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Achieving Housing Affordability in the U.S. through Sustained Use of AI and Robotic Process Automation for Prefabricated Modular Construction

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Abstract

The rising housing issues occasioned by high costs in the United States (US) are traceable to the high costs of building materials and construction. This study proposes the combined leveraging of AI and Robotic Process Automation (RPA) for prefabricated modular construction as a strategic means of reducing high costs of housing and increasing efficiency in construction. It argues that doing so would pave way for housing affordability in the US. Deploying descriptive survey and qualitative method alongside the applicable interpretive and descriptive techniques, the study demonstrates in the course of its analysis that AI and RPA are viable means of reducing costs of construction and housing, and increasing efficiency. It submits that amidst the established constraints to the ideal extent of leveraging AI for construction activities, the leveraging of AI and RPA for prefabricated modular construction yields huge positive results among which are reduced costs of construction and housing and increased efficiency in construction. Government and construction organizations are charged to play enabling roles in the adoption and sustainability of AI and RPA in construction activities, including prefabricated modular construction, so as to achieve reduced costs of housing and increase efficiency in construction.

Keywords: Housing Affordability, Sustained Use, AI, Robotic Process Automation, Prefabricated Modular Construction.

Introduction

High costs of construction, limited housing supply and slow growth in income worsen the challenges faced by Americans and residents (Akinola, 2024; Kim et al., 2017). One of the ways of reducing housing and construction issues in the U.S. is by leveraging artificial intelligence (AI) and Robotic Process Automation (RPA) for prefabricated modular construction (Pan et al., 2020). Ways in which modular construction can be applied have great potentials for improved production, waste reduction, and reduction of construction durations. The application of technologies using advanced algorithms and machine

learning promotes better ways of construction from the design stage through manufacturing to assembly (Akinola, 2024; Obiuto et al., 2024; Kocaturk et al., 2023; Araya et al., 2021; Bataglin et al., 2021).

Ozdemir (2024) and Li et al. (2017) indicate that robotics and AI technologies can be integrated into manufacturing activities, supply chains, and other process-based solutions. The incorporation of AI and robotic automation in construction would revolutionize the building production process to make it more efficient with less labor cost and allow for maximal use of resources (Kodete et al., 2024; Pasupuleti et al., 2024; Thuraka et al., 2024; Araya et al., 2021; Karunanithi, 2021). As Griffiths (2021) affirms, the 3D printing technology would bring building components that are to be produced with better precision, higher speed, and cost effectiveness. It is affirmed that 3D printing technology has been a path for producing complex architectural designs and specialized building elements that have previously been either problematic to produce or quite expensive (Kocaturk et al., 2023).

This study argues that AI algorithms can also be used during the design phase to optimize the building's structural integrity, energy efficiency, and material use for overall cost savings throughout the whole life cycle of the building. AI and robotic automation integrated with prefabricated modular construction can provide more tangible solutions to the issues of labor shortages in the construction industry (Karan & Irizarry, 2020). This statement highlights the link between AI and RPA in construction as a whole and prefabricated modular construction in particular. Using these two sets of technological innovations in combination would help address construction inefficiency and costs that translate to or worsen housing costs in the US. The proposal of this study would no doubt increase the use of robotics among construction companies in US from the 55% of usage to an appreciable percentage.

Robotic automation in construction could help automate repetitive and labor-intensive jobs, thereby reducing dependence on manual labor and the associated costs (Araya et al., 2021). This could be achieved through improved productivity, safer conditions, and a reduction in time spent on construction works, which have the capacity of impacting positively on construction and housing (Kopsida & Brilakis, 2021). Given the foregoing, this study sets out to show that AI and RPA can be leveraged for prefabricated construction towards attaining housing affordability in the US, drawing evidence from extant literatures to back up its thesis and claims. The rationale for this study is that since costs of housing generally have traces to construction costs, it is worthwhile to deploy technological means of reducing costs and increasing efficiency, which would thereby influence the costs of housing in the US. The novelty of this study lies in its unique proposal, which is proposing a combined leveraging of AI and RPA for costs reduction and efficiency increase in both construction and housing in the US as well as beyond.

Statement of Problem

There a range of housing and construction challenges in the US, as in other nations of the world. As an advanced nation that is tech-savvy, its construction industry ought to have significantly adopted the various technological innovations that are changing the narratives of industry. Regrettably, the adoption of AI and smart technologies in this sector is currently insignificant. Consequently, high costs and inefficiency consistently characterize the construction industry and magnify the constraints to housing affordability and construction efficiency in the US. It is quite regrettable that only 55% of construction companies in US, Europe and China currently use robotics for construction (Thibault, 2022).

Aim of the Study

The aim of this study is to explore the impact of AI and RPA on prefabricated construction. Its specific objectives are to:

i. Demonstrate that affordable housing can be attained in US through leveraging of AI and RPA for prefabricated modular construction.
ii. Show reduced costs and increased efficiency as the impact of AI and RPA on prefabricated construction.
iii. Correlate cost reduction, construction efficiency and housing affordability in the U.S. on the basis of leveraging AI and RPA for prefabricated modular construction.

Methodology

To realize the above objectives, the study adopts the descriptive survey design and the qualitative method to source, synthesize and analyze secondary data drawn from library and the internet materials. That is, the study relies majorly on secondary data. The analysis of the study follows its nature, scope and adopted design and method. Descriptive, interpretive and critical techniques are used for the analysis. Using exclusion criteria, the study excluded some of the internet sourced materials proven to be from predatory journals and other questionable or unverifiable websites and databases.

On the other hand, inclusion criteria are considered in selecting the literatures made use of in the study. The analysis is done thematically, systematically and content-based. Four images are adapted from free-royalty sites. The four images run through several sites. Thus, referencing them to one source means disregarding the others. While the authors attribute no particular source(s) to the images (figures 1-4), they do not claim ownership of the images. Rather, they give implicit credit to the originators of the images.

Prefabricated Modular Construction

Fig 1: How AI increases efficiency and productivity

Fig. 2: Robots coming to site

Here, the study avers that the prospects of AI affirmed in various other spheres of life (Akinola, 2024; Kodete et al., 2024; Pasupuleti et al., 2024; Nwadinobi et al., 2024; Okusi, 2024; Oyeyemi et al., 2024; Thuraka et al., 2024; Krstić et al., 2022; Huang, 2021; Jain & Jain, 2019) are also realizable in the field of prefabricated modular construction. The current insignificant realization of the commonly attested benefits of AI in prefabricated modular construction clearly justifies the assertion of this study that they are yet to be applied in this subfield of construction at a significant rate. Studies indicate that in other subfields of the construction industry, AI and smart technologies are yet to be adopted and applied appreciably, even in developed nations like the USA (Akinola, 2024; Kodete et al., 2024; Pasupuleti et al., 2024; Thuraka et al., 2024). The shared observation of such studies lends credence to the above expressed position of the current study on the extent of the application of AI and smart technologies in the prefabricated modular construction subfield of the construction sector.

Studies such as Karan and Irizarry (2020) and Bock et al. (2018) state that using AI algorithms right from design optimization through material use to allocation of resources and even scheduling is result-oriented. The results realized include optimization, increased efficiency, site safety, fostering the attainment of green environment and cost-effectiveness. The study lends credence to the present on in terms of cost-effectiveness and increased efficiency. However, like many others, it does not affirm the impact of cost-effectiveness and increased efficiency on prefabricated modular construction. Although Akinola's (2024) study emphasizes the possibility of using AI and smart technologies to attain reduced costs of construction and housing in the US, it does not engage with the impact of AI on prefabricated modular construction.

Furthermore, in the field of construction in particular, AI can help foster the realization of structural integrity, energy efficiency, and material use. These help in reducing costs throughout the life cycle of the building. This study further posits that the application of AI and RPA to prefabricated modular construction also allows for the realization of quality control during the manufacturing process. As Zhu et al. (2019) note, when utilized, AI computer-vision-based systems can enable real-time detection and correction of errors in

the prefabricated components during the manufacturing process. Their thought reflects the thematic concern of the present study on cost reduction and increased efficiency. That is, by enabling real-time detection and the correction of errors, AI technologies are capable of reducing costs and increasing efficiency. In the same vein, smart technologies are capable of enabling the said detection and correction too.

Again, AI technologies deployed for construction purposes help in analyzing the visual data taken during the manufacturing process for an inconsistency with the result obtained. This allows for a balance to be made and attained. Besides, AI improves quality by automating the process of inspection and lowering the costs of rework and waste. This point on automation highlights the fact that AI technologies and RPA are indeed capable of reducing costs of construction and housing in the US. There is no doubt that when combined, they are bound to produce more results. Besides, AI can also be used for the derivation of predictive maintenance and energy management in order to help the organization save on a number of costs, while achieving a better level of sustainability. The prediction leads to prevention future expenses on repairing or replacing failed equipment. In addition, AI algorithms use energy-efficient HVAC, lighting, and other building systems at the right point in time and environment. It follows that AI algorithms impact positively on construction activities, including prefabricated modular construction.

Thus, the use of AI for prediction of construction activities helps avert equipment failure and thereby saves costs that would have been incurred if equipment failure had occurred. This is to say without such predictions, using AI algorithms, the equipment failure would not have been detected during prediction and actions taken ahead. The foregoing points are given credence by Kusiak et al. (2020), who observe that AI algorithms process data from sensors embedded in the building systems to mine for patterns and anomalies that translate into working environments. These are managed through proactive maintenance and energy optimization.

Robotic Automation in Prefabricated Modular Construction

Fig 3: A robot installing drywall

Fig 4: How robots are being used in construction

As Bock et al. (2018) note, AI algorithms are powerful enough in the engineering design phase to bring in trends that are capable of reducing waste of materials, time and resources. As regards this present study, the implication of the statement is that AI algorithms can reduce costs and increase efficiency, which help in tackling housing affordability challenges. The application of Robotic Process Automation to prefabricated modular construction is advocated by this paper, because of the prospects of doing so.

That is, using RPA in prefabricated modular construction is very advantageous. The advantages include productivity, cost reduction, and safety. Jia et al. (2019) indicate that applications for robots are unlimited in tasks requiring material handling, component fabrication, and assembly. Their statement affirms the assertion that using RPA can produce different results. Since robots can be characterized by a consistent working ability with high precision, the rate of errors is very minimal (Jia et al., 2019). This allows for quality construction works.

Productivity and efficiency in construction are also enhanced, since reliance on manual labor is minimized and repetitive and physically demanding tasks are automated. Robotic automation can be implemented to optimize the processes during the manufacturing phase related to cutting, welding, and 3-D printing of building components. Wong et al. (2018) note that due to the integration of robotic arms and sophisticated sensors, accurate manipulations can be done for the assembly of modular elements. Such automation would result in not only time reduction for production but also an improvement in the overall efficiency within the process and flexibility in configuration to the building components. For instance, robotic arms can apply adhesives or perform welding tasks with precision while maintaining quality consistently without human error. This robotic automation can also be worked into construction techniques, so that advanced techniques for additive manufacturing can be applied and again increase productivity and flexibility in design.

Also, robotics ensures the safety of construction sites (Ozdemir, 2024). For example, Liu et al. (2021) observe that robots can perform very risky activities, such as lifting huge weights and working at great heights, without suffering from fatigue. Obviously, RPA reduces the chances of accidents and injuries at work. There are also robots that are collaborative. These work with humans to assist them with their strength and precision. The collaboration gives a mixture of the best of human and robot capabilities, such that the working environment becomes safer yet more productive. It can produce the budged models that are fully complying with the required characteristics, so the exaggerated output from ineffective waste use can be minimized. Moreover, robotization along with the automated operations lowers costs, as it reduces the labor need and increases labor productivity rate as well as outcomes.

Production implemented with it would eliminate errors and reduce time spent on construction, thereby promoting a smooth process in production as well. Park et al. (2020) observe that activities of interdependent and AI-aided production systems play a decisive role in this matter, since they ensure substantial decrease in the cost of housing and

contribute to the increase in time speed. By reducing labor costs, as the number of workers gets reduced, RPA helps in reducing housing costs, thereby paving way for housing affordability. Similarly, the building components can be customized for low-cost manufacturing with the ability to integrate AI and robotic automation. This way, automation reduces overall cost in construction and dependence on manual labor, which can undoubtedly impact positively on costs of houses.

It becomes succinct from the foregoing that the application of AI and robotic automation in prefabricated modular construction can lead to reduced costs of production and improved affordability of housing. Therefore, with optimization and efficiency realized from the use of RPA for construction, the processes of constructing houses get accelerated, and costs get reduced. Therefore, it is quite obvious that RPA reduces costs, saves time and resources, and prevents delays. Effects of delays on construction projects cannot be overemphasized. Thus, by preventing delays, RPA does a lot when applied to construction activities, such as prefabricated modular construction. It is in view of the huge prospects of RPA in construction that this study advocates its adoption and application to prefabricated modular construction for efficiency and cost reduction so as to attain housing affordability in the US.

Before moving on to the challenges of AI and RPA, it is important to present tabulated examples of AI technologies and smart technologies that are cost-effective:

Table 1: Cost-effective AI and smart technologies (ST)

AI techs	Smart techs
Robotic process automation Machine learning, Computer vision, Reinforcement learning, Natural language processing	Building Automation Systems, Internet of Things, Renewable Energy Systems, Smart Water Management Systems
Obiuto et al. (2024) Pasupuleti et al. (2024) Rasheed et al. (2024) Ivanova et al. (2023) Srivastava (2021) Qasim and Kharbat (2020) Nikitas et al. (2020) Naser (2019) Kim et al. (2017 & 2015)	Kodete et al. (2024) Alamleh et al. (2023) Pan and Zhang (2023) Munir et al. (2022) Pan et al. (2022) Kochovski and Stankovski (2021) Liu et al. (2020) Nguyen and Koren (2019) Molana and Sadi-Nezhad (2018)

Source: Adapted from Akinola (2024)

Constraints to Leveraging AI and RPA for Prefabricated Modular Construction

The application of AI and RPA in prefabricated modular construction would have been much more than it is currently, but the challenges to their adoption have been limiting the extent

to which they are adopted and applied. In other words, the extent to which AI and RPA can be leveraged for increased effectiveness and costs reduction leading to housing affordability remains currently constrained by several challenges. The Table 2 below presents the common challenges, as affirmed by extant studies:

Table 2: Constraints to Leveraging AI and RPA for Prefabricated Modular Construction

Challenges	Citations
High cost	Zou et al. (2018)
Poor knowledge of and training on AI and RPA application to prefabricated construction	
Integration and compatibility of various AI and robotic platforms	Wu et al. (2021)
Fear of displacement from employment and the complexity of implementation	Bock et al. (2018)
Lack of technical-how-how among personnel, and logistics shortage	Gul et al. (2020), Jones et al. (2020)

Source: Authors, 2024

The long-term cost saving and productivity gained through AI and robotic automation can make up for the considered high costs of AI and RPA that discourage many firms. That is to say, the high costs of these innovative technologies set in at the investment stage as a challenge, but get eliminated or made up for later on. Collaboration among professionals or experts would help address the constraints arising from integration and compatibility of various AI and robotic platforms (Wu et al., 2021). Fears about implementation complexities and displacement from employment can be addressed through the instrumentality of effective communication (Nwangene, 2024).

The issue of lack of technically skilled personnel can be addressed through sustained practice and reliance on technical education. The problem can be addressed through graduate internships, which provide mastery-level training to individuals ahead of their tedious professional tasks (Chowdhury et al., 2019). The rotation of job responsibilities can also help to address the issues of lack of technical-how-how (Mahalingam et al., 2020). Job redesign to key into the contemporary trends would also help to address the issues (Chowdhury et al., 2019; Etim-Robert, 2016). For Gul et al. (2020), the issues can be addressed in part by deploying virtual reality and simulation technologies for solutions. Mahalingam et al. (2020) indicate that different kinds of virtual and augmented reality simulations can help in improving the effectiveness of learning and developing of competencies. Their opinion confirms that AI and RPA are capable of tackling cost issues that culminate to expensive house rents in the US.

Chowdhury et al. (2019) observe that on-the-job training is efficacious for employees and even students on industrial training. Similarly, Azhar et al. (2019) note that on-the-job

training is one way through which employees and professionals of different fields can get familiarized with technological innovations, such as AI and RPA for prefabricated modular construction. For Azhar et al. (2019), this training can make those who were initially restrictive to become submissive and interested in the innovations. Also, Al-Jibouri et al. (2020) are of the view that the issues of technical-know-how can be laid-off by developing a sustainable collaboration among professionals. Collaboration makes the AI algorithms, robotic systems, and software interfaces developed fit the norms and routines of construction.

Conclusion

The study has shown that AI and RPA have the potentials for reducing as well as saving costs of construction, which thereby make houses affordable for citizens and residents alike. From observation, inference, introspection, professional experience, and secondary data sources, the study has proven its proposition that AI and RPA can be leveraged for prefabricated modular construction in order to make houses affordable in the US as well as elsewhere across the globe. When leveraged, the costs of construction get reduced, while efficiency increases. The reduction in costs paves way for reduced costs of accommodation. This means that houses become affordable as a result of reduced and saved costs. Spending less on construction makes it possible for rents to be affordable. Also, with AI and RPA, construction is more efficient.

On the whole, the study demonstrates that that the application of AI and RPA in different stages of modular construction process results in effective optimization of design, material procurement, assembly operations, project scheduling, quality projects, increased productivity, efficiency, and cost effectiveness. These constitute the benefits of AI and RPA in offsite construction. The paper also highlights the concerns about the adoption of these innovations. By consistently checking for quality through inventory control, document management, material handling, and logistics, cost-effectiveness, optimization, efficiency, and quality are sustainably attained. Besides, by proving the potentials of AI and RPA for attaining housing affordability in the US as well as elsewhere, the study draws deserving attention to undermined or unexplored opportunities offered by AI and RPA to construction and housing management and affordability.

Recommendations

In view of the above, the study makes the following recommendations:

- Organizations in the construction sector are charged to duly deploy AI and RPA for prefabricated modular construction and other construction activities, so as to reduce costs, save time, increase efficiency, and ensure quality, optimization, and better competition with competitors.
- The US Government should officially encourage the application of AI and other technological innovations like RPA in construction activities, as a way of

strategically tackling the rising accommodation issues having bearing to high costs, inefficiency and site accidents.

- Government interventional involvement should focus on enacting and implementing policies supporting the adoption of AI and smart technologies in construction and other activities, and reviewing regulations to address regulatory issues.
- Training and re-skilling programs on data interoperability, AI, RPA and other systems compatibility, among others, would help address some of the major challenges of leveraging AI and RPA for modular construction.
- More studies should be carried out on AI and smart technologies in prefabricated construction and other construction activities. Increasing research through funding and collaborative research for more empirical findings leading to more tangible solutions would help a lot. Research would also help increase interest in the adoption of AI and smart technologies in the construction activities. With more research, awareness would increase.
- Other causes of the rising high costs of houses and building materials in the US should be investigated both scholarly and legislatively or administratively to figure out the issues at stake and address them accordingly, so as to make housing affordable for both the poor and the rich in the country.
- Ethical issues surrounding use and adoption of AI and smart technologies can be addressed through sensitization, mass awareness campaign, and carefully prepared and popularized guidelines to using and adopting AI and smart technologies in various spheres.

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