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Validating the Relative Importance of Technology Diffusion Barriers– Exploring Modular Construction Design-Build Practices in the UK

Hector Martin[a], Maia Garner[b], Anupa Manewa[b], and Aaron Chadee[c]

[a]Department of Civil Engineering, Queen's University Belfast, Belfast, UK; [b]Built Environment, Liverpool John Moores University, Liverpool, UK; [c]Department of Civil and Environmental Engineering, University of the West Indies, Port of Spain, Trinidad and Tobago

ABSTRACT

This research investigates the low use of modular construction despite its recognized cost, time, quality, safety, and sustainability advantages. Using technology diffusion theory, this study seeks to identify and rank the characteristics that impede modular building adoption, such as relative advantage, compatibility, complexity, trialability, and observability. A survey of industry professionals in the United Kingdom was undertaken, and the results, validated by a one-sample t-test, showed that attitudes toward modular building, rather than technical difficulties, are the key impediments to broad adoption. The degree to which modular construction resonates with prospective adopters' current values, past experiences, and requirements determines its acceptance. Traditional mind-sets, the presence of traditional constructs, resistance to change, prior attitudes, bid prices, hesitation, and skepticism are all associated with non-adoption. Professional positions serve as a bridge between adopters and non-adapters. The research also emphasizes the importance of design-build project delivery systems and early supplier chain participation in accelerating the mainstream adoption of modular construction.

KEYWORDS

Questionnaire validation; content validity; technology adoption; offsite manufacturing; sustainability

Introduction

The construction industry faces a variety of difficulties, including declining productivity, cost overruns, project delays, and environmental pollution. Various industry studies have emphasized these concerns at length (Farmer, 2016; GOV UK, 2021; Mace, 2018). In response to these urgent issues, modular construction (MC), a construction method that has the potential to provide transformative solutions, has emerged as a beacon of hope. With a market share valued at US$101.3 billion in 2022 and at a growth rate of 5.8%, the modular construction industry is projected to reach US$ 168.2 billion by 2031 (Transparency Market Research, 2023). Its 6.3% market share suggests significant efficiency potential (Modular Building Institute, 2023). MC evolves around offsite manufacturing, which involves the construction of high-precision prefabricated modules in controlled factory environments using computer-aided manufacturing techniques

CONTACT Hector Martin hector.martin@qub.ac.uk Department of Civil Engineering, Queen's University Belfast, Elmwood Avenue, Belfast BT9 6AZ, UK

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(Lawson et al., 2014; Velamati, 2012). MC has demonstrated the potential to improve key performance indicators such as productivity, quality control (Blismas et al., 2006), lifecycle costs, waste reduction (Jaillon et al., 2009), onsite safety (Fard et al., 2017), energy efficiency, and occupant comfort (Steinhardt & Manley, 2016). However intriguing it may be, the implementation of MC has not been universal. Despite its potential, MC is used in only 3–5% of new construction projects in North America (Ferdous et al., 2019). These statistics vary between 10 and 40% in Europe – where the UK, France, and Germany have rates below 10%, and Scandinavia globally dominates above 40% (Keyes, 2021; Rahman, 2014). Similarly, in Asia, Japan is a global leader, but India and Indonesia adopt cautiously owing to cost (Ferdous et al., 2019; Marinelli et al., 2022; Wu et al., 2019). On the continent of Africa, modular adoption is in a state of incipiency (Bello et al., 2023). This disparity between promise and achievement raises an important question: Why is the integration of MC into the conventional construction industry proceeding at an apparently lethargic pace despite the continued construction market delivery failures raised by Chadee et al. (2023)?

The profound divergence between the flexible requirements of construction supply chains and the precision-driven effectiveness of manufacturing supply chains is a fundamental barrier (Heaton et al., 2022). The integration of manufacturing and construction processes is not seamless, which makes bridging this divide a difficult task. Hussein et al. (2021) summarized strategies to improve supply chain management in the context of MC, pointing to the emergence of certain technologies as potential game-changers in this complex environment. In this group of technologies, digital applications stand out. Throughout the construction process, technologies such as Building Information Modelling (BIM), 3D printing, and autonomous automation have demonstrated the ability to facilitate smoother information exchange and collaboration between stakeholders. By combining digital expertise with conventional construction knowledge, these instruments have the potential to increase the precision and efficiency in the modular building construction industry. Nonetheless, as promising as these innovations may be, their successful implementation within the construction industry faces significant obstacles.

However, these obstacles need not impede the prospects for MC's widespread adoption. They require comprehensive insights that address stakeholder interactions, industry-wide perspectives, and the complex dynamics of modular construction (Khan et al., 2022; Wuni & Shen, 2020). Gaining a thorough comprehension of these obstacles and potential solutions requires a nuanced examination of the obstacles' underlying causes and strategies for overcoming them as barriers hinder the industry's assimilation and distribution of technology, impeding transformation and value realization (Barbosa et al., 2017).

