aided Architectural Design in Europe
16	Digital Fabrication for DfMA of a Prefabricated Bridge Pier	2022	South Korea	The 17th East Asia-Pacific Conference on Structural Engineering & Construction
17	Digitisation of bamboo culms for structural applications	2020	United Kingdom	Journal of Building Engineering
18	Early-age creep behaviour of 3D printable mortars: Experimental characterisation and analytical modelling	2021	Italy	Materials and Structures
19	Environmental design guidelines for digital fabrication	2017	Switzerland	Journal of Cleaner Production
20	Environmental Impact of a Mono-Material Timber Building Envelope with Enhanced Energy Performance	2017	Germany	Sustainability
21	Fostering innovative and sustainable mass-market construction using digital fabrication with concrete	2022	Switzerland	Cement and Concrete Research
22	Framework for technical specifications of 3D concrete printers	2021	South Korea	Automation in Construction
23	Identifying enablers and relational ontology networks in design for digital fabrication	2022	Switzerland	Automation in Construction
24	Rethinking reinforcement for digital fabrication with concrete	2018	Italy	Cement and Concrete Research
25	Toward Lean Management for Digital Fabrication: a Review of the Shared Practices of Lean, DfMA and dfab	2019	Switzerland	27th Annual Conference of the International Group for Lean Construction (IGLC)
26	Towards Automated Installation of Reinforcement Using Industrial Robots	2019	Sweden	2019 24th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)
27	Using Computer Vision for Monitoring the Quality of 3D-Printed Concrete Structures	2022	India	Sustainability

Figure 3 displays the distribution of chosen documents based on their year of publication, while Figure 4 illustrates the distribution of chosen documents based on the country where the research was conducted.

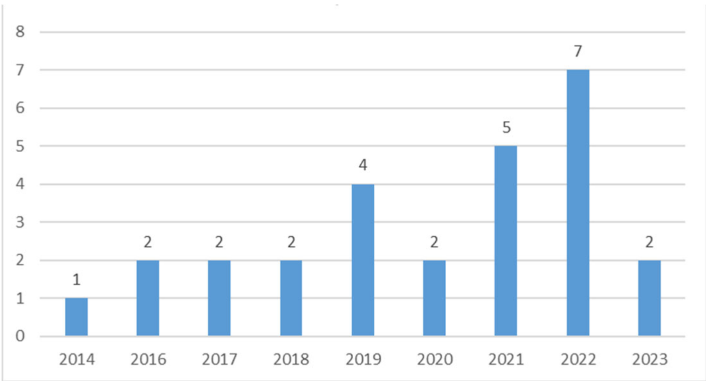

Figure 3: The distribution of chosen documents based on their year of publication

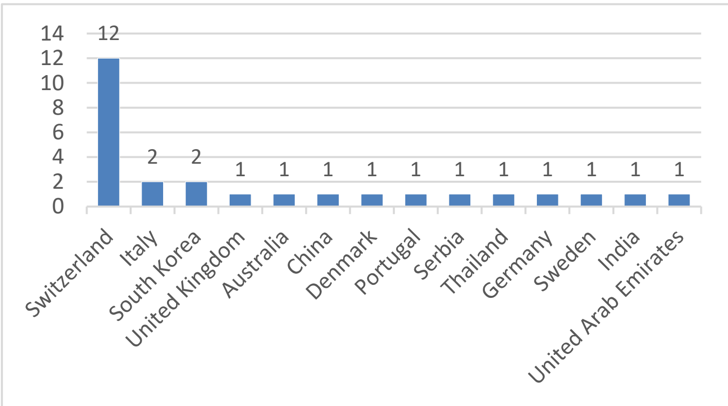

Figure 4: The distribution of chosen documents based on the country where the research was conducted

4. RESULT AND DISCUSSIONS

4.1 Qualitative Analysis and Discussion

The study aim to present an overview of the impacts of digital fabrication in the construction industry.

4.1.1 Importance of digital fabrication in the construction industry

Due to industry fragmentation, the AEC sector adopts new technologies more slowly than other sectors, but the emergence of Digital Fabrication (DFAB) offers a systematic innovation that can help with this problem (Ng, Graser and Hall, 2023). Recent studies have focused on the impact of new digital technologies like Building Information Modelling (BIM) on design management (Ng, Graser and Hall, 2023). Although a complete consolidation that outlines the factors contributing to the design process for digital fabrication is currently unavailable (Ng *et al.,* 2022). However, research on Dfab is still in its early stages. It lacks well-developed mechanisms allowing full-scale project adoption in the sector (Ng and Hall, 2019).

According to Ng et al. (2022), igital Fabrication is becoming increasingly common due to its potential to improve project efficiency by connecting design and construction processes, and it can be categorized into five groups: technological systems, organizational framework, contractual terms, and business models. Two possible approaches for dfab management are provided by lean construction management and design for manufacture and assembly (DfMA) (Ng and Hall, 2019). Adopting DFAB has many advantages, such as increased productivity and resource efficiency, reduced waste in the building industry, and increased worker safety (Graser, Kahlert and Hall, 2021).

Projects offer a distinct opportunity to investigate and add to the emerging understanding of Dfab in AEC due to their capacity to integrate complex knowledge (Graser, Kahlert and Hall, 2021). The adoption of Dfab in AEC faces significant challenges due to the industry's fragmentation, weak coordination between contractors, and high participant turnover between project phases, making the organizational and social context as important for industry adoption as technological feasibility (Graser, Kahlert and Hall, 2021). To minimize environmental impacts, structural complexity should result from material reduction strategies such as structural optimization or multi-functionality (Agustí-Juan, Jipa and Habert, 2019).

According to Agustí-Juan, Jipa and Habert (2019), Digital fabrication techniques that achieve multi-functionality lead to a construction process that is efficient in its use of materials and has significant environmental benefits during production. The on-site mass production of complex, customised structures is made possible by digital fabrication in building (Agustí-Juan and Habert, 2017). With the projected increase in global population, it is necessary to rethink traditional building methods and establish new techniques to reduce the environmental impact of the construction sector. Digital fabrication can aid in this effort by reducing material usage and overall environmental impact (Naboni, Breseghello and Kunic, 2019).

However, to make a positive change in the built environment, this mode of digital architecture is expected to work towards fully automated production forms and processes that promote equality, sustainability, democracy, diversity, and inclusiveness (Žujović *et al.,* 2022). Collaboration between structural engineers, roboticists, builders, and material scientists will be crucial for digitally fabricating concrete (Wangler *et al.,* 2016).

4.1.2 The state-of-the-art of Digital Fabrication related to the construction industry

Academic and industrial applications have explored various additive technologies in different scales and contexts, from thermoplastics to clay, gantry 3D printers to robotic arms and drones (Naboni, Breseghello and Kunic, 2019). Many researchers are looking into robotic 3D printing, a new digital fabrication technique, to address the problem of traditional building methods' declining productivity (Yuan *et al.,* 2022).

On-site digital fabrication, which aims to bring additive fabrication processes to construction sites, is divided into three main categories: large-scale robotic structures, mobile robotic arms, and flying robotic vehicles (García de Soto *et al.,* 2018). Scholarship explores the use of digital systems, such as BIM platforms that can help stakeholders coordinate the management data, including 3D models and algorithms that link to digital fabrication (Ng *et al.,* 2022).

The data from the researched case study by Graser, Kahlert and Hall (2021) indicates that implementing DFAB projects can increase its acceptance as a legitimate practice in AEC. However, for DFAB adoption to be successful, it needs to be accepted not just within the project organization but also outside it. Large-scale AM machines are being used to construct recent architectural projects globally, which has sparked a growing interest in implementing and expanding the technology within the construction industry and architecture (Tuvayanond and Prasittisopin, 2023). A study by Bitting et al. (2022) provides an overview of the current state of research and applications of mycelium-based materials, emphasizing digital fabrication, production, and design and discussing issues such as low mechanical properties and the absence of standardized production methods. The use of digital design information to drive production processes, such as 3D extrusion printing, CNC machines, and robotic assembly, is known as digital fabrication, and it is an essential component of modern construction processes (Ng *et al.,* 2022).

Wu, Wang and Wang (2016) explored the significance of component design about 3D printing capabilities and raw material performance and the potential benefits of using BIM to support design variations and improve performance, while also reducing the time and costs associated with design changes and reprinting.

Despite the potential advantages of automation, there have been few cases of robots being used to automate construction in recent years (Relefors *et al.,* 2019). The prefabricated bridge construction process has used DfMA, a design method commonly used in manufacturing manufacturing (Kim, Cuong and Shim, 2022). Digital fabrication techniques can be categorized into subtractive methods such as milling and cutting, and additive methods such as 3D printing, which has become increasingly popular and accessible for home use (Agustí-Juan and Habert, 2017).

Bischof, Mata-Falcón and Kaufmann (2022) assert that widespread adoption of digital fabrication in the construction industry is critical to making a meaningful impact on improving its environmental impact, but currently, it has not yet reached the mass market. Chung, Lee and Kim (2021) point out that despite the rapid expansion of research and market for 3D concrete printing (3DCP), there is a lack of a widely accepted technical specification framework for comparing 3DCPs with various characteristics. Despite automation initiatives in both research and industry, such as Built Robotics and MX3D, the construction industry has not yet demonstrated a shift towards automation (Relefors *et al.,* 2019).

4.1.3 How Digital Fabrication improves the construction industry

Digital fabrication has the potential to bring about extensive positive impacts, such as improved material efficiency and waste avoidance, reuse of materials, workplace health and safety, integrative work design, and productivity (Graser, Kahlert and Hall, 2021). The integration of digital and manual tasks was crucial for the project, and there was a need for better collaboration processes with digital machinery (Graser, Kahlert and Hall, 2021). The productivity rate for robotic construction is constant, which means it doesn't depend on the complexity level of the construction (García de Soto *et al.,* 2018). Concrete 3D printing reduces waste production by 60%, construction time by 50-70%, and labour costs by 50-80%, potentially decreasing construction costs by up to 35% while improving the industry's sustainability (Senthilnathan and Raphael, 2022).

To promote sustainable development opportunities through the use of digital systems, design modeling with parametric modeling capacity can be utilized to minimize rework and waste by testing the feasibility and soundness of integrated digital twin models through physical mockups prior to tendering (Ng *et al.,* 2022). Despite being promoted in various countries, there is a lack of consistency and diversity in stakeholder perspectives and research advancements regarding the implementation of digital fabrication, with interdependencies between industry needs creating complexities for stakeholders to adopt such projects, further hindering their adoption on a larger scale, highlighting the need for a better understanding of industry practitioners' needs and how they are related to one another (Ng *et al.,* 2022).

According to the research by Ng and Hall (2021), Target Value Design (TVD) implementation can help manage and optimize DFAB processes to meet time, cost, profit, and aesthetic requirements in less time while maintaining the needs of stakeholders. The conventional Design-Bid-Build model's separate processes can impede the implementation of digital fabrication techniques by making it difficult for stakeholders to manage project costs (Ng and Hall, 2021). Digital fabrication is anticipated to result in a more sustainable construction industry by enabling more efficient structural design that uses materials only where necessary and by reducing waste generation through more efficient construction techniques, particularly about formwork (Wangler *et al.,* 2016).

5. RECOMMENDATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The impacts of digital fabrication in the construction industry are still an area that requires further research. Several recommendations and directions for future research can be made based on the reviewed literature. One area that requires investigation is the potential economic benefits of digital fabrication in construction projects. Future studies could conduct a cost-benefit analysis to provide a clearer understanding of the potential economic benefits that could be achieved by implementing digital fabrication in the construction industry. Another area that requires exploration is the potential environmental benefits of digital fabrication in the construction industry. Future studies could focus on the potential environmental benefits that could be achieved through digital fabrication in the construction industry, such as reducing waste and carbon emissions. In addition, future research could investigate the best strategies for implementing digital fabrication in the construction industry. This could include examining the barriers to adoption, identifying practical training and education programs, and exploring the potential role of government policies and incentives. The reviewed studies provide valuable insights into the impacts of digital fabrication in the construction industry. They are applicable in various areas within the field, including but not limited to construction management, architecture, and engineering. For example, the studies provide insights into the potential benefits of digital fabrication in terms of cost, time, and quality management in construction projects. They also provide insights into the potential for digital fabrication to revolutionize the design and construction of buildings and other structures, as well as improve the efficiency and effectiveness of engineering processes in the construction industry.

One potential research question that could be addressed in future studies is: What are the best strategies for overcoming the barriers to adoption of digital fabrication in the construction industry? This question would be designed to address the identified need for research on implementation strategies and could help to provide insights into how digital fabrication can be successfully integrated into the construction industry.

6. CONCLUSION

The research on the impacts of digital fabrication in the construction industry highlights the potential benefits and challenges associated with adopting this technology. Through a systematic literature review, the study explores the current state of digital fabrication (Dfab) in construction, its significance, and its potential to improve the sector.

The study's extensive research has provided valuable insights into how digital fabrication could bring about a revolution in the construction sector. Firstly, Dfab enables the creation of intricate and customized structures that were previously impossible using conventional methods, thus offering new possibilities for innovative and sustainable designs that can shape the industry's future. Secondly, Dfab has the capacity to substantially lower construction costs and minimize material waste, thereby boosting efficiency and contributing to resource conservation, a crucial factor for environmental sustainability. Additionally, the adoption of Dfab could enhance worker safety by automating hazardous tasks and reducing the necessity for manual labor in risky conditions. Despite the intriguing benefits, the study has brought to light the difficulties that prevent Dfab from being widely used in the building industry. To effectively utilise the promise of digital fabrication, significant barriers such as high starting prices and a lack of digital expertise in the market must be overcome. Also, there are organisational and operational challenges when incorporating Dfab into conventional building processes and delivery models, which emphasises the necessity of communication and cooperation across many disciplines.

The qualitative analysis conducted in this study highlights the importance of seamless integration and collaboration among various stakeholders, such as architects, engineers, roboticists, and material scientists, for the successful deployment of Dfab technologies in the construction industry. Furthermore, the adoption of digital fabrication calls for a comprehensive redesign of the design process, considering technical development, organizational contexts, contractual provisions, and business models.

This study was limited to academic journals, articles, and conference proceedings found in the listed scientific sources. Following an inductive methodology that only used secondary data, the qualitative analysis and discussion were conducted. Primary data, however, might have provided a more in-depth and analytical grasp of the subject.

The study recommends further research to investigate the economic and environmental benefits of implementing Dfab in construction projects. Additionally, it emphasizes the need to identify effective strategies for overcoming barriers to adoption to ensure successful integration.

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