Implementation Strategies for Modular Construction Systems in Developing Countries: Perspectives of Nigerian AEC Professionals

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Abstract: This study aimed to develop effective strategies for implementing Modular Construction Systems (MCS) in developing countries, with a specific focus on the perspectives of Nigerian Architecture, Engineering, and Construction (AEC) professionals. A quantitative research approach was adopted, involving a survey of 227 AEC professionals in Nigeria. The survey collected respondents' perceptions on the developed MCS strategies in developing countries using a structured five-point Likert scale questionnaire. The professionals were identified through a snowball sampling technique. The results indicated that all fourteen hypothesized strategies were statistically significant for implementing MCS in developing countries. The strategies that received the highest mean scores were "Increasing awareness among professionals and stakeholders," "Creating an enabling environment within the industry," and "Government participation in the usage of MCS." The Kruskal-Wallis test revealed that professionals, regardless of their varied professions, held similar opinions on the identified strategies. The study has practical implications for the AEC industry in developing countries by providing valuable insights into strategies for implementing MCS. It can also assist policymakers in making informed decisions. Overall, this study offers a pathway for implementing MCS, addressing the housing shortage, and improving the quality of housing in developing countries.

Keywords: *AEC Industry, Construction technique, Developing countries, Modular construction systems, Stakeholders*

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1. Introduction

The Architecture, Engineering, and Construction (AEC) industry is recognized as a major contributor to global economic development, contributing significantly to Gross Domestic Product (GDP), infrastructural developments, and job creation. Olanrewaju et al. (2018) and the World Economic Forum (2018) reported that the industry contributes approximately 5% and 6% to the global GDP, respectively, while a more recent report by McKinsey Global Institute (2022) suggests a contribution of around 13% to global GDP. Bello et al. (2022) predict a further increase in the industry's GDP contribution in the near future. The provision of infrastructure and housing by the construction industry has been shown in studies to contribute to the socio-economic development of various sectors (Oladinrin et al., 2012).

However, Bello et al. (2023b) identified that the AEC industry has faced longstanding difficulties that have negatively impacted productivity and the industry's reputation. These challenges include time constraints, high costs, inadequate quality, fragmented supply chains, and limited sustainability. To address these issues, long-term, sustainable, energy-efficient solutions backed by circular economy principles are needed. Van der Ham and Opdenakker (2021) suggest strategies such as mass customization, industrialization, and modernization of construction processes to enhance productivity. Modularization of traditional and inefficient construction techniques (CCMs) is identified as a means to achieve these goals (Van der Ham and Opdenakker, 2021; Wuni and Shen, 2020). Modular construction systems (MCS) have emerged as a cutting-edge technique and technology that can overcome the limitations of CCMs and drive construction processes towards greater efficiency (Bello et al., 2023b).

MCS is a revolutionary construction method that differentiates itself from conventional construction by producing modules off-site in a controlled environment, leading to improved productivity and quality (Nekouvaght Tak et al., 2020). This construction technique can cater to various building types, including residential, multi-family, educational, and high-rise buildings (Schoenborn, 2012). More stakeholders are adopting MCS by integrating design, production, and assembly, which has led to an expanding market share for industrialized construction in the industry (Cao et al., 2021). In modular construction, a unit is designed by an architectural firm, manufactured in a factory, and then installed on-site (Kim et al., 2014). Traditional scheduling methods for conventional construction projects may not be suitable for modular construction due to different resource constraints (Lee & Hyun, 2019). Notable examples of high-rise modular buildings in urban areas include the 32-story B2 Tower in New York (Farnsworth, 2014) and the 28-story Apex House in North London (Offsite Hub, 2017).

Despite successful case studies, there remain challenges for designers and planners at the outset of industrialized construction projects (Pullen et al., 2019). The literature suggests that industrialized construction requires early consideration and incorporation of fabrication throughout the project's design and planning stages (Justin et al., 2019; Manu et al., 2019). Attempting to modularize a design originally intended for on-site construction can lead to rework and adjustments during fabrication (Hamid et al., 2018; Justin et al., 2019), increased material wastage (Manu et al., 2019), and ineffective communication between designers (Yuan et al., 2018). New industrialized building companies have been careful to avoid the negative aesthetic connotations associated with "modular," "box-like," or "cookie-cutter" architecture (Cao et al., 2021).