The integration of design-and-build (DB) project delivery has emerged as a promising avenue in this pursuit, as procurement forms play a crucial role in promoting change, innovation, and efficiency in infrastructure delivery (Crook et al., 2002). The DB method integrates design and construction activities for modular components from the beginning to the final implementation; thus, it specifies the designer's code or standards in addition to the required material and labor (Heaton et al., 2022). This strategy streamlines the supply chain and has the potential for enhanced buildability, risk reduction, financial stability, and increased productivity (Chappell, 2008; Martin & Ramjarrie, 2021). Despite the compelling theoretical benefits, the practical realities of implementing this approach in the fragmented, project-focused construction industry remain complex and require additional explanation given Jones and Laquidara-Carr (2020) acknowledging that integrated project delivery with modular is preferred over traditional procurement methods.

Practitioners do not fully understand the enablers or areas where improvements are immediately needed to accelerate further adoption of modular approaches. Using technology diffusion theory, this study provides new insights into why modular buildings are not as prevalent as anticipated and why design-and-build procurement holds promise for promoting widespread adoption in the United Kingdom. This theory describes the incremental adoption and diffusion of new technologies in a market or industry (Acikgoz et al., 2023). It proposes that the adoption of emerging technologies comprises stages, including awareness, interest, evaluation, trial, and eventual adoption (Mukoyama, 2003) and is influenced by the characteristics of the technology itself, the characteristics of the adopters, and the prevailing environment. Critically, addressing MC obstacles requires more than just technological and supply chain efficiency, as posited in earlier research (Marinelli et al., 2022; Ribeiro et al., 2022; Wuni & Shen, 2020). This necessitates a comprehensive but incremental comprehension of the barriers affecting stakeholder attitudes, behaviors, and interactions with the current industry environment (Acikgoz et al., 2023; Azhar et al., 2013). Hence, this study examines the barriers, the process of technology diffusion, and the incorporation of MC into a design-and-build procurement structure. Consequently, our study answers the following question: What is the relative significance of technology adoption barriers when contemplating modular design-build projects? This work intends to demystify identified complexities, promote knowledge exchange, and shed light on the pathways leading to the widespread adoption of modular construction.

Context and practice of modular construction in the UK

The historical trajectory of modular buildings reveals a narrative characterized by the transformation of paradigms and the emergence of new possibilities within the realm of construction. The origins of prefabrication techniques in the United Kingdom can be traced back to the establishment of the Crystal Palace factory in 1851. This factory serves as a notable example of off-site manufacturing and on-site assembly, employing novel light and inexpensive iron, wood, and glass materials (Johnson, 2007). The period following World War II saw the rise of modular buildings, characterized by the implementation of prefabricated housing projects designed to meet the growing need for housing. The production of enameled steel homes was initiated with the intention of optimizing the housing market. Despite being manufactured in large quantities, their widespread adoption was hindered by the volatile nature of commodities markets and public apprehension toward housing constructed mostly from metallic materials. The course of postwar high-rise and prefabrication programs was significantly influenced by the partial collapse of Ronan Point in 1968. This occurrence served as a turning point in the narrative, intensifying worries over the quality and safety of prefabricated structures.

Upon contemplation of the immediate historical period, it becomes evident that the realm of modular buildings in the United Kingdom highlights not only its development but also its enduring obstacles. Approximately 10 years ago, modular construction constituted a small proportion of building projects, with just 2.1% of initiatives and 3.6% of new developments being attributed to this method (Buildoffsite, 2008). Following the global financial crisis, there was a significant decline in the yearly pace of new home buildings in England, reaching levels comparable to those observed in 1920. Specifically, between 2009 and 2010, a mere 115,000 new dwellings were erected (GOV UK, 2015). Currently, experts in the industry, such as Latham (1994), Egan (1998), and Farmer (2016), have emphasized the potential benefits of modular buildings. This has further emphasized the need for alternative solutions, as traditional techniques face challenges in meeting the increasing need for housing. Against this context, there was a noticeable but limited progression, with modular construction accounting for 7.5% of residential properties in the United Kingdom over the period spanning from 2017 to 2018.

In light of the United Kingdom's objective to address its housing deficit of 53,000 residences, coupled with the government's pledge to build 300,000 new houses each year, modular building has emerged as a crucial mechanism for achieving equilibrium between housing demand and supply (Hooper, 2019). The scholarly findings of Davies et al. (2018) highlight that labor shortages and weather limits are significant factors contributing to delays in traditional building projects, thereby impeding development at the construction site. In the present scenario, the utilization of off-site construction inside regulated industrial environments has a strategic benefit by effectively managing risks, accelerating the building process, and improving quality assurance. The potential of modular buildings extends beyond their efficiency, as evidenced by the ability of the same on-site labor to construct four times as many residences as conventional techniques in half the time (The National Audit Office, 2005). The aforementioned facts provide a significant challenge to the existing state of affairs and indicate the possibility of profound and impactful change.

