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OVERCOMING THE BARRIERS TOWARD WIDESPREAD ADOPTION OF PREFABRICATION: AN APPROACH INVOLVING EMERGING TECHNOLOGIES

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ABSTRACT

Today, prefabricated construction is rapidly expanding due to the development of factory-prefabricated components, fast construction site assembly, and sustainability. Despite the advantages, there are several problems, such as a lack of process standardization, poor communication and coordination, a lack of variety and transportation logistics, and a lack of trust and collaboration among stakeholders. Fortunately, the successful evolution of emerging technologies has facilitated growth in the building sector. By implementing literature reviews, this research aims to understand better the issues disrupting the widespread adoption of prefabricated construction and integrate innovative solutions and approaches to these issues. We will discuss prefabricated construction and its applications within the building sector by (1) comparing it to conventional construction method; (2) investigating the advantages and barriers toward widespread adoption of prefabricated construction; (3) developing an approach for applying advanced technologies in prefabrication, and (4) applying an approach to demonstrate how prefabrication overcomes conventional building issues. Our research suggests that an integrated approach combining advanced technologies during the prefabrication process will help solve the most significant problems that construction projects face, such as productivity, quality, safety, and sustainability. Additionally, the integration will provide a promising strategy to transform the construction industry from traditional to industrial.

KEYWORDS

Prefabrication, modular construction, off-site construction, Building Information Modeling, Blockchain.

INTRODUCTION

Modular or prefabricated construction is one of the advancing breakthroughs in the construction industry (NIST, 2015). However, the outcome could be more encouraging due to a lack of standardization, poor communication, a lack of collaboration among stakeholders, and the complexity of transportation logistics (Z. Zhang et al., 2022). One of the main reasons that holds back the advancement and widespread application of modular construction is the need for more standardization (Razkenari et al., 2020). However, most modern buildings attempt a complex and innovative design. These designs need further preparation and customization (Eastman et al., 2011). Due to their lack of industry experience, most modular construction companies need assistance learning what is required on-site and how to proceed throughout the manufacturing

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phase. Moreover, there are several contracts because of the complexity and the many stakeholders involved in prefabrication (Razkenari et al., 2020). Also, their complexity has created confusion over time. The builders and suppliers keep facing their challenges and creating coordination and trust is a new challenge.

An answer to the need for coordination and trust among stakeholders in traditional construction practices has been the Integrated project delivery (IDP) method, along with a single Smart contract between various stakeholders. The same approach can be applied to solve a distinct set of problems in the modular construction approach since the foundation of these problems still needs coordination and trust among stakeholders. Technology such as BIM is commonly used to design projects. However, one critical approach is integrating the supplier and design teams right from the start so the feasibility of building the prefabricated blocks can be quickly done. The complexity of numerous contracts has limited each stakeholder's capacity and left no space for transparency. A single contract signed by all suppliers and builders prior to the start of the project is one solution.

Among construction technologies, BIM and Blockchain stand out as reliable and complete methods in construction because it is a potential instrument that helps stakeholders understand the advantages of prefabricated construction, allowing them to have better control. In conducting this review, this research attempts to answer the following key questions:
RQ1: What is the current state of prefabricated construction in research-related fields?
RQ2: What are the advantages and barriers of prefabricated construction compared to traditional building methods in terms of advanced technologies?
RQ3: What are the technological advancements or solutions in prefabricated construction from a research perspective?
RS4: How might emerging technologies promote prefabricated construction from a research standpoint?

The successful approach and widespread adoption of technology in prefabricated construction are the most promising strategies for transforming the construction mode from traditional to industrial. The purpose of this research is to examine the current barriers that are holding the prefabricated construction approach back and to bring solutions to those challenges using innovative technologies such as BIM and Blockchain. The authors hypothesize that advanced technologies assist in problem resolution in prefabricated construction.

METHODOLOGY

The authors conducted a literature review to find relevant data on the uses of emerging technologies as a solution to the barriers toward the widespread adoption of prefabrication. This study's methodology provides a set of data analyses to present the qualitative approach through concepts, experiences, and insight into scholarly publications. Initially, data was gathered from a variety of sources. The original search keywords are prefabricated construction, modular construction, off-site construction, emerging technology, Building Information Modeling, BIM, Blockchain, etc. The initial literature review identified research gaps and emerging trends in the construction industry's relevant modular or prefabrication topics. This step helped the researchers become familiar with the current state of knowledge and the constraints of a particular topic.

Additionally, the literature review attempted to answer the research questions raised below about applying technologies in prefabrication. The study provided basic knowledge on the uses of emerging technologies to solve the challenges in the prefabricated construction method and developed an approach for the data analysis. The research approach was used as a filter in the decision support framework, which will assist researchers in choosing technology for review. Lastly, the research applied the integrated approach for the applications of advanced technologies jointly to the prefabrication methods as a solution to the challenges that are consequences of the traditional construction methods, including BIM and Blockchain. The study delivered a research concept schema or a roadmap for academic researchers to analyze and discuss technologies using the suggested approach.

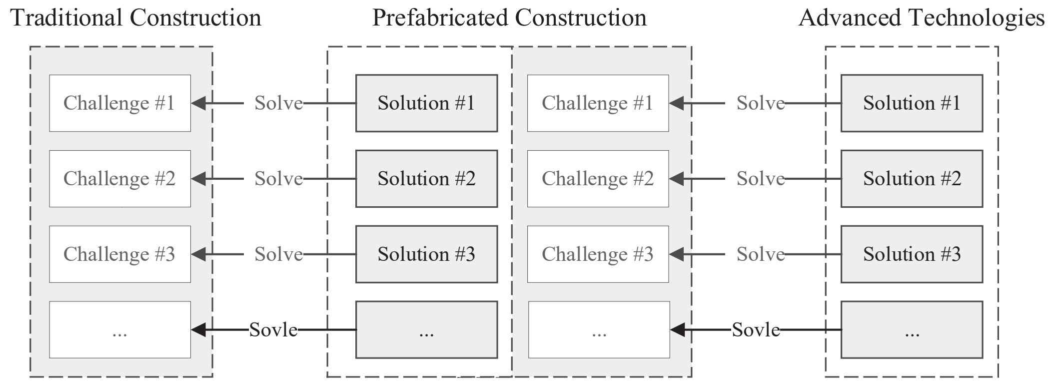

Figure 1: Proposed research conceptual schema

RESEARCH BACKGROUND

Several problems occur in the traditional construction method, one of them being sustainability, as 2.2 billion tons of construction waste are generated globally, of which 600 million are in the USA (*BigRentz*, 2021). Nearly 30% of all material delivered to the site ends up in the landfill. Construction costs rise, delays occur, and 98% of all construction projects incur cost overruns or delays (Tafesse et al., 2022). Time delays, productivity, and weather account for 60% of cost overruns (*Weatherbuild*, 2018). Safety is one factor that needs to be thoroughly enhanced regularly on the construction site, and it does not depend on physical health but on mental health. Noise pollution is abundant; 51% of all construction workers have experienced dangerous noise exposure, and approximately 14% of laborers have a hearing impairment (NIOSH, CDC, 2021). Construction methods and techniques also change with the seasons, so construction relies on clear weather; therefore, workers' livelihoods depend on weather conditions (Myers & Swerdloff, 1967). Longevity also plays a role, as it is easier to tear down than to renovate at the final phase of a structure's life, and it is harder to control quality (Tavares et al., 2021).

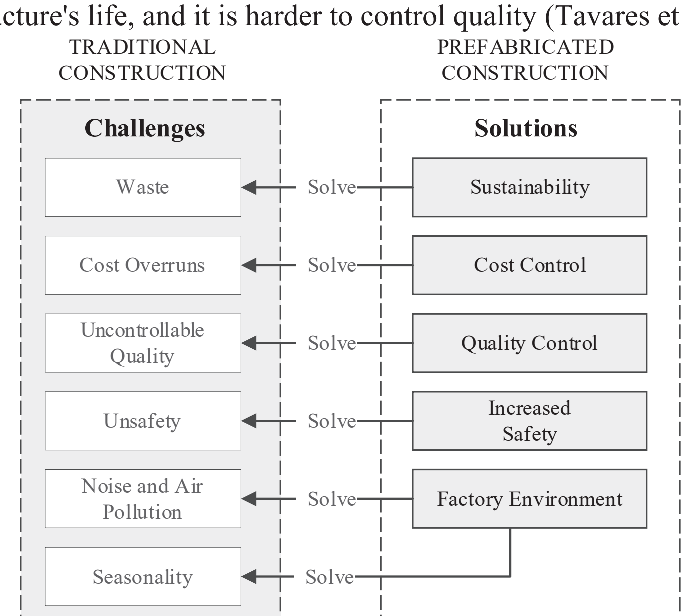

Figure 2: Traditional methods versus Prefabrication

Accordingly, the study suggests using prefabrication or modular construction to address these problems (Figure 2). The advantages of the modular method are quality assurance and predictable outcomes (S. Wu et al., 2022). Due to this factory environment, there is a reduction in noise and air pollution in the surrounding community, a smaller site footprint, and less material stored at the factory. We can work in any weather condition (Wilson, 2019). The costs are also reduced as they decrease by combining factory and site activities. Doing that can reduce the project duration and site assembly time. There is also a reduced labor requirement, which improves productivity (Zadeh et al., 2018). Safety also increases as there is better control of dangers to health and safety in an industrial environment, a 63% overall reduction in safety accidents, and a reduced chance of fall-related injuries (*Chubb North America*, 2020). Finally, wastage reduces as there is 52% less construction waste, 44% less energy consumption, and 9% less contribution to global warming (Z. Wu et al., 2021).

LITERATURE REVIEW

While prefabricated construction has numerous benefits, this practice still needs improvement and has some issues. They need more standardization in the process, which means more familiarity and expertise to implement prefabrication. Prefabrication demands accurate and trustworthy data as well as increasingly automated equipment. There needs to be better communication and coordination than there has historically been. There needs to be more cooperation between builders and their suppliers, and a lack of communication with vendors of off-site prefabrication requires risks of unanticipated expenses and flaws. All supply chain participants and companies should have (Lopez et al., 2022). Traditional construction gives us beautiful and aesthetic buildings, and there is a lot of variety in modular construction that needs more variety because complex designs involve more planning and custom designing. Everything is restricted to what can fit on a truck (Eliwa et al., 2020). Transportation also disturbs the smooth working flow of prefabrication, as difficulties arise from the movement of prefabricated components to prevent storage issues and idle time; fabricated parts need to be delivered only in order to prevent the supply chain from becoming more complex (Stroebele & Kiessling, 2017). Finally, stakeholders need more trust and collaboration because supplier companies typically carry the most risks, and factory follow-ups and performance monitoring are often done improperly. A systematic performance measurement system and real-time analysis are necessary to analyze and continually improve the manufacturing process due to the complexity of prefabrication, the significant number of stakeholders engaged, and the number and complexity of contracts (Chen & Samarasinghe, 2020).

Furthermore, Z. Zhang et al. (2022) successfully reflected the recent changes in the Australian prefabrication industry in particular and explored the benefits and challenges of implementing prefabrication from industrial perspectives globally.

Table 1: Benefits and challenges shared by academia and industry interviews, adapted from Z. Zhang et al. (2022)

	Benefits/ Solutions	Challenges
1	Time saving	Cost inefficiency
2	Better quality	Lack of skilled workforce
3	Energy saving	Lack of standardisation
4	Improved construction safety	Transportation & logistics issues
5	General cost benefits	Misconceptions
6	Reduce on-site work and labour	Inflexible for design change
7	Reduce on-site construction waste	Market demand
8	Addressing skills shortage	Site access
9	Lower production cost	Lifting safety

10	Less disruptive to neighbours	Protection during transportation
11	Relief housing demand	Compliance and inspection
12	Waste recyclability	Lack of automated adoption
13	Material saving	Bankability
14	Light weight of prefab. materials	Moisture control
15	Increase project certainty	Fire, thermal and acoustics testing
16	---	Payment process

Note: Table 1 showed summary results of the industry's perspectives on the challenges of using prefabrication. It provided a valuable reference for all parties in the prefabrication supply chain, to update their knowledge or understanding of the barriers toward widespread adoption of using prefabrication and their corresponding recommendations.

Through a literature review and interviews, Z. Zhang et al. (2022) classified the significant challenges into eight aspects related to feasibility, design, manufacturing, transportation, on-site construction, standardization, skills and knowledge, finance, and market. The authors summarized recommendations to tackle these barriers, particularly in adopting digital technologies in prefabricated construction. The application of cloud-based technology, the Internet of Things (IoT), BIM, and Blockchain, has been proven effective in improving information exchange, reducing uncertainties during logistics, and therefore improving the schedule performance of prefabricated construction. The findings could help local industries and governments develop roadmaps and policies promoting prefabrication. Similarly, Jin et al. (2018) implemented a holistic review approach incorporating bibliometric search, "*scientometric*" analysis, and in-depth qualitative discussion for reviewing and summarizing off-site construction literature published between 2008 and 2018. The authors proposed a framework to link current research areas in off-site construction to future research directions. The study found that sustainability, standardization, safety, and productivity are the performance measurements of prefabrication projects. Supply chain management, standardization, automation, fragmentation, and logistics are project delivery processes for off-site construction, considering the life cycle assessment approach. At the same time, the inclusion of multiple stakeholders and project parties in the design stage of a modular project is regarded as critical in some social and cultural contexts. The readiness of stakeholders to adopt off-site construction within a specific country or cultural context is crucial, as well as global cross-country comparisons. This review-based study provided both academic and practical implications. Scholarly, this study added to the body of off-site construction knowledge by focusing on developing off-site construction research in the last decade.

With the potential of applying digital technologies, the construction industry is at the point of a transformation driven by prefabricated construction. However, based on the detailed literature review, the authors have explored common challenges while implementing prefabricated construction. Some of the identified barriers include (a) lack of design, (b) lack of standardization, (c) poor communication and coordination, (d) transportation and logistics issues, and (e) lack of trust and collaboration among stakeholders.

Generally, the current research on prefabricated construction focuses on improving technology and addressing the barriers to the widespread adoption of prefabrication and its opportunities. The current studies aim to solve the challenges of prefabricated construction by applying BIM and Blockchain technology in different applications. However, combining these two technologies to collectively solve the challenges faced in the widespread application of modular construction is a new approach. Moreover, the values of integration and "*building trust among all the stakeholders*" from integrated project delivery are enforced by involving various suppliers, builders, architects, fabricators, engineers, and transporters right from the beginning. In such a case, the feasibility and duration of each sub-procedure can be accurately calculated.

Also, allowing them to coordinate through a Blockchain setup sets the steppingstone for developing a culture of trust and coordination.

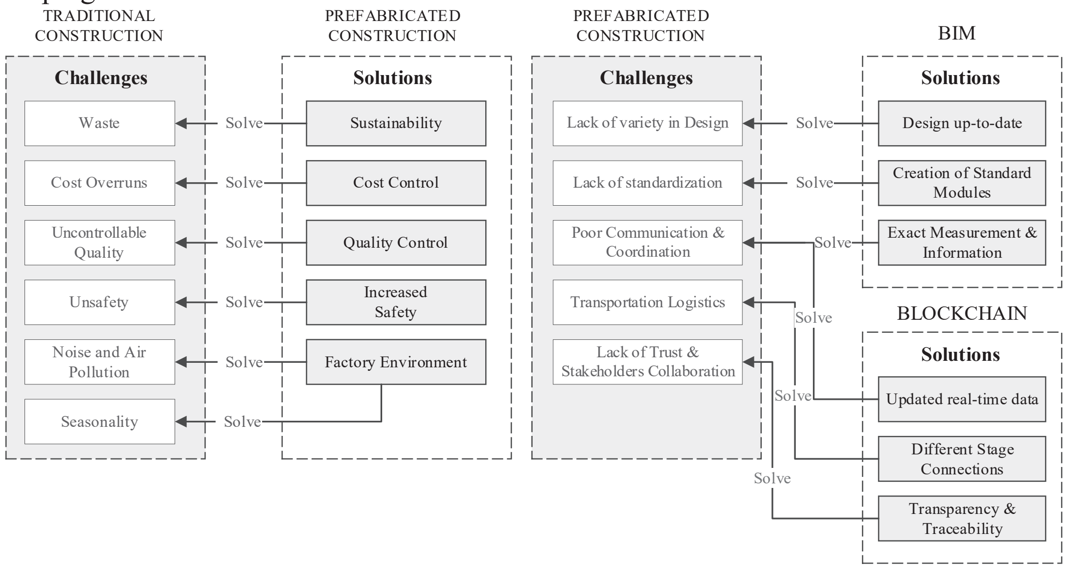

Figure 3: Proposed research conceptual schema to address the barriers toward widespread adoption of prefabrication in literature review.

DISCUSSIONS

Building Information Modeling (BIM) and Blockchain are emerging technologies that have the potential to advance prefabricated construction significantly. In combination, BIM and blockchain have the capability to greatly enhance the efficiency, quality, and transparency of modular construction, leading to improved outcomes for construction stakeholders. By leveraging these technologies, prefabricated construction can become more reliable, efficient, and cost-effective, making it a more sustainable option for a broader range of projects.

This section presents the relevant data found in the literature on the uses of BIM and Blockchain to aid the problems commonly raised in the prefabrication method.

BUILDING INFORMATION MODELING (BIM)

Originally, it took a remarkably long time for BIM to displace its predecessor, which at first started with hand-drafting, computer drafting, computer-aided design (CAD), and other computer-based systems. BIM is technically designed to increase information integration among project stakeholders significantly. Integrated information is the foundation and the source of integrity and insight, which allows an integrated team to make the best decisions for the project. By using visualization as a platform, BIM can help an integrated team create the aesthetics of a design and interpret the values of the building's owner and end users. Simulation is another primary use of BIM, which allows teams to evaluate alternative designs and strategic interventions to reduce risks and negative impacts. In addition to monitoring the initial cost, the team can now analyze energy consumption, workflow, natural light, and previously unmeasurable values like "*openness*" and "*connectedness*" (Martin Fischer et al., 2017). The Architecture, Engineering, and Construction (AEC) industry continues to push forward to build quicker, smarter, and more efficiently. As a result, using BIM has become crucial to achieving these goals of creating structures in a shorter timeframe while maintaining safety and sustainability. BIM is used in the world of prefabrication to make this construction more precise and efficient. While prefabrication has its issues, such as a lack of variety, standardization, and communication, BIM can be used as an effective method to ensure these issues are addressed and avoided.

BIM offers the unique ability to design with the intention of prefabricated, allowing for designs to be specified and designed around how they are to be sent directly to the shop and then from the shop to the site (Jang & Lee, 2018). In most cases, construction projects include errors only discovered once they are already on site due to a lack of communication between the AEC parties. Using BIM, these errors can be discovered quickly and designed in a way that they can visualize the building components, identify clashes, and then create shop drawings that either compensate for or fix the issue. This saves a tremendous amount of money in the later stages of construction when time is a crucial aspect of the project. To truly earn the benefits of BIM in prefabrication, the total collaboration between the architects and subcontractors is crucial to creating efficient prefabricated parts that include all the necessary mechanical, electrical, and plumbing (MEP) for the intended prefabricated structure. In the case of the 500,000 ft2 Miami Valley Hospital, a 12-story addition was added using prefabricated modular bathrooms, casework, headwalls, and workstations (*Architecture | NBBJ*, 2012). Architects worked countless hours with different MEP contractors, nurses, managers, and more to find the most efficient design while creating a usable and effective space. It was estimated that using this method increased productivity by 300% and saved more than two months off the 30-month project total. BIM helped achieve these feats by allowing the architects to find ways in which parts of the overall model could be designed for prefabrication and fit onto the truck for transportation.

BLOCKCHAIN

Blockchain has been around for a couple of years; however, its use within the construction industry has yet to be fully utilized. The use of Blockchain within prefabrication offers the AEC industry vital support in notarization-related applications to reduce the time for authenticating documents, transaction-related applications to facilitate automated procurement and payment, and source-related applications to improve the transparency and traceability of construction supply chains (Li et al., 2021). These solutions greatly help reduce typical issues within prefabrication, such as collaboration between multiple parties, shipping planning, and trust/ stakeholder collaboration. The Blockchain is a mode of Distributed ledger technology (DLT) where all the processes of business or construction can be verified and uploaded. It acts as a distribution network where no single authority is needed to maintain the verification of involved parties, giving stakeholders complete access to track construction history and check the recorded data conveniently (Li et al., 2021). Because of its highly trustworthy database, the Blockchain allows massive construction data to be kept impartially; in other words, an extensive range of information may be used in a traceable, secure, and sustainable manner (Li et al., 2021). We can then use Blockchain to create and automate various parts of the prefabrication process. An event completion, whether that be material arrival at the fabrication facility or completion of the fabricated item, would then trigger the next step within the automated contract to begin quality checks, time recording, payments, and so on. Within the supply chain, prefabrication can be difficult in terms of tracking regarding the status of the condition or location of the designated object. Blockchain offers the ability to track smart construction objects (SCOs) through their sensing, processing, and communicating capacities to facilitate information exchange among various construction resources (Lu et al., 2021). By attaching a Radio-frequency identification (RFID) or Quick response (QR) code to these SCOs, we can create checkpoints along the supply chain that automatically track these objects and update the Blockchain contracts with relevant and accurate data regarding the positioning and status of prefabricated items. Figure 4 shows a detailed SCO plan for construction processes with two types of models (Lu et al., 2021), which are model 1: a low-energy, single GPS sensor for location-based service in off-site logistics and model 2: high-frequency multiple motions and environmental sensors for off-site production and on-site assembly.

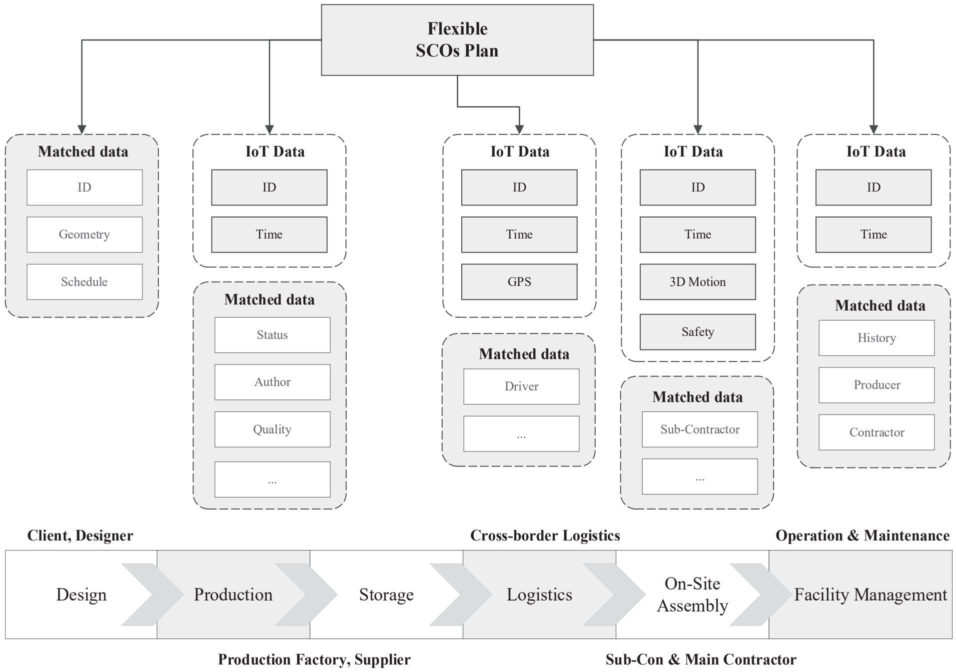

Figure 4: An SCO plan for construction processes: Off-site production, logistics, and on-site assembly services, adapted from Lu et al. (2021)

RESULTS & FINDINGS

The challenges or barriers mentioned earlier still exist in the prefabricated construction method. Figure 5 below illustrates how each of those five issues could be solved by implementing an integrated approach using BIM and Blockchain technologies during the prefabrication process.

First, the lack of variety is caused by complex designs requiring more planning and custom design with size restrictions so that the prefabricated fragments can fit in the truck for transportation (Eliwa et al., 2020).

Second, the lack of standardization in the prefabrication process demands more precise and trustworthy data, as well as more automated machinery (Rose Morrison, 2021). There is also a need for more familiarity and expertise in implementing prefabrication because workers need to be able to create documents accurately and efficiently. Using BIM helps analyze constraints to give maximum efficiency in designing project fragments that can be prefabricated and fit on a truck. It allows for the prefabrication of sophisticated systems such as irregular exterior paneling and MEP modules (Jang & Lee, 2018). BIM helps analyze the exact data, providing the exact measurements of the fragments the subcontractor requires for module prefabrication.

Third, poor communication and coordination are common among builders and their suppliers. BIM reduces discrepancies in a final model among both designers and manufacturers, shrinking the procurement schedule as an embedded BIM execution plan can facilitate design cooperation from the start of a project and any required adjustments or modifications on a model that can be incorporated before the proper production phase without adversely affecting the project and product duration and quality (Mostafa et al., 2020). Also, to aid the poor communication and coordination among stakeholders, Blockchain technology allows multiple shareholders to obtain smart connected product (SCP) status data in real-time while linking various stages, responding quickly to worrying occurrences, and reducing energy consumption (Li et al., 2021). Furthermore, by combining Physical asset tracking (PAT), Digital asset management (DAM), and Distributed ledger technology (DLT) contracts through apps, industry partners may leverage a variety of (current or unique) asset tracking and management systems and link them to smart contracts and Blockchain technology (van Groesen & Pauwels, 2022). Organizations are able to pre-set prerequisites on the Blockchain that allow customers to effortlessly engage in the Smart product-service systems (SPSS) chains for (1) notarization-related implementations to shorten the amount of time required for document authentication; (2) money transfer applications to support automated sourcing and payment; and (3) authenticity applications to enhance the traceability and transparency of construction supply chains (Li et al., 2021).

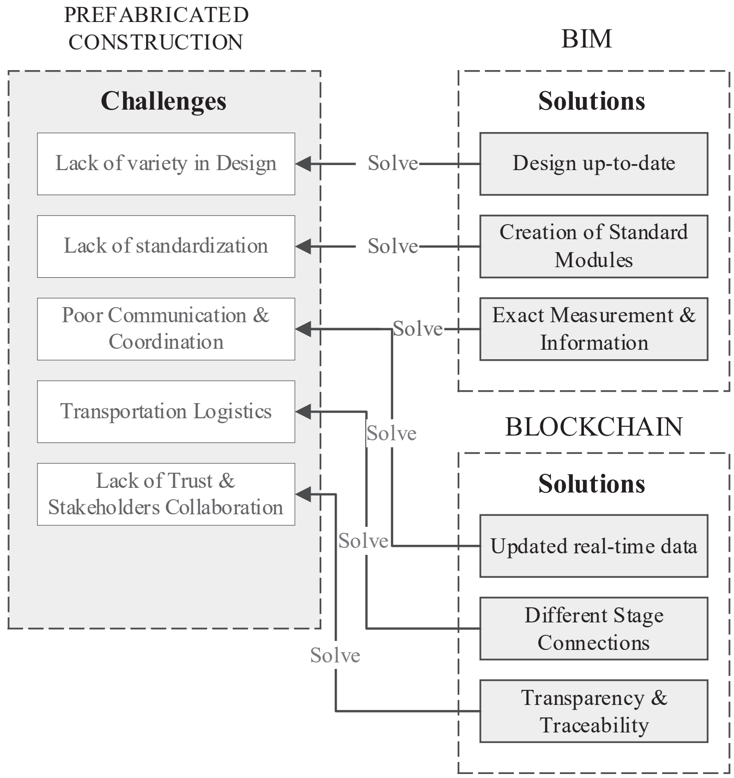

Figure 5: BIM and Blockchain technologies to aid Prefabrication challenges.

Fourth, transportation logistics in the prefabrication process are essential given the difficulties of transporting prefabricated components, such as reduced waiting time and warehousing concerns since the fabricated parts must be shipped just-in-time to prevent further intricacy within the actual supply chain (Stroebele & Kiessling, 2017). Lastly, the lack of trust and collaboration between stakeholders is quite common in the prefabrication construction method, given that, typically, supplier firms bear most of the risks and the need to effectively handle performance appraisals and follow-ups in the production process. The number of complex agreements is also impressively large due to their intricate nature and the many stakeholders engaged in prefabrication. A precise performance evaluation and real-time analysis system are required to monitor and constantly improve the manufacturing process (van Groesen & Pauwels, 2022). Blockchain technology creates traceability and transparency in a collaboratively managed register; its usage diminishes miscommunications and disputes among relevant parties; and it automates the evaluation of advancement and conformity to contractual responsibilities in arranging individually manufactured parts via geographic data tracking technologies. Additionally, QR Codes may be used to track the status of manufactured elements utilizing a mechanism of *"fabricated," "delivered," "ready for assembly," "assembled," "ready for verification,"* and "*verified*" (van Groesen & Pauwels, 2022).

Apparently, the widespread adoption of BIM has been considered a strategy to accelerate the growth of prefabricated construction following decades of slow advancement in the industrialization of construction (Bimal Patwari and Scott Pittman, 2022). The findings reveal potential solutions when applied to construction projects. BIM can address these challenges and provide technical support for the growth of prefabricated construction. Using Blockchain and Smart contracts in prefabrication improves supply chain transparency and traceability in automated procurement, payment, and document authentication. Thus, the construction industry has benefited from advanced digital technology, and the combination of BIM and Blockchain technology within the construction context will discover more benefits of prefabricated construction presently. It is suggested that BIM will help solve the most significant problems that prefabricated construction projects confront now, such as Lack of design and standardization, poor communication and coordination, transportation and logistics, and Lack of trust and stakeholders' collaboration.

FUTURE RESEARCH

This paper presents the investigations and literature review findings in the prefabrication field of the construction industry. Even though there have been few implementations of Blockchain in the construction sector, the study predicted that there would be significant benefits for latecomers. The many advantages of combining Blockchain with BIM were emphasized. Future research is needed to expand and enhance the application of innovative technologies in prefabrication, such as construction 3D printing (C3DP), Virtual reality (VR), Augmented reality (AR), and the Digital twin (DT). In addition, several current techniques or approaches are being considered for the integration of advanced technologies into prefabricated construction, such as Cloud-based computing, which stores data generated by BIM; integration platforms like BIM360; collaborative workflows as Integrated Project Delivery (IPD); Machine learning, and Artificial Intelligence (AI) which are being used to automate and optimize processes. Developing and implementing new technologies in the prefabrication industry that address supply-chain issues, safety concerns, and management challenges is necessary. There should be a need for suitable research methodologies to integrate various other technologies to ease the use of prefabrication in the construction industry, keeping the industry's traditional approaches in mind. In general, using advanced technologies in prefabricated construction offers many potential solutions but presents significant challenges that must be overcome to realize its potential fully.

CONCLUSIONS

This research contributes to the body of knowledge by addressing the barriers to the widespread adoption of prefabricated construction projects and developing an integrated approach for applying advanced technologies to the prefabrication process. Our research suggests that an integrated approach combining BIM and Blockchain technologies during the prefabrication process will help solve the most significant problems that prefabrication projects face, such as a lack of design, a lack of standardization, poor communication and coordination, transportation and logistics issues, and a lack of trust and collaboration among stakeholders' collaboration. Together, BIM and Blockchain can help to streamline the prefabricated construction process in terms of design up-to-date, the creation of standard modules, exact measurements, and information, updated real-time data, different stage connections, transparency, and traceability. Most significantly, the approach proposed in our research advanced the prior works by proposing a conceptual schema for addressing each problem highlighted in previous studies. In addition, this research demonstrates how prefabrication addresses challenges associated with traditional construction and how the challenges associated with prefabrication can be addressed through our proposed integrated approach involving technologies. This study benefits professionals and academics by providing a framework for comparative analysis and investigation into the benefits and drawbacks of various approaches. Although modular or prefabricated construction has a long history, adoption remains remarkably slow. After decades of limited development in the industrialization of construction, the widespread adoption of innovative approaches and emerging advanced technologies is now seen as a viable approach to accelerating the growth of modular construction in the near future.

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