Another challenge in MCS arises from the potential threats to workload balance within the module manufacturing line, known as floating bottlenecks (Mullens, 2004). Floating bottlenecks refer to activities that cause bottlenecks to shift between operations due to changes in product mix, assembly line design, and workforce arrangements. Floating bottlenecks primarily affect production time, costs, quality, and efficiency. Value Stream Mapping (VSM) has been widely used as a practical tool to assess and improve manufacturing processes and analyze strategies for future development (Zhang, 2017).

Overcoming the barriers in the industry requires researchers to provide frameworks and strategies, while active collaboration among industry practitioners, government bodies, and researchers is crucial (Wuni & Shen, 2019). Enhanced usage of integrated project delivery models through collaboration among project participants can facilitate the implementation of MCS (Wuni & Shen, 2019). Effective supply chain management and coordination pose significant challenges for MCS (Hwang et al., 2018).

Over the past two decades, the global shipbuilding industry transformed conventional one-off fabrication into one that uses design standardization and modularization (CII, 2007). The construction sector has also been exposed to modularization multiple times (CII, 2006), which has also been combined with lean construction concepts (Green and May 2005). In addition, Nekoufar and Karim (2011) have discussed applying this idea to significant infrastructure and industrial projects using lean project management. Other areas where MCS has been applied include pipeline construction and oil and gas plants (Wang et al., 2018).

Although modular construction has been adopted and implemented over the past recent years in the construction industry and which have been proven to be a sustainable alternative to the conventional method of construction, considering cost efficiency, completion time, safety, and higher quality, it reduces errors, life-cycle performance and returns on investment (Innella et al., 2019). However, this development has been apparent in developed nations (Venables et al., 2004), with insignificant implementation in developing countries, especially African countries (Kibert et al., 2017). Therefore, one huge challenge is transforming the conventional design and construction approach to one based on manufacturing that requires the appropriate framework, tools, and technology that can change the perceived image of modular construction (Taghaddos et al. 2012). Although previous studies have proposed technologies and tools associated with the design, operation, and optimization of module manufacturing systems, this field of research is currently fragmented (Yang et al., 2017).

According to (Goodier and Gibb, 2007), fabricating off-site is the production and preassembly of building modules before being transported to the location for final assemblage. The study of Sabharwal et al. (2009) indicates that the overall production performance can be enhanced through subassemblies' optimized manufacturing process. Furthermore, improved output rate and reduced material handling costs can be achieved when a series of wall and floor fabrication tasks are restructured into a parallel workflow (Yang et al., 2017).

By the late 1990s, industrialized housing had been adopted, making construction to be more efficient compared to the traditional method, and has been widely adopted by various countries, with Denmark accounting for (43%) of the precast level, followed by the Netherlands (40%), and (31%) attributed to Germany and Sweden (Jaillon & Poon, 2008). The concept of industrialized construction was adopted from the manufacturing industry, where end products are pre-completed (Gann, 1996). In industrialized construction, prefabricated components are designed, manufactured, and then put together to create new buildings (Cao et al., 2021). The percentage of off-site manufacturing for modular construction ranges between 60 and 70%, compared to 30 to 50% for hybrid construction and 15 to 25% for panelized construction (Lawson, 2014).

According to Mostafa et al. (2016), the manufacturing and construction industry has an insignificant relationship.

However, the construction industry can grow and develop more significantly by adopting manufacturing applications such as lean principles.

Numerous merits of adopting and implementing MCS have been documented in the literature such as (Chen et al., 2010). Other identified benefits include a higher level of accuracy (Tam et al., 2007), enhanced completion duration (Ahmadian et al., 2016; Lee & Hyun, 2019), increased quality control (Ji and Xu, 2010), enhanced safety and reduction in space usage (Arashpour et al. 2016), enhance site management (Chen et al., 2010), efficient against adverse weather (Chiang et al., 2006), government encouragement and support (Tam et al., 2007), cost-saving (Lessing et al., 2005), reduce wastage (Nikmehr et al., 2017). Pan et al. (2012) also reports the benefits of implementing through literature which has been extensively studied, including life cycle performance, high return on investment, whole life cost, reduced reduction time, defects, health, and safety risk, environmental impacts, and increased predictability. Considering the available literature, it can be established that there is limited adoption and implementation of MCS and a lack of research regarding developing countries, especially African countries.

Existing literature on MCS has predominantly focused on factors influencing its implementation, with limited studies on strategies for implementation. This study aims to bridge the identified knowledge gaps, such as limited literature and the need for country-specific strategies for MCS implementation. Previous research has also called for further investigation into strategies for MCS implementation.

Therefore, this study aims to develop strategies for implementing MCS in the AEC industry of developing countries, specifically engaging professionals in the built environment industry. As highlighted in the literature, challenges faced by the AEC industry may vary across regions, emphasizing the need for region-specific research. Furthermore, most studies on MCS adoption and implementation have predominantly focused on developed countries, with limited literature addressing developing nations, particularly African countries. Hence, this study focuses on developing countries. The outcomes of this study will propose effective strategies that can serve as a pathway for implementing MCS in the AEC industry of developing countries.

2. Materials and methods

This study is structured into five distinct phases, as depicted in Figure 1. Its objective is to develop effective strategies for the implementation of MCS in the AEC industry of developing countries. The study employs a quantitative research approach to investigate the strategies, as it enables the collection of quantitative data, statistical analysis, and future replication (Saunders et al., 2016). Similar approaches have been used in previous construction-related studies (Bello et al., 2023a; Akinradewo et al., 2021; Olanrewaju et al., 2020). Given the difficulty in determining the research population, a snowball non-probability sampling technique was adopted, as seen in other MCS-related studies (Bello et al., 2023b; Akinradewo et al., 2021). The selection criteria for participants in the study require them to be chartered in their respective regulatory bodies, ensuring that respondents with relevant expertise contribute adequately. Initial participants are requested to refer other professionals to participate. Data was collected through a structured questionnaire with a five-point Likert scale, designed using Google Forms and distributed virtually among the respondents. This approach is considered cost-effective and efficient for distribution and collection.

A total of 227 responses were received and considered for the study, which is deemed sufficient based on previous construction-related studies (Akinradewo et al., 2021; Olanrewaju et al., 2020). The data were analyzed using Statistical Package for Social Science (SPSS) V26. Reliability and consistency of the data were assessed using Cronbach's alpha coefficient. According to Maree and Pietersen (2016), coefficients of 0.90, 0.80, and 0.70 are considered highly reliable, moderately reliable, and low reliable, respectively. The obtained data demonstrated a reliability coefficient of 0.876, indicating moderate reliability and suitability for analysis. Descriptive statistics (Mean Score (MS)) and inferential statistics (Kruskal-Wallis one-way ANOVA) were employed for data analysis, and the results are presented in tables for clarity.

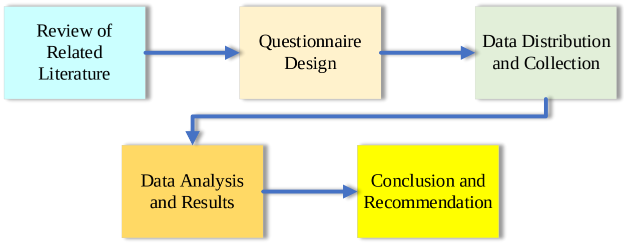

Figure 1: Research framework

3. Results

Table 1 shows the details of the respondents. As shown in Table 1 total respondent of 227 participated in the study. The estate and quantity surveyors are the least participated professionals in the study representing 1.32% and 2.64%, respectively. The builders have the highest participation in the study with 39.65%, followed by the engineer accounting for 31.28%, and architects accounting for 25.11%. The majority (52.42%) of the respondents possessed a Bachelor's degree, followed by a master's degree accounting for 37.89%, the Higher National Diploma (HND), Post Graduate Diploma, and Doctorate degree accounting for 5.73%, 2.64%, and 1.32% respectively. The years of experience ranged from less than 5 years to 21 years above. 53.30% of the respondents have 11-15 years of cognate experience representing the most significant percentage, followed by 16-20 years having 18.94% participation. Less than 5 years and 5-10 years account for 12.33% and 14.54%, respectively, and 21 years account for 0.88%, the minor participation. The respondents were asked to report the clients that majorly engaged their services; 81.94% reported that private clients engaged them mainly, and 18.06% reported government engagements. Lastly, the firm's size was reported as small, medium, and large, accounting for 79.30%, 17.18%, and 3.52%, respectively. The background of the study indicates that the respondents considered are adequately qualified to contribute meaningful responses to the study. The respondents have been trained academically and practically in their respective fields.

Table 1: Background of Respondents

Background of Respondents		
Professional Background	**Frequency**	**Percentage**
Architect	57	25.11
Builder	90	39.65
Engineer	71	31.28
Estate Surveyor	3	1.32
Quantity Survey	6	2.64
Total	**227**	**100.00**
Highest Academic Qualification		
HND	13	5.73
Post graduate diploma	6	2.64
Bachelor degree	119	52.42
Master's degree	86	37.89
Doctorate degree	3	1.32
Total	**227**	**100.00**
Years of cognate experience		
Less than 5 years	28	12.33
5-10 years	33	14.54
11-15 years	121	53.30
16-20 years	43	18.94
21 years above	2	0.88
Total	**227**	**100.00**
Main Clients of the Respondent		
Government	41	18.06
Private	186	81.94
Total	**227**	**100.00**
Size of Firm		
Small 0-49 employees	180	79.30
Medium 50-249 employees	39	17.18
Large 250 above employees	8	3.52
Total	**227**	**100.00**

3.1. Mean ranking of the developed strategies for MCS implementation

The rankings of the fourteen strategies are presented in Table 2 based on their mean scores, from highest to lowest. The results indicate that all fourteen hypothesized strategies are statistically significant ($p < 0.05$) for the implementation of MCS in developing countries. Table 2 also displays the Skewness and Kurtosis values, which were examined to assess data normality. The results indicate that the data are normally distributed. Furthermore, the investigation of maximum and minimum scores (not reported in the results) revealed no bias in the data. The range of MCS implementation strategies varies from "Increase of awareness among the professionals and stakeholders" (S-K = -1.186; K-S = 0.763; MS = 4.47; SD = 0.718; t = 20.291; df = 226; Sig = 0.000*), ranked highest, to "MCS research fundings" (S-K = -0.249; K-S = -1.340; MS = 3.75; SD = 1.117; t = 3.415; df = 226; Sig = 0.001*), ranked lowest.

A benchmark of 3.5 was used to determine the significance of the MCS implementation strategies based on the mean scores. This benchmark has been employed by Olanrewaju et al. (2020) to assess the importance of different variables. All the MCS implementation strategies in this study exceed the benchmark of 3.5, indicating that they are all crucial for implementing MCS in developing countries. Additionally, the statistical significance of all fourteen hypothesized strategies was confirmed ($p < 0.05$). Since all the strategies exceed the set benchmark and are statistically significant, they are all essential for the successful implementation of MCS in developing countries.

3.2. Kruskal Wallis (one way ANOVA)

It is necessary to investigate the difference in the respondents' opinions (Architect, Builder, Engineer, Estate Surveyor, Quantity Survey) on the essentiality of the MCS implementation strategies. This informs the user of the Kruskal Wallis test and investigates the respondents' opinion variations. As shown in Table 3, there is no statistically significant difference in opinions on the hypothesized strategies for MCS implementation in developing countries. The finding in Table 5 indicates that irrespective of the professional background of the respondent, there was consensus among them on the strategies for MCS systems in developing countries.

Table 2: Mean Ranking of the Developed Strategies for MCS Implementation

Code	Strategies	S-K	K-S	MS	SD	Test Value = 3.5			R
						t	df	Sig. (2-tailed)	

STR1	Increase of awareness among the professionals and stakeholders	-1.186	0.763	4.47	0.718	20.291	226	0.000	1
STR2	Creating enabling environment within the industry	-1.091	0.251	4.43	0.758	18.531	226	0.000	2
STR3	Government participating in the usage of MC	-1.438	1.987	4.34	0.880	14.436	226	0.000	3
STR4	Adequate transportation system to transport large modules	-0.892	-0.081	4.24	0.900	12.349	226	0.000	4
STR5	Encourage interoperability among the professionals	-0.966	0.339	4.20	0.893	11.785	226	0.000	5
STR6	Institutions should be more rigorous in teaching MC	-0.807	-0.249	4.13	0.920	10.280	226	0.000	6
STR7	Encourage usage of new and improved technological tools such as BIM, IOT	-0.785	-0.474	4.11	1.001	9.188	226	0.000	7
STR8	Professional bodies to trained members and encourage usage of MC	-0.539	-1.007	3.91	1.073	5.783	226	0.000	8
STR9	Government subsidies on MCS	-0.519	-1.008	3.88	1.069	5.428	226	0.000	9
STR10	Establishing of policies and codes for MC	-0.505	-1.016	3.89	1.095	5.303	226	0.000	10
STR11	Establishing effective communication in the AEC industry	-0.444	-1.034	3.87	1.046	5.362	226	0.000	11
STR12	Encourage flexibility in AEC industry	-0.514	-0.841	3.85	1.046	5.362	226	0.000	12
STR13	Regular employees training on MC	-0.298	-0.898	3.80	0.996	4.566	226	0.000	13
STR14	MC research fundings	-0.249	-1.340	3.75	1.117	3.415	226	0.001	14

Note; S-K = Skewness, K-S = Kurtosis, MS= Mean Score, SD = Standard Deviation, df = Degrees of Freedom, Sig. Significance at 95% Level ($p < 0.005$), R = Rank

Table 3: Kruskal Wallis (One way ANOVA)

Code	strategies	Chi-Square	K-W	df	Asymp. Sig.
STR1	Increase of awareness among the professionals and stakeholders	178.974[a]	8.208	4	0.002*
STR13	Regular employees training on MC	89.278[b]	86.313	4	0.016*
STR14	MC research fundings	17.352[a]	96.340	4	0.007*
STR4	Adequate transportation system to transport large modules	187.339[b]	57.262	4	0.011*
STR2	Creating enabling environment within the industry	166.181[a]	15.990	4	0.038*
STR3	Government participating in the usage of MC	231.921[b]	5.652	4	0.020*
STR9	Government subsidies on MCS	121.219[b]	47.183	4	0.038*
STR12	Establishing effective communication in the AEC industry	25.282[a]	91.052	4	0.006*
STR5	Encourage interoperability among the professionals	170.819[b]	36.910	4	0.003*
STR7	Encourage usage of new and improved technological tools such as BIM, IOT	147.736[b]	85.480	4	0.041*
STR11	Encourage industry flexibility	88.705[b]	84.852	4	0.028*
STR8	Professional bodies to trained members and encourage usage of MC	31.907[a]	77.049	4	0.016*
STR6	Institutions should be more rigorous in teaching MC	74.269[a]	72.967	4	0.004*
STR10	Establishing of policies and codes for MC	92.361[b]	94.498	4	0.001*

Note; K-W =Kruskal Wallis, df = Degrees of Freedom

4. Discussion

Various strategies have been identified in this study to encourage the implementation of MCS in developing countries. Among these strategies, creating adequate awareness has been ranked as the highest, indicating that raising awareness about MCS is a crucial strategy for its implementation in developing countries. Wuni and Shen (2019) emphasize the importance of awareness in implementing MCS and highlight the lack of awareness as a critical barrier in the AEC industry. The results of this study support the belief that creating awareness is an effective strategy for implementing MCS in developing countries.

Another essential strategy for MCS implementation in developing countries is establishing an enabling environment. A conducive environment is crucial for the successful implementation of MCS as it provides the necessary conditions for its growth. This includes having appropriate regulatory frameworks, industry standards, and policies in place to facilitate widespread adoption of MCS and promote innovation in the industry.

Government plays a significant role in implementing modular construction, as seen in developed countries like the United Kingdom, United States, Sweden, China, and Hong Kong. Some developing countries, such as Malaysia and Singapore, have also followed suit and achieved positive outcomes in terms of MCS implementation (Wagner, 2022; Aderemi et al., 2019; Wuni & Shen, 2019). Adequate transportation is identified as a major barrier to MCS in developing countries, as highlighted in the literature (Adindu et al., 2020; Xu et al., 2019; Alagbe & Aina-Badejo, 2019; Faiz et al., 2016). Developing an efficient transportation system is crucial to overcome this challenge and promote the shift from traditional construction methods to MCS.

Universities and industry stakeholders play a crucial role in implementing MCS due to their expertise and resources. Universities can contribute through research and development, studying various aspects of MCS such as design, construction techniques, and materials. This research helps identify best practices and enhance the efficiency and effectiveness of modular construction. Universities can also provide training and education on modular construction, building a skilled workforce to support its implementation.

Industry stakeholders, including construction companies, manufacturers, consultants, and professional bodies, also contribute significantly to implementing modular construction. Their practical experience and knowledge help identify and overcome construction challenges. They can also ensure that modular units meet the required standards and regulations. Collaboration between universities and industry stakeholders is vital for successful modular construction implementation, leveraging their strengths and resources to drive innovation and improve project efficiency.

The use of technological tools like Building Information Modeling (BIM) and the Internet of Things (IoT) in modular construction offers significant benefits in terms of efficiency, accuracy, collaboration, flexibility, and sustainability. BIM facilitates communication and collaboration among different stakeholders, ensuring alignment and shared goals. Effective communication is crucial in modular construction, where coordination between design, prefabrication, transportation, and construction teams is necessary. Improved communication helps identify and resolve issues, leading to a smoother and more efficient MCS implementation. Modular construction involves prefabricating building components off-site before transportation and assembly on-site, resulting in faster construction times and increased efficiency. However, it requires different construction processes and a skilled workforce to be implemented effectively.

5. Conclusion

MCS has the potential to significantly benefit construction projects by reducing time and costs, improving efficiency and quality, and creating safer working environments. It also contributes to sustainability through reduced waste and energy consumption. The study developed fourteen effective strategies for MCS implementation, which were found to be essential and statistically significant. Regardless of their profession, the respondents held similar views on the strategies, indicating their importance for implementing MCS in developing countries.

MCS offers a promising solution to address the housing and infrastructure needs of developing countries, fostering social and economic development. This study contributes to the theoretical understanding of MCS implementation strategies and provides practical implications for industry stakeholders and governments in making informed decisions. Further research is recommended to conduct detailed cost analyses, explore design flexibility, evaluate durability and sustainability aspects, assess building codes and regulations, and conduct case studies of completed projects to gain more insights into the practical applications and limitations of MCS.

Based on the findings, it is recommended that industry professionals consider incorporating modular design and construction techniques into their projects due to the numerous benefits they offer. Future research should focus on conducting detailed cost analyses, including life cycle cost analysis, to compare the long-term economic benefits of modular construction with traditional methods. Exploring the design flexibility of MCS in adapting to different conditions and requirements is another important area for future investigation. Additionally, studying the durability, sustainability, and energy efficiency of modular buildings will contribute to their improvement. Evaluating local building codes and regulations concerning modular construction will provide insights into its adoption and acceptance. Finally, conducting case studies of completed modular construction projects will provide valuable practical insights and assess end-user satisfaction.

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