When examining the trend toward prefabricated dwellings, the discourse has an inventive character. Initially conceptualized as a short-term solution to address housing shortages, modular modules are currently viewed as permanent solutions and a part of the housing transformation. In light of changing demands in the housing sector, there is a growing need to reassess the design and layout of both single-family and multi-family dwellings (Thai et al., 2020). When negotiating this change, it is crucial to comprehend its influence on stakeholders' attitudes and behaviors.

The different degrees of acceptance of modular buildings among countries have been further elucidated in the international environment. The United Kingdom is currently facing challenges related to the historical foundations of conventional building practices. By contrast, countries such as Japan and Sweden have adopted modular techniques, considering them an integral part of their cultural identity (Manley & Widén, 2019). The congruence between ideals and practices observed in these cultures facilitates the smooth integration of modular buildings into their construction milieu, effectively addressing the challenges posed by rising urbanization and spatial limitations (Sun et al., 2020). In contrast, it can be seen that within the United Kingdom, a complex interplay between existing societal conventions, perceptions, and aesthetic considerations gives rise to many obstacles that modular systems must navigate in order to achieve success. Moreover, labor dynamics play a significant role in contributing to the existing imbalance. The labor market in the United Kingdom's construction industry, which has historically been shaped by robust trade unions, has exhibited early reluctance toward the use of off-site fabrication methods (Agapiou, 2019). On the other hand, Japan and Sweden have undergone more seamless transitions because of their historical acquaintances with prefabricated components. The intricate interactions described here constitute the primary aspect of the global divergence in the acceptance of modular buildings.

In brief, the developmental trajectory of modular buildings in the United Kingdom has been characterized by a combination of advancements and ongoing obstacles. The complex interplay among culture, politics, industry, and urban dynamics is evident in the global context of modular buildings. Gaining a thorough understanding of these contexts by conducting an extensive analysis of relevant scholarly works reveals a complex web of historical perspectives and current necessities that jointly influence the course of modular construction's development. Notably absent is the role of technology in this understanding.

Technology diffusion theory

Roger's Diffusion of Innovation (DOI) Theory was introduced in 1962 (Rogers et al., 2014), making it one of the earliest concepts in social science. Rogers (2003) argued that diffusion theory emphasizes a series of decisions, actions, and choices that influence the evaluation of new ideas anterior to their widespread acceptance. In the context of technology diffusion, it takes substantial time for individuals within an economy to adopt new technology. The diffusion of innovations includes patterns that explain the how and why of diffusion, as well as the rate at which new ideas, behaviors, or products proliferate within a community. In contrast to other theories of change that emphasize persuading individuals to alter their behaviors, diffusion theory focuses on the evolution or "reinvention" of products and behaviors to better meet the requirements of individuals and groups. When analyzing the diffusion of innovations, it is the innovations themselves that endure change, not the individuals (Robinson, 2009). Thus, diffusion is as important as innovation, as new technologies cannot have a significant economic impact until they are broadly adopted (Mukoyama, 2003). When each adopter perceives the advantages of new technologies, the rate of adoption increases significantly. Relative advantage, compatibility, complexity, trialability, and observability are the five primary factors that influence innovation adoption. Relative advantage refers to the degree to which an innovation is perceived as superior to its antecedents, whereas compatibility refers to the degree to which it aligns with the values, prior experiences, and requirements of potential adopters. The level of difficulty associated with comprehending and implementing modular approaches is referred to as the complexity. Trialability refers to the extent to which an innovation can be tested on a small scale, whereas observability refers to the innovation's visibility (Rogers et al., 2014).

Although the theory focuses primarily on the adoption of behaviors as opposed to their cessation or prevention, its limited application in construction research has resulted in fragmented and inadequately explained interactions among the previously proposed factors that account for the diffusion of modular approaches (Ezcan & Goulding, 2022; Shin et al., 2022). Recent research has sought to broaden the application of diffusion theory, specifically in the context of modular technological process innovation for 4D BIM and its potential to improve construction planning (Gledson, 2021). Specifically, Shin et al. (2022) contributed to a greater understanding of the adoption of modular practices at the industry level. Their research expanded the concept of technology beyond its technical characteristics and incorporated the notion of expected outcomes. The study found that outcome expectations, private interests, and institutional barriers significantly affected attitudes and behavioral intentions, with perceived utility and perceived ease of use serving as mediators. Private interests emerged as the most influential factor influencing technology adoption, while institutional barriers reduced perceived utility and affected attitudes (Shin et al., 2022). Using this information as a foundation, the current research investigates the relationship between modular construction scalability, visibility, and its compatibility and comparability with extant approaches, as well as the design and construction context.

Research method

Research philosophy and approach

The research is grounded on a philosophical and methodological framework that is rooted in positivist empiricism. This framework emphasizes acquiring knowledge through a systematic combination of sensory experience, reason, and logic. The aforementioned philosophical standpoint functions as a guiding principle in exploring obstacles to the adoption of modular Design-Build projects within a technological framework. Consistent with this philosophical standpoint, the research methodology adopts a deductive path, wherein the investigation starts with established ideas and subsequently collects and examines empirical evidence to corroborate existing assumptions. The purpose of this deductive approach is to establish a logical progression from theoretical concepts to empirical evidence, with the aim of shedding light on the complex dynamics of modular construction.

Research design

The core of this research project is a cohesive integration of a comprehensive study of existing literature and a carefully designed questionnaire survey. This deliberate combination aligns with the complexities of the research inquiries being addressed. The purpose of this coordinated interaction is to elucidate the subtle complexity surrounding impediments to technology adoption, specifically in the context of modular Design-Build projects.

The primary objective of this study design is to analyze the quantitative aspects in order to determine the relative importance of obstacles in the context of modular Design-Build projects. Theory triangulation has been used to increase the validity of the findings; hence, the literature review was used to inform the data collection and explain the quantitative findings. Patton (1999) asserts that this reduces the specific limitations associated with the data collection method. By adopting the empirical rigor inherent in the scientific process, this approach has the potential to shed light on overarching patterns, linkages, and insights that go beyond specific instances (Gerdes & Conn, 2001). This, in turn, allows for a comprehensive understanding of the barriers to technological adoption.

Questionnaire design

The structure of an effective questionnaire intricately interweaves methodological precision and dynamic aspects of content validity (Creswell, 2002). In this endeavor, the current study developed its questionnaire by harmonizing the literature with the evolving complexities of technology diffusion. The curation of publications was guided by availability while exploring Google Scholar, establishing a foundational diversity in modular construction methods. The search terms included modular, barriers, uptake, and dissemination. The illustrative Table 1 reveals that categorical dimensions such as financial, attitude, industry, process

Table 1. Literature analysis of barriers to the uptake of modularization

	Principal grouping of Barriers							
Authors	Financial	Attitudinal	Industry	Process	Technical	Aesthetic	Knowledge	Policy
O'Connor *et al.* (2014)					X			
Elnaas *et al.* (2014)	X	X		X			X	X
Wuni and Shen (2020)	X	X	X	X	X	X	X	X
Goodier & Gibb (2007)	X	X	X				X	X
Rahimian *et al.* (2017)	X	X		X	X		X	
Rahman (2014)	X	X	X				X	X
Blismas & Wakefield (2009)	X	X		X			X	
Pasquire & Gibb (2002)	X	X		X		X		
Ku & Taiebat (2011)	X	X					X	X
Pan *et al.* (2007)	X	X	X	X	X	X	X	X
Blismas & Wakefield (2009)	X	X		X	X		X	

technicality, aesthetics knowledge, and policy surfaced as signposts across this spectrum. However, the evolution of technology diffusion necessitated a more nuanced perspective on these classifications, recognizing that innovation's trajectory transcends individual progress. In response to this call for change, a recalibration ensued, condensing 11 seminal publications through the prism of innovation diffusion.

Yusoff (2019) six staged content validation process of preparing the content validation form (questionnaire grouping to confirm), selecting a review panel of experts, conducting content validation, reviewing the domain and items, providing scores for each item, and calculating CVI was adopted. Through meticulous amalgamation, rephrasing, and synthesis, the authors used meta-analysis to develop a validation form of the condensed classification of the 40 barriers. In this process, questions about existing barriers and how they met the tenets of technology diffusion were answered for each factor identified under each new categorical dimension.

There are no hard and fast guidelines regarding a validation panel size, as validation is mathematically determined. However, at least two persons must be used, and time and money considerations are good guides (Yusoff, 2019). This study uses Heaton et al. (2022) suggested four criteria: familiarity and experience with the topic, willingness and capacity to contribute, availability to engage, and effective communication skills for selecting questionnaire validators. In addition, job designation within the construction industry was relevant, as questions can only be deemed relevant within the expertise domain of practice and understanding (Rowe et al., 1991). Two persons were selected: a practitioner currently working in modular planning, design, construction, and deployment and an academic to provide a grounded understanding of the theoretical domain. The insight of an expert in the field and the knowledge of an experienced professor improved the quality and clarity of the instrument.

Reviewers were notