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ECONOMIC FACTORS INFLUENCING THE ADOPTION OF MODULARITY METHODOLOGY IN THE BUILT ENVIRONMENT

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Abstract: In the built environment, modularity methodology has become a viable substitute for traditional building techniques, with possible cost, efficiency, and sustainability advantages. The varying degrees to which modular building techniques are widely adopted across different locations and industries indicate the existence of economic considerations that impact decision-making processes. This study aims to understand better the many economic factors influencing the built environment's adoption of modularity methodology. The study employed a quantitative survey approach using a questionnaire to gather data from architects, civil engineers, quantity surveyors, mechanical and electrical engineers, construction managers, and project managers. The data were examined using SPSS, and inferential statistics and the appropriate measure of dispersion were applied. The research findings will aid in developing a thorough grasp of the economic factors influencing the use of modular construction, educating decision-makers in government, business, and investment, as well as developers about the advantages and disadvantages of doing so. Ultimately, the results will support sustainable economic development and innovation in the construction sector by facilitating the creation of evidence-based strategies and interventions to encourage a broader acceptance and integration of modular construction solutions in the built environment.
Keywords: Modularity Methodology, Investment, Cost Efficiency, Time savings

1 INTRODUCTION

Modularity is a term used to describe a methodology in the construction industry that has been around for at least half a century (Wuni et al., 2022). In recent years, modularity has been applied more frequently in construction and design in various built environments. Modularity is a methodology that uses a coordinated subdivision of a system into smaller parts which can be united to perform the whole system. Pervez et al. (2022) argued that the economical factor is a vital factor for the growth in implementing modularity methodology in the industry. As modularity gains recognition as a methodology capable of reducing costs for end-users, there has been a surge in research aimed at understanding its implementation in the design stage to achieve cost savings while simultaneously enhancing product quality Research in this field, like Abdelmageed & Zayed (2020); Wuni & Shen (2020), have concentrated on several facets of modular design to streamline procedures and maximise opportunities for stakeholders. These studies highlight how crucial modular interfaces, standardisation, and architecture are to enable smooth integration and assembly. Architects, designers and developers can obtain better flexibility, scalability, and reusability while cutting development time and costs by decomposing complicated systems into modular components. Uptake of modularity in the construction industry is intrinsically tied to economic factors (Yang et al., 2023). In general terms, modular systems are more suitable for temporary structures rather than permanent structures, however in some instances the whole life cost of a modular system can still be less than that of a traditional build. This is particularly relevant to systems required to quickly adapt to changes in functional requirements or those requiring frequent expansion. An advantage of modular systems is the speed of construction and the likely earlier project completion date compared to traditional construction (Gan et al., 2022). This can provide cost savings to the client in the form of earlier facility utilization or reduced labor costs and can also inject savings into the economy by completing projects ahead of schedule. For example, there are great cost savings to the public if a hospital can be built in 12 months rather than the usual 3-4 years.

One of the most significant economic factors influencing adoption of modularity is globalization (Young et al., 2020). Here the ability to reuse, reconfigure and redeploy modular systems provides cost-effective solutions to an increasingly mobile society. An example is the relocation of military facilities due to changes in strategic alignment and the use of temporary disaster relief facilities. This is also true for facilities built in developing nations whereby the construction of traditional infrastructure may not be cost effective given the possibility of future relocation, however this is juxtaposed with the skills transfer and infrastructure development that would occur with traditional construction. The economic factors of risk taking, flexibility, market demand, life cycle costs, competitive advantage, and modularity adoption fit within the neoclassical economic theory, which portrays firms as existing purely to maximize profits in the economy (Tsz et al., 2023). It is assumed that companies operate within a free market economy, competing against one another to offer products and services in demand by consumers. There is perfect knowledge of the market conditions and a given price and product are offered. Salama et al., (2021) opined that any divergence from perfect competition allows a firm to gain economic profit. In turn, the higher economic profit a firm has, the greater its stake in that industry. Should a firm make a loss, it will leave that particular industry. Economic models give way to optimal plant size and fixed/variable costs at which marginal cost equals marginal revenue (Ottasowie et al., 2024). For any innovation to be successful for a company, there must be a positive impact upon profits; either by cost reduction (leading to price reductions for consumers) or through product differentiation and increased sales. Taking into consideration cost efficiency as a means of achieving the same level of output with the least expenditure of resources, it is a good starting point to look at the factors affecting economies of scale for the industry. Should the building and construction industry have an increased use of off-site manufacture and larger prefabricated units, the nature of these products moves closer to manufacturing (Abdul & El-adaway, 2020). This is a sector where the industry is very much split between large and small firms, with the hopes of high subcontracting work for the larger firms and independent projects for the smaller. High dependency of small firms to carry out specific tasks would lead to inefficiency due to diseconomies of coordination among the firms. A larger firm aiming to subcontract work would incur the same problem. Thus, a product that is aimed to use companies specializing in one area, i.e. a subcontractor, to slot it into a greater whole, lends itself to being best provided by a large firm in a stable market position. Off-site construction enabling a switch to this method of production would only be undertaken by these large firms, citing risk management that smaller firms would default to reverting to on-site construction due to fear of lack of future work and economic hindrances (Knoppen & Knight, 2022). At this point, modularity could offer a way for the small firms to simulate their product with hopes of gaining future industry change. A large firm would adopt modularity as a means of product differentiation and high sales volume. In both cases, the aim would be cheaper production and cost efficiency with increased profit due to lowered costs.

Several academics have argued in favour of incorporating modular building techniques into the built environment, pointing to possible financial advantages. Guidelines for applying modular techniques, locating training data sources, and defining the kinds of data required for certain applications in the construction industry have been offered by several academics. The development of modular construction, together with the use of modularity methodology, has the potential to expedite the achievement of sustainable development goals. But many poor countries still fail to meet these goals, and the construction sector is still one of the least digitalized in the world, with difficulties in using digital technology and modular approaches. Numerous studies have connected economic barriers, such as cultural resistance, the high upfront costs of switching to modular construction, frets about security and trust, a lack of technical know-how, inadequate infrastructure for technology, and restricted access to dependable internet services, with the slow adoption of modular construction. It's clear that a number of unsolved financial concerns prevent modular construction techniques from being widely used. To close the current gap and fully utilise modular building to fulfil the needs of sustainable development, it is imperative to address issues like the economic variables driving modularity approach within the construction sector.

2 METHODOLOGY

The purpose of this study is to evaluate the economic factors influencing the adoption of modularity methodology within the built environment. The survey design was motivated by the use of a quantitative technique, which resulted in the use of a structured questionnaire survey. The structured questionnaire developed is similar to that Adekunle et al., (2024) that used closed-ended questions to gather input on the use of machine learning techniques in the construction sector. Participants in the research include academics and industry experts from South Africa's building industry who work for various organizations. The study employed random sampling and a snowball sampling strategy for data collection within the study population to get larger coverage. One hundred and fifty-six (156) questionnaires were collected, and each one was assessed for analytic readiness. The questionnaire was divided into two parts: one assessed the demographics of the respondents, and the other provided access to a wide range of barriers to the promotion of ML as identified by a careful analysis of the literature. Using Cronbach's alpha, the reliability of the research instrument was evaluated. The result of 0.916 achieved proved the validity of the research instrument used in the study. Furthermore, the result of the study was analysed using the mean itesm score (MIS) and Kruskal-wallis test to compare the independent groups when the dependent variable is measured on an ordinal or continuous scale.

3 FINDINGS AND DISCUSSION

The results showed that women, who made up 29.8% of the respondents, received less answers than men, who made up 70.2% of the respondents. In terms of profession, 15.2% of respondents were civil engineers, 11.5% were mechanical and electrical engineers, 30.8% were quantity surveyors, 19.4% were project managers for construction, and 23.1% were architects. Furthermore, contracting companies employed 38.4% of the respondents, the government employed 18%, and consulting firms employed 43.8%. The responses were trustworthy and respectable since, on average, more than 80% of respondents had over five years of work experience in the construction industry, a very high proportion.

The independent variables that reflect the economic factors impacting the built environment's adoption of modularity approach are listed in Table 1 below. It is evident that factors with the same mean were arranged according to their standard deviation, or how far they deviated from the mean. According to Mishra et al. (2019), the standard deviation (SD) measures how dispersed a set of data is in respect to the set's mean value. A large standard deviation (SD) number indicates that the data deviates significantly from the mean, whereas a smaller SD value indicates that all of the values fall within a tolerable range of the mean. Additionally, a Walli Kruskal-test was used to compare respondents' opinions based on the number of years of experience. Three difficult elements to the promotion of ML in the built environment—resistance to new methods, distrust of machine learning methods, and uncertainty of the required data—were demonstrated to not substantially differ from the mean values. The p-values are higher than 0.05, which is consistent with a research by Otasowie et al. (2023) that revealed no significant difference between variables with p-values more than 0.05 and vice versa. This is the result of the fact that the p-values are higher than 0.05. For the remaining factors, the mean values of each response group are statistically distinct.

Table 1: Demography of Interviewees

Factors	MIS	SD	R	P-Values
Time savings	4.84	0.893	1	0.000
Resource Optimisation	4.81	0.766	2	0.037
Scalability and Flexibility	4.73	0.881	3	0.000
Risk Management	4.73	0.640	4	0.003
Cost efficiency	4.68	1.046	5	0.000
Competitive Advantage	4.62	1.015	6	0.000
Labour costs and Availability	4.60	0.922	7	1.142
Technological Advancement	4.57	0.784	8	0.000
Stakeholder's Management	4.55	1.058	9	0.000
Financing Models	4.53	1.022	10	0.000
Market Demand	4.49	1.004	11	0.084
Regulatory environment	4.47	0.836	12	0.158
Life-cycle costing	4.44	0.945	13	0.015
Investment	4.25	0.967	14	0.000

According to the findings of this study the most influential economic factor to the adoption of modularity methodology in the built environment is time savings. Killingsworth et al. (2021) suggested that time is a key factor in the modular concept as reducing the amount of time it takes to produce a certain output has a direct equation to a saving in costs. The use of off-site construction with a well-managed and efficient manufacturing process in a controlled environment takes a large percentage of the build duration off the construction phase (Ramesh et al., 2022). First of which, it negates the possibility of any time loss due to bad weather or site-based issues that are often encountered with traditional methods of construction. This is because the manufacturing facility is not hindered by such environmental factors and the product can be stored and protected for when it is needed. However, Enshassi et al. (2022) argued that the presence of considerable uncertainty in market demand often poses a significant risk for construction investments. The utilization of modular construction can serve as an effective strategy to mitigate risk in an uncertain market. This is primarily due to the inherent flexibility of modular construction, as the modules can be customized in a large-scale manner, allowing for a higher level of postponement compared to traditional construction methods (Wuni et al., 2022). Consequently, companies can customize modules in close proximity to the time and location they will be utilized. This stands in contrast to customizing an entire system, as the modules can be conveniently stored until they are needed, thereby negating the need for a build-to-order system. The implementation of extensive postponement strategies and the ability to store modules can result in significant cost savings and heightened operational efficiency within a system (Pervez et al., 2022). Risk at any level affects the client, designers, the construction team, material and component suppliers. It is a problem if the implications or probability of its occurrence are not fully understood. The study by Salleh et al. (2023) revealed that the Malaysian department of occupational safety and health defined risk as the combination of the rate of an event occurring and its potential severity of harm or damage. Risk events can come from a myriad of different sources because of the complex and dynamic nature of the construction environment, which is often compounded by external factors. These factors can be anything from an economic downturn, change in government, fluctuation in material costs, fires, changes in legislation, or natural disasters. A large number of construction contracts were forced to be terminated because the clients had run out of money to finance the projects (Madah et al., 2022). Natural disasters such as earthquakes can present grave amounts of risk to an ongoing construction project. However, many past and present modular construction projects worldwide have sought to adopt a modular methodology primarily to escape from various problems being experienced in the conventional construction methods. This is often in a bid to create innovations in construction for change and sustainability in their pursuit of a better future. So therefore, the significance of considering modularity lies in its ability to reduce costs, provide efficient time and resources, and reduce risk and innovation (Bhosekar et al., 2021). This is primarily due to the standardization and optimization of the modules and interfaces between them. It has been argued that cost is one of the main driving factors behind the adoption of modularity. In the construction industry, projects are generally over budget and/or late. Whilst costs are often difficult to define, modularity begins to look more attractive. A specific cost advantage of modularity is the ability to mass-produce standard modules at a lower cost per unit than making a one-off product of equal quality. This is due to the experience and learning curve effects. If a module is described as durable, then future costs of replacement or maintenance can be minimized thus reducing the total life-cycle cost of a product. Furthermore, modularity can lead to cost savings from disassembly post building life for recycling and re-use of materials.

In addition, this study revealed that modularity offers firms the ability to respond to competitors' moves with greater speed and effectiveness than they can before adopting modularity approach as observed by Yan et al. (2022). A modular design is composed of a number of discrete sub-assemblies or modules. If the design of these modules is imitated by a competitor, the original design can be reverse-engineered in order to discover the precise arrangement and interconnection of modules. Then, only those modules which embody the truly distinctive features of the original design need be manufactured and assembled. This can be an extremely cost-effective method of closing the "advantage gap" between the original innovator and imitating firms. If the original design firm is first to market with the new modules, they can cause "confusion" in the eyes of the client if the imitating firm quickly follows with a similar product. The consumer may be uncertain as to which firm's product is the imitator. Also, the modules of the new design can be designed in such a way that they are easily adaptable to existing products, thus facilitating a strategy of product improvement and reduction in labor cost as a means of competition. Labor costs are a key determinant in considering the adoption of modular methodologies (Ribeiro et al., 2022). Building trades are cyclical in nature and during construction booms, the cost of skilled labor significantly increases. There is often pressure to complete projects quickly using onsite methods, so contractors override cost considerations and use labor inefficient systems. The study of Khan et al. (2022) revealed that in the UK construction industry, there is evidence to suggest a shortage of skilled labor. The skills shortage is partly driven by demographics and is exacerbated by an image problem relating to construction being hard work with long hours in an outdoors environment. Wage rates for skilled construction workers compared to other industries play a major role in attracting labor to the construction industry. Using manufacturing methods, skilled craftsmen can be trained to work in factories to produce standardized building components (Avva & Chamberlin, 2020). This training pathway can potentially attract apprentices to the industry with the promise of interesting work along with cleaner and safer working conditions. The productivity rates and wage levels in prefabrication can differ from region to region based on local economic and industry conditions. An area with low opportunity costs for skilled labor may mitigate the savings that can be achieved by switching from traditional methods.

Furthermore, it is crucial to talk about how expensive it might be to construct modular systems (Agapiou, 2022; Adekunle et al., 2022). Therefore, traditional procuring client organisations using operational budgets have historically perceived the ability to purchase design and build services on a phased or partial basis as unsatisfactory due to the lack of a fixed deliverable. This has reduced interest from potential providers in comparison to conventional approaches. The lack of perceived accessibility to project financing, from either internal or external sources, can be a significant inhibiting factor (Wuni & Shen, 2020). The often higher headline cost results from a front loading of expenditure in comparison to phase-based traditional contracts. This is particularly the case in systems applying a capacity for concurrent site and factory-based work which commodity type implementation should be aiming to avoid. A situation when viewed in terms of financing cash flow and risk in a life cycle cost context may offer no real cost disadvantage to the client organisation. However, it may be more difficult to perceive and/or effectively communicate the financial case. However, Investment is a resource most often considered in financial terms, but can be seen as broader in the sense of any resources committed towards an activity, with the expectation of some benefit (Beladi et al., 2021). It includes sunk costs in plant, equipment, and training, ongoing commitments to expenditure in areas such as R&D and marketing. Investment decision making tends to be oriented to the future, concerned with the prospective expected cash flows that the decision will generate and the level of risk attached to these. High levels of specificity in asset types increase the risks and costs associated with re-purposing or re-deploying assets and conversely increases flexibility. As such, there is a correlation between the level of investment and the time period the investor is seeking for payback of that investment. When compared to traditional building methods, the prospect for cost reductions and efficiency advantages generally draws investors to modular construction. Shorter project schedules, lower labour costs, less wasteful use of materials, and improved quality control are all possible with modular construction. Nevertheless, achieving these advantages usually necessitates an initial outlay of funds for worker training, production facilities, equipment, and modular design.

4 CONCLUSION AND RECOMMENDATION

The use of modular construction has been shown to be cost effective in repetitive building, such as family housing, and has become highly successful in Sweden in the implementation of their industrialized building system for home building. In Australia, similar systems can adapt from the Swedish industrialized building in learning from the blanket automation and rationalization of design into factory phase. In Singapore, the implementation of system products and off-site construction is highly successful in public housing and can be adapted to whole building or parts system products through design standardization of system parts. At the global level, the use of modularity in the production of system products based on new materials, technologies, and methods holds potential to revolutionize building processes and products. This may take a long time to filter to industry practices, but the development of new products methodology can be greatly accelerated by the saving from increased productivity and the shift in risk from clients to contractors mentioned earlier. Thus, the greatest economic benefits from modular methods may not come from the method itself but the enablement of further method and product development. It is widely believed that the greater standardization and productization of building components will allow a shift of work away from construction sites and into factories, thus improving safety and productivity while reducing skilled labor shortages. Industry penetration by external firms at the expense of on-site work by the client's own skilled labor can be shown to reduce overall economic efficiency for the project. This is suggestive of a complex interplay of sometimes conflicting economic interests between the various stakeholders in the built environment, but overall it seems clear that trends towards globalization and the adoption of manufacturing practices in construction will create an environment increasingly conducive to modular approaches.

Manufacturers of products aimed at the construction industry are witnessing a favourable environment for introducing modular products in the residential and non-residential building markets. Modular building is beginning to gain acceptance over traditional construction, and the interest in this method is growing as more companies begin to understand the cost, quality, and time benefits of this method. Under traditional building arrangements, it has been common for contractors to avoid any involvement in design as it commits them to a greater level of responsibility. Lack of contractor involvement in design has, in the past, led to the development of designs which are difficult and costly to build. High clarity designs with a full allocation of materials mean that contractors are able to provide more accurate quotes for the cost of construction. This, however, is a double-edged sword for modular building as high design clarity, documentation, and contractibility means that it will be easier for contractors to outsource the prefabrication at lower costs. With design work at the factory often being seen as a form of outsourcing, the move towards prefabrication will need to be supported by assurances of quality and reliability if the failure of the past is not to be repeated. The lack of skilled and experienced workers has been a barrier to modern methods of construction as an increase in mechanization and automation has led to a decreased demand for skilled labor. This has meant that MMC has had difficulty in attracting labor from traditional sectors of the construction industry. The quality of construction from MMC is often higher than previous methods, but there are as yet insufficient incentives for new skilled workers to enter the industry. The fact that tradesmen are often self-employed subcontractors means that it is hard to attract them away from short-term contracts with the promise of future training and development. The results of this research validate the importance of considering economic factors on innovation. The need for greater understanding at decision maker level is required for effective implementation of new methods and technologies. Pre-assembly of modules and just-in-time delivery can greatly reduce onsite materials inventories and the more controlled factory environment is conducive to certain recycling and reuse practices.

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