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Integrating modular and prefabricated construction techniques in affordable housing: Architectural design considerations and benefits

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Abstract

This review paper examines integrating modular and prefabricated construction techniques in affordable housing, focusing on architectural design principles, benefits, and case studies of successful implementations. The research highlights the core principles of modular design, including flexibility, scalability, and standardization. It explores prefabrication methods emphasizing efficiency and sustainability. The study underscores the significant advantages of these techniques, such as reduced construction time, cost savings, and the ability to maintain or enhance quality and durability. Through an analysis of case studies, the paper identifies key lessons learned, including the importance of early planning, quality control, and flexibility in design. The conclusion discusses the challenges in widespread adoption, such as regulatory barriers and public perception, while suggesting future research areas and practical recommendations to integrate these methods further into affordable housing. The findings suggest that modular and prefabricated construction holds significant potential to address the global affordable housing crisis by providing high-quality, cost-effective, and rapidly deployable solutions.

Keywords: Modular Construction; Prefabricated Housing; Affordable Housing; Architectural Design Principles; Cost Efficiency

1 Introduction

The global affordable housing crisis presents a significant challenge for policymakers, developers, and communities (Ebekozien, 2020). The demand for affordable housing has escalated, driven by rapid urbanization, population growth, and economic disparities. According to the United Nations, approximately 1.6 billion people live in inadequate housing conditions, expected to rise as urban populations swell. This growing demand has strained traditional construction methods, often involving lengthy timelines and high costs, making it difficult to meet the urgent need for affordable homes (Coupe, 2021).

Conventional construction techniques, while time-tested, are increasingly being viewed as insufficient to address the current housing shortage. These methods are time-consuming and prone to cost overruns and delays, which can further exacerbate the affordability crisis. Additionally, the environmental impact of traditional construction is a growing concern, with the industry accounting for a significant percentage of global carbon emissions (Lu, Tam, Chen, & Du,

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2020). In response to these challenges, there is a pressing need for innovative construction methods to deliver high-quality, durable, and sustainable housing at a reduced cost and in a shorter timeframe (Kiessling, 2024).

Modular and prefabricated construction techniques have emerged as promising solutions to this crisis. These methods involve the off-site fabrication of building components, which are then transported to the construction site for assembly. This approach contrasts sharply with traditional on-site construction methods, offering numerous benefits, including faster construction times, reduced waste, and improved cost efficiency. Producing building components in a controlled factory environment allows for greater precision and quality control, resulting in more durable and resilient structures. As such, integrating modular and prefabricated techniques into affordable housing projects is gaining traction as a viable solution to the global housing shortage (Shibani, Agha, Alharasi, & Hassan, 2021).

1.1 Objectives

The primary objective of integrating modular and prefabricated construction techniques into affordable housing is to address the critical need for cost-effective, high-quality housing solutions. By leveraging these innovative methods, the goal is to reduce construction time. Maintaining or enhancing the final structures' quality and durability is significantly costly. These objectives are particularly relevant in affordable housing, where financial constraints and the need for rapid development often dictate project feasibility.

One of the key objectives of this research is to examine the architectural design principles fundamental to the successful implementation of modular and prefabricated construction methods in affordable housing. Understanding these principles is crucial for ensuring that the integration of these techniques does not compromise the aesthetic and functional aspects of the housing units. The research explores how modular and prefabricated designs can be tailored to meet the specific needs of affordable housing projects, including considerations for space efficiency, adaptability, and sustainability.

Another important objective is to highlight the benefits of modular and prefabricated construction in the context of affordable housing. These benefits include the potential for cost and time savings and the ability to achieve higher quality and durability compared to traditional construction methods. By providing a comprehensive analysis of these benefits, the research seeks to demonstrate the value of these techniques as a viable alternative to conventional construction in addressing the affordable housing crisis.

1.2 Scope

The scope of this research encompasses a comprehensive examination of the architectural design principles required for the successful integration of modular and prefabricated construction techniques in affordable housing. The research will delve into the specific design considerations unique to these construction methods, including the challenges and opportunities they present. This analysis will cover various aspects of architectural design, such as structural integrity, spatial configuration, and material selection, focusing on how these elements can be optimized to meet the demands of affordable housing projects.

In addition to the architectural design principles, the research will explore the practical benefits of modular and prefabricated construction techniques in affordable housing. This includes an in-depth analysis of how these methods can reduce construction time and costs and the potential for improving the quality and durability of the final structures. The research will draw on case studies of successful implementations of modular and prefabricated construction in affordable housing projects worldwide, providing real-world examples of how these techniques can be effectively applied.

Furthermore, the research will address the broader implications of integrating modular and prefabricated construction techniques into affordable housing. This includes an exploration of the environmental and social impacts of these methods, as well as the potential for scaling up their use to address the global housing shortage. The research will also consider the challenges and barriers to the widespread adoption of modular and prefabricated construction, including regulatory and logistical issues. It will propose potential solutions to overcome these obstacles.

Overall, this research aims to provide a comprehensive framework for understanding the role of modular and prefabricated construction techniques in affordable housing. By examining these methods' architectural design principles, benefits, and broader implications, the research seeks to contribute to the ongoing efforts to address the global affordable housing crisis through innovative and sustainable construction solutions.

2 Architectural Design Principles for Modular and Prefabricated Construction

2.1 Fundamentals of Modular Design

Modular design is based on building components or modules that can be easily assembled to form a complete structure (Srisangeerthanan, Hashemi, Rajeev, Gad, & Fernando, 2020). This approach to construction is characterized by its flexibility, scalability, and standardization, which are essential to its success in various applications, including affordable housing. Flexibility is one of the most critical aspects of modular architecture. Unlike traditional construction methods, where changes to the design or structure often result in significant delays and additional costs, modular construction allows for adjustments to be made relatively easily (Lacey, Chen, & Hao, 2022). This is because modular buildings comprise standardized units that can be reconfigured or expanded. This flexibility is particularly valuable for affordable housing projects as it enables developers to adapt the design to meet the specific needs of different communities or accommodate future growth. For instance, additional modules can be added to a building without requiring major structural changes, making it easier to scale up the housing capacity (Thai, Ngo, & Uy, 2020).

Scalability is another key principle of modular design. Using prefabricated modules allows for the efficient production of building components, which can then be assembled on-site in a fraction of the time required for traditional construction methods. This scalability is crucial in addressing the affordable housing crisis, where there is a need to produce large quantities of housing units quickly and efficiently. The ability to scale up production without compromising quality or increasing costs is one of the primary advantages of modular construction (Eloranta, 2021). Furthermore, modular design allows for replicating successful housing models across different locations, ensuring consistency and quality in affordable housing developments (Pasco, Lei, & Aranas Jr, 2022).

Standardization is the third fundamental principle of modular design. Standardization involves using uniform building components that can be mass-produced in a factory setting. This not only enhances efficiency but also ensures a high level of quality control. Standardization extends beyond physical components to design processes and construction practices in modular construction. This consistency is crucial for maintaining the integrity and durability of modular buildings, especially in affordable housing projects where cost constraints can often lead to compromises in quality. By adhering to standardized designs and processes, developers can ensure that each housing unit meets the required safety, durability, and comfort standards (Kolbeck et al., 2023).

2.2 Prefabrication Techniques

Prefabrication techniques play a central role in the modular construction process. Prefabrication involves the off-site production of building components, which are then transported to the construction site for assembly. This method offers several advantages over traditional on-site construction, particularly regarding efficiency and sustainability (Wu et al., 2021). One of the primary benefits of prefabrication is efficiency. Since most of the construction work is carried out in a controlled factory environment, the process is less susceptible to delays caused by weather conditions or labor shortages, which are common in traditional construction. The factory setting also allows for advanced manufacturing techniques, such as automation and robotics, which can significantly speed up the production process while reducing labor costs (Razkenari, Fenner, Shojaei, Hakim, & Kibert, 2020). Additionally, the precision and accuracy achieved in a factory setting result in higher-quality components that require less rework and adjustments during assembly. For affordable housing projects, this efficiency translates into shorter construction timelines and lower overall costs, making it possible to deliver housing units more quickly to those in need (Zhang, Tan, Shi, Hou, & Zhang, 2022).

Sustainability is another critical aspect of prefabrication. The construction industry is one of the largest contributors to global carbon emissions, and there is growing pressure to adopt more sustainable practices. Prefabrication offers several environmental benefits, including reduced waste and lower energy consumption. Since components are manufactured in a factory, materials can be optimized to minimize waste, and any surplus can be recycled more easily than on a traditional construction site. Furthermore, the controlled environment of a factory allows for better energy management, reducing the overall carbon footprint of the construction process (Du, Pang, Bao, Guo, & Deng, 2021). Prefabrication also enables the use of sustainable materials, such as recycled steel or engineered wood, which further enhances the environmental credentials of modular buildings. In the context of affordable housing, where sustainability is often a key consideration, prefabrication provides a viable solution for creating eco-friendly housing that is both cost-effective and energy-efficient (Liu, Li, Teng, & Dai, 2022).

The materials used in prefabrication are also critical to the success of modular construction. Lightweight and durable materials, such as steel, wood, and concrete, are commonly used to produce modular components. These materials are chosen for their strength, durability, and ease of transport, making them ideal for use in modular construction (Roscetti,

Atkins, & Lacroix, 2022). Additionally, advances in material science have led to the development of new materials that offer enhanced performance characteristics, such as improved thermal insulation and fire resistance, essential for ensuring the safety and comfort of affordable housing units (Nam, Yoon, Kim, & Choi, 2020).

2.3 Integration with Affordable Housing Requirements

Integrating modular and prefabricated construction techniques with the specific requirements of affordable housing projects presents challenges and opportunities. While these innovative construction methods offer numerous benefits, their successful application in affordable housing requires careful consideration of various factors, including cost, quality, and sustainability. One of the primary considerations in integrating modular construction with affordable housing is cost. Affordable housing projects are often constrained by tight budgets, making it essential to ensure that using modular and prefabricated techniques does not result in cost overruns. However, the cost efficiency of modular construction can be leveraged to meet these budgetary constraints. Modular methods can lower the overall cost of housing units by reducing the time and labor required for construction. Additionally, the standardization and scalability of modular construction allow for economies of scale, further driving down costs. For developers, this means they can deliver more housing units within the same budget, helping alleviate the affordable housing crisis (Trambley, 2020).

Quality and durability are also critical considerations in affordable housing projects. While cost is a significant factor, the housing units produced must be high quality and capable of withstanding the test of time. Modular construction offers several advantages in this regard, including using high-quality materials and precision manufacturing techniques. The controlled factory environment ensures that each component is produced to exact specifications, reducing the likelihood of defects and ensuring consistent quality across all units. Furthermore, the durability of the materials used in modular construction, such as steel and concrete, contributes to the longevity of the housing units, making them a sustainable solution for affordable housing (Bello, Eje, Idris, Semiu, & Khan, 2023).

Sustainability is another important factor in integrating modular construction with affordable housing. Many affordable housing projects are in areas where environmental considerations are a priority, such as urban centers with strict energy use and emissions regulations. Modular construction, emphasizing sustainability, aligns well with these requirements (A. A. Akinsulire, C. Idemudia, A. C. Okwandu, & O. Iwuanyanwu, 2024c). The use of energy-efficient materials and the reduction of waste during the construction process contribute to the overall sustainability of the housing units. Additionally, incorporating green technologies, such as solar panels and energy-efficient HVAC systems, into modular buildings enhances their environmental performance. For affordable housing projects, residents can benefit from lower energy costs and a reduced environmental impact, contributing to the overall goal of creating sustainable communities (Moghayedi et al., 2021).

3 Benefits of Modular and Prefabricated Construction in Affordable Housing

3.1 Cost Efficiency

One of the most compelling benefits of modular and prefabricated construction in affordable housing is its potential to reduce overall costs significantly (Mandala & Nayaka, 2023). The cost-efficiency of these methods arises from several factors, including material savings, labor efficiencies, and the ability to streamline the construction process. Material savings are a key component of the cost-efficiency offered by modular and prefabricated construction (Khan, Yu, Liu, Guan, & Oh, 2022). In traditional construction methods, material waste is often a significant issue due to the on-site nature of building work, where unpredictable variables like weather and human error can lead to excess material use and wastage. In contrast, modular construction involves producing building components in a controlled factory environment, where materials can be precisely measured, cut, and assembled with minimal waste. This controlled setting allows for better inventory management and the reuse of materials that might otherwise be discarded on a traditional construction site. The result is a reduction in material costs, which is especially crucial in affordable housing projects where budgets are often constrained (Sesay, 2022).

Labor efficiencies also contribute to the cost savings associated with modular and prefabricated construction (Subramanya, Kermanshachi, & Rouhanizadeh, 2020). Traditional construction is labor-intensive, requiring skilled workers on-site for extended periods. This increases labor costs and exposes the project to delays and cost overruns due to labor shortages or scheduling conflicts. In contrast, modular construction shifts much labor-intensive work to a factory setting, where tasks can be automated and streamlined. This reduces the number of skilled workers required on-site and shortens the overall construction timeline, leading to lower labor costs. Moreover, the controlled environment of a factory allows for a more consistent workflow, reducing the likelihood of costly errors and rework.

These labor efficiencies make modular construction an attractive option for affordable housing, where minimizing labor costs without compromising quality is essential (Ahmadzadeh Amid, Noorzai, & Golabchi, 2023).

Another important aspect of cost efficiency is the streamlining of the construction process. Modular construction allows for the simultaneous production of building components and site preparation, a process known as parallel construction. This contrasts with traditional construction methods, where site preparation must be completed before building work can begin, leading to longer timelines and higher costs. Modular techniques reduce the overall project duration by enabling parallel construction saving labor and materials. Additionally, the ability to produce modules in a factory means that construction is less affected by external factors such as weather conditions, further reducing the risk of delays and cost overruns. Streamlining the construction process through modular techniques offers a significant advantage for affordable housing projects, where time and budget constraints are often critical (Yang, Pan, & Pan, 2022).

3.2 Time Savings

Reducing construction time is one of the most significant benefits of modular and prefabricated construction techniques, particularly in the context of affordable housing. Completing projects in a shorter timeframe accelerates the delivery of much-needed housing units, reduces costs, and allows developers to respond more quickly to market demands. One of the primary reasons for the time savings associated with modular construction is the shift of building component production to a factory setting. In traditional construction, all work is carried out on-site, meaning that each project phase must be completed before the next can begin (Khan et al., 2022). This sequential approach often leads to delays, especially when unforeseen issues arise or when the project is dependent on favorable weather conditions. In contrast, modular construction allows for the simultaneous production of modules in a factory while site preparation is ongoing. This parallel construction process significantly reduces the project timeline, enabling housing units to be completed in a fraction of the time required for traditional construction methods (Mandala & Nayaka, 2023).

Another factor contributing to time savings is the efficiency of factory-based production. In a controlled environment, work can continue uninterrupted by external factors such as weather, labor disputes, or supply chain disruptions, which are common in traditional construction. Advanced manufacturing techniques, including automation and robotics, further enhance the speed and efficiency of module production. These technologies enable the precise and rapid assembly of building components, reducing the likelihood of errors and the need for rework. As a result, the construction process is faster and more predictable, allowing developers to meet tight deadlines and deliver housing units on time (Bayliss & Bergin, 2020).

The time savings offered by modular construction are particularly important in affordable housing, where the need for rapid development is often pressing. Faster project completion means that housing units can be delivered more quickly to those in need, helping to alleviate the affordable housing crisis (Henderson & CMVP, 2020). Additionally, shorter construction timelines reduce the financial burden on developers, who can quickly realize returns on their investments and reinvest in new projects. For government and nonprofit organizations involved in affordable housing, the ability to deliver projects on time and within budget is critical to meeting the growing demand for affordable housing (Mandala & Nayaka, 2023).

3.3 Quality and Durability

While cost and time savings are significant advantages of modular and prefabricated construction, these benefits should not come at the expense of quality and durability. Modular construction techniques can maintain or even enhance the quality and durability of affordable housing units, offering consistency and reliability that is often difficult to achieve with traditional construction methods (Landers et al., 2020). One of the main reasons for the enhanced quality of modular construction is the controlled factory environment in which building components are produced. In traditional construction, on-site work is subject to various external factors, including weather conditions, which can affect the quality of the final product. In contrast, the factory setting used in modular construction provides a stable environment where materials can be stored and handled under optimal conditions, reducing the risk of damage and deterioration. Furthermore, using precision manufacturing techniques in a factory setting allows for tighter tolerances and greater accuracy in producing building components, leading to higher quality in the final assembly (Tsutsumi et al., 2020).

Another factor contributing to the quality and durability of modular construction is the use of high-quality materials. In order to withstand the rigors of transportation and on-site assembly, modular components are often constructed from materials that are stronger and more durable than those used in traditional construction. For example, steel and engineered wood are commonly used in modular construction for their strength, durability, and resistance to environmental factors such as moisture and temperature fluctuations. These materials contribute to the structural

integrity of the housing units and enhance their longevity, making them a sustainable option for affordable housing (Pervez, Ali, Pamucar, Garai-Fodor, & Csiszárik-Kocsir, 2022).

The controlled nature of modular construction also allows for rigorous quality control processes. In a factory setting, each module undergoes thorough inspections and testing to meet the required standards before being transported to the construction site. This level of quality control is difficult to achieve in traditional construction, where on-site inspections may be less frequent and less thorough. Modular construction reduces the likelihood of defects by ensuring that each module meets strict quality criteria. It ensures that the final assembly is of a consistently high standard (Winston, 2022).

Durability is another key consideration in affordable housing, where the longevity of the housing units is critical to their sustainability (Anderson, Wedawatta, Rathnayake, Domingo, & Azizi, 2022). Modular construction techniques contribute to the durability of the housing units by using materials and construction methods designed to withstand the test of time. The precision and accuracy of modular construction also contribute to the durability of the final product, as the tight tolerances achieved in a factory setting result in a more stable and resilient structure. Additionally, incorporating advanced building technologies, such as energy-efficient insulation and durable exterior finishes, further enhances the longevity of modular housing units (Atta, Dalla Valle, Campioli, Chiaroni, & Talamo, 2021).

4 Case Studies

4.1 Successful Implementations

Modular and prefabricated construction techniques have been increasingly recognized for their potential to address the affordable housing crisis. Various projects worldwide have successfully utilized these innovative methods to deliver high-quality, cost-effective, and sustainable housing solutions. A few notable examples provide valuable insights into how these techniques can be effectively implemented. One of the most cited successes is the Ninety7Fifty on the Park project in suburban Chicago, Illinois. Completed in 2013, this residential development utilized modular construction to create 295 apartment units. The project was completed in just over ten months, significantly shorter than the typical construction timeline for a project of this scale. This reduced timeframe was achieved by manufacturing the building modules off-site while simultaneously preparing the foundation on-site, allowing for rapid assembly once the modules were delivered. The project met its budget and demonstrated that modular construction could deliver high-quality, aesthetically pleasing housing. Using durable materials and precision manufacturing techniques ensured the final product was structurally sound and visually appealing, making it a model for future affordable housing developments (A. A. Akinsulire, C. Idemudia, A. C. Okwandu, & O. Iwuanyanwu, 2024a; A. A. Akinsulire et al., 2024c).

Another successful implementation of modular construction can be seen in the Monadnock Valley in the Bronx, New York. This project, completed in 2016, involved the construction of 65 modular apartment units designed to provide affordable housing to low-income families. The project was notable for its focus on sustainability, with the modular units incorporating energy-efficient materials and technologies such as high-performance insulation and solar panels. The factory-controlled environment where the modules were produced allowed for strict quality control, ensuring that each unit met high energy efficiency and durability standards. The project was completed on time and within budget, demonstrating modular construction's cost-effectiveness and environmental benefits in an urban setting.

The Y project in Mitcham, London, is another excellent example in the United Kingdom. This innovative housing project, developed by the YMCA, consists of 36 prefabricated units that provide temporary housing for homeless individuals. The units were manufactured off-site using a modular system, allowing for rapid assembly on-site. The project was completed in five months, significantly faster than traditional construction methods would have allowed. The Y units are designed to be energy-efficient, with high insulation levels and double-glazed windows, reducing energy costs for residents. The project's success highlights the potential of modular construction to provide quick, cost-effective housing solutions for vulnerable populations.

4.2 Lessons Learned

While these case studies demonstrate the potential of modular and prefabricated construction techniques, they also offer valuable lessons for future projects. Understanding the successes and challenges encountered in these projects is essential for optimizing the use of modular construction in affordable housing. One key lesson is the importance of early planning and coordination. In all three case studies, the project's success was closely tied to the early involvement of all stakeholders, including architects, engineers, contractors, and manufacturers. This early collaboration ensured that the design of the modular units aligned with the overall project goals and that any potential issues were identified and

addressed before construction began. In the Ninety7Fifty on the Park project, for example, close coordination between the design team and the module manufacturer was essential in ensuring that the modules were produced to the correct specifications and that they could be easily assembled on-site. This level of coordination is crucial for avoiding costly delays and ensuring that the project stays on schedule (A. Akinsulire, C. Idemudia, A. Okwandu, & O. Iwuanyanwu, 2024a, 2024b).

Another important lesson is the need for flexibility in design and construction. Modular construction offers many advantages but requires a different approach to design and building than traditional methods. In the Y project, for instance, the design of the modular units had to be adapted to fit the site's constraints and meet local building codes. This required a high degree of flexibility and creativity on the part of the design team. Similarly, in the Monadnock Valley project, modular construction required the site layout and foundation design adjustments to accommodate the prefabricated units. Being open to adapting the design and construction process to fit the project's specific needs is essential for successfully implementing modular construction techniques.

The case studies also highlight the importance of quality control in modular construction. The factory setting where modular units are produced allows for higher quality control than is typically possible in traditional on-site construction. However, this also means that any errors in the manufacturing process can have significant consequences for the final assembly. In the Monadnock Valley project, for example, rigorous quality control processes were implemented to ensure that each module met the required standards before being transported to the site. This helped avoid costly rework and ensured the final product was high quality. Ensuring quality control measures are in place throughout the manufacturing and assembly process is essential for achieving the desired outcomes in modular construction.

4.3 Comparative Analysis

When comparing the outcomes of modular and prefabricated construction with traditional methods in similar contexts, several key differences emerge that underscore the benefits of these innovative techniques. Time efficiency is perhaps the most significant advantage of modular construction over traditional methods. The case studies demonstrate that modular construction can significantly reduce the project timeline. For example, the Y project in London was completed in just five months, a timeframe that would have been nearly impossible to achieve with traditional construction methods. Similarly, the Ninety7Fifty on the Park project in Chicago was completed in just over ten months, thanks to the parallel construction process made possible by modular techniques. This time efficiency is particularly valuable in affordable housing projects, where there is often an urgent need to deliver housing units quickly to meet demand.

In terms of cost efficiency, modular construction also offers clear advantages. Producing building components in a factory setting allows for better control over materials and labor costs, leading to significant savings. The Monadnock Valley project, for example, was completed within budget thanks to the cost savings achieved through modular construction. In contrast, traditional construction methods often face cost overruns due to delays, material waste, and labor inefficiencies. The streamlined process of modular construction, emphasizing efficiency and standardization, helps minimize these risks and keep projects within budget.

Quality and durability are other areas where modular construction can outperform traditional methods. The controlled environment of a factory allows for stricter quality control, ensuring that each module is built to high standards. This level of quality control is difficult to achieve in traditional on-site construction, where external factors such as weather and human error can impact the final product. The case studies illustrate how modular construction can produce high-quality, durable housing units that meet or exceed traditional construction standards. For example, the use of high-quality materials and precision manufacturing techniques in the Monadnock Valley project resulted in housing units that are both durable and energy-efficient, providing long-term benefits for residents (A. A. Akinsulire, C. Idemudia, A. C. Okwandu, & O. Iwuanyanwu, 2024b).

5 Conclusion

This research has underscored the advantages of integrating modular and prefabricated construction techniques into affordable housing projects. The key findings highlight that these methods offer substantial benefits in terms of cost efficiency, time savings, and the ability to maintain or even enhance the quality and durability of housing units. Modular construction, with its streamlined processes and precision manufacturing, has proven to be a viable solution for rapidly delivering affordable, high-quality housing. Case studies like Ninety7Fifty on the Park, Monadnock Valley, and the Y project exemplify how these techniques can be successfully implemented to address the urgent need for affordable

housing, demonstrating that modular construction is not just a theoretical concept but a practical, proven approach to tackling the housing crisis.

Despite the clear benefits, several challenges and considerations must be addressed for the widespread adoption of modular and prefabricated construction in affordable housing. One significant challenge is the initial investment and infrastructure required to establish modular construction facilities. While these techniques can reduce costs over the long term, the upfront costs of setting up factories, purchasing specialized equipment, and training workers can be a barrier, particularly in regions with limited industrial capacity. Additionally, regulatory hurdles and zoning laws often favor traditional construction methods, creating obstacles to the approval and implementation of modular projects. Local building code variations can also complicate the design and production process, as modules must be adapted to meet different regulatory requirements across regions.

Another consideration is the perception of modular housing. Despite advances in design and construction quality, a lingering stigma is still associated with prefabricated and modular homes, often viewed as lower quality or less durable than traditionally built homes. This perception can affect both consumer acceptance and the willingness of developers to invest in modular construction. Overcoming these challenges requires not only technical and logistical solutions but also efforts to educate the public and stakeholders about the true capabilities and benefits of modular housing.

Several avenues for further research and practical steps can be taken to enhance the integration of modular and prefabricated construction techniques in affordable housing. Research should focus on optimizing the design and manufacturing processes to reduce costs and improve efficiency. This includes exploring new materials and construction technologies that can enhance the sustainability and resilience of modular homes. Additionally, more extensive studies on the long-term performance of modular housing, particularly in diverse climatic and environmental conditions, would provide valuable data to support broader adoption.

Practical recommendations for implementation include promoting policy reforms that facilitate the approval and development of modular housing projects. This could involve updating building codes to accommodate modular designs better and incentivizing developers to invest in modular construction. Public-private partnerships could also play a crucial role in driving the adoption of modular techniques, particularly in regions where the need for affordable housing is most acute.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Ahmadzadeh Amid, S., Noorzai, E., & Golabchi, M. (2023). Identifying factors affecting waste production throughout the construction project life cycle and proposing BIM-based solutions. *The TQM Journal, 35*(6), 1449-1470.

[2] Akinsulire, A., Idemudia, C., Okwandu, A., & Iwuanyanwu, O. (2024a). Dynamic financial modeling and feasibility studies for affordable housing policies: A conceptual synthesis. *International Journal of Advanced Economics, 6*(7), 288-305.

[3] Akinsulire, A., Idemudia, C., Okwandu, A., & Iwuanyanwu, O. (2024b). Public-Private partnership frameworks for financing affordable housing: Lessons and models. *International Journal of Management & Entrepreneurship Research, 6*(7), 2314-2331.

[4] Akinsulire, A. A., Idemudia, C., Okwandu, A. C., & Iwuanyanwu, O. (2024a). Strategic planning and investment analysis for affordable housing: Enhancing viability and growth. *Magna Scientia Advanced Research and Reviews, 11*(2), 119-131.

[5] Akinsulire, A. A., Idemudia, C., Okwandu, A. C., & Iwuanyanwu, O. (2024b). Supply chain management and operational efficiency in affordable housing: An integrated review. *Magna Scientia Advanced Research and Reviews, 11*(2), 105-118.

[6] Akinsulire, A. A., Idemudia, C., Okwandu, A. C., & Iwuanyanwu, O. (2024c). Sustainable development in affordable housing: Policy innovations and challenges. *Magna Scientia Advanced Research and Reviews, 11*(2), 090-104.

[7] Anderson, N., Wedawatta, G., Rathnayake, I., Domingo, N., & Azizi, Z. (2022). Embodied Energy Consumption in the Residential Sector: A Case Study of Affordable Housing. *Sustainability, 14*(9), 5051.

[8] Atta, N., Dalla Valle, A., Campioli, A., Chiaroni, D., & Talamo, C. (2021). Construction technologies for sustainable affordable housing within fragile contexts: proposal of a decision support tool. *Sustainability, 13*(11), 5928.

[9] Bayliss, S., & Bergin, R. (2020). *The modular housing handbook*: Routledge.

[10] Bello, A. O., Eje, D. O., Idris, A., Semiu, M. A., & Khan, A. A. (2023). Drivers for the implementation of modular construction systems in the AEC industry of developing countries. *Journal of Engineering, Design and Technology*.

[11] Coupe, T. (2021). How global is the affordable housing crisis? *International Journal of Housing Markets and Analysis, 14*(3), 429-445.

[12] Du, Q., Pang, Q., Bao, T., Guo, X., & Deng, Y. (2021). Critical factors influencing carbon emissions of prefabricated building supply chains in China. *Journal of Cleaner Production, 280*, 124398.

[13] Ebekozien, A. (2020). Community participation in affordable housing provision in developing cities: a study of Nigerian cities. *Journal of Human Behavior in the Social Environment, 30*(7), 918-935.

[14] Eloranta, J. (2021). Changing traditional construction with modular design platforms.

[15] Henderson, E., & CMVP, L. (2020). *Modular Construction for Energy Efficient, Affordable Housing in Canada*: RDH Technical Bulletin.

[16] Khan, A., Yu, R., Liu, T., Guan, H., & Oh, E. (2022). Drivers towards adopting modular integrated construction for affordable sustainable housing: A total interpretive structural modelling (TISM) method. *Buildings, 12*(5), 637.

[17] Kiessling, R. A. (2024). *Affordable Housing: Exploring Mass Timber in Hawaii as an Alternative Building Material.* University of Hawai'i at Manoa,

[18] Kolbeck, L., Kovaleva, D., Manny, A., Stieler, D., Rettinger, M., Renz, R., . . . Forman, P. (2023). Modularisation Strategies for Individualised Precast Construction—Conceptual Fundamentals and Research Directions. *Designs, 7*(6), 143.

[19] Lacey, A. W., Chen, W., & Hao, H. (2022). Experimental methods for inter-module joints in modular building structures–A state-of-the-art review. *Journal of Building Engineering, 46*, 103792.

[20] Landers, R. G., Barton, K., Devasia, S., Kurfess, T., Pagilla, P., & Tomizuka, M. (2020). A review of manufacturing process control. *Journal of Manufacturing Science and Engineering, 142*(11), 110814.

[21] Liu, S., Li, Z., Teng, Y., & Dai, L. (2022). A dynamic simulation study on the sustainability of prefabricated buildings. *Sustainable Cities and Society, 77*, 103551.

[22] Lu, W., Tam, V. W., Chen, H., & Du, L. (2020). A holistic review of research on carbon emissions of green building construction industry. *Engineering, Construction and Architectural Management, 27*(5), 1065-1092.

[23] Mandala, R. S. K., & Nayaka, R. R. (2023). A state of art review on time, cost and sustainable benefits of modern construction techniques for affordable housing. *Construction Innovation*.

[24] Moghayedi, A., Awuzie, B., Omotayo, T., Le Jeune, K., Massyn, M., Ekpo, C. O., . . . Byron, P. (2021). A critical success factor framework for implementing sustainable innovative and affordable housing: a systematic review and bibliometric analysis. *Buildings, 11*(8), 317.

[25] Nam, S., Yoon, J., Kim, K., & Choi, B. (2020). Optimization of prefabricated components in housing modular construction. *Sustainability, 12*(24), 10269.

[26] Pasco, J., Lei, Z., & Aranas Jr, C. (2022). Additive manufacturing in off-site construction: Review and future directions. *Buildings, 12*(1), 53.

[27] Pervez, H., Ali, Y., Pamucar, D., Garai-Fodor, M., & Csiszárik-Kocsir, Á. (2022). Evaluation of critical risk factors in the implementation of modular construction. *Plos one, 17*(8), e0272448.

[28] Razkenari, M., Fenner, A., Shojaei, A., Hakim, H., & Kibert, C. (2020). Perceptions of offsite construction in the United States: An investigation of current practices. *Journal of Building Engineering, 29*, 101138.

[29] Roscetti, D., Atkins, A., & Lacroix, D. (2022). *Prefabrication and Modular Construction—A Potential Solution to Affordable and Temporary Housing in Ontario?* Paper presented at the Canadian Society of Civil Engineering Annual Conference.

[30] Sesay, M. M. (2022). Reducing Landfill Waste in Sierra Leone with Construction Industry Material Waste Management.

[31] Shibani, A., Agha, A., Alharasi, T. A., & Hassan, D. (2021). Prefabrication as a Solution for Tackling the Building Crisis in the UK. *Journal of Civil Engineering Research, 11*(1), 10-18.

[32] Srisangeerthanan, S., Hashemi, M. J., Rajeev, P., Gad, E., & Fernando, S. (2020). Review of performance requirements for inter-module connections in multi-story modular buildings. *Journal of Building Engineering, 28*, 101087.

[33] Subramanya, K., Kermanshachi, S., & Rouhanizadeh, B. (2020). *Modular construction vs. traditional construction: Advantages and limitations: A comparative study.* Paper presented at the Creative Construction e-Conference 2020.

[34] Thai, H.-T., Ngo, T., & Uy, B. (2020). *A review on modular construction for high-rise buildings.* Paper presented at the Structures.

[35] Trambley, L. (2020). The affordable housing crisis: Tiny homes & single-family zoning. *Hastings LJ, 72*, 919.

[36] Tsutsumi, D., Gyulai, D., Kovács, A., Tipary, B., Ueno, Y., Nonaka, Y., & Fujita, K. (2020). Joint optimization of product tolerance design, process plan, and production plan in high-precision multi-product assembly. *Journal of Manufacturing Systems, 54*, 336-347.

[37] Winston, N. (2022). Sustainable community development: Integrating social and environmental sustainability for sustainable housing and communities. *Sustainable Development, 30*(1), 191-202.

[38] Wu, Z., Luo, L., Li, H., Wang, Y., Bi, G., & Antwi-Afari, M. F. (2021). An analysis on promoting prefabrication implementation in construction industry towards sustainability. *International Journal of Environmental Research and Public Health, 18*(21), 11493.

[39] Yang, Y., Pan, M., & Pan, W. (2022). Integrated offsite logistics scheduling approach for high-rise modular building projects. *Journal of Construction Engineering and Management, 148*(6), 04022032.

[40] Zhang, Z., Tan, Y., Shi, L., Hou, L., & Zhang, G. (2022). Current state of using prefabricated construction in Australia. *Buildings, 12*(9), 1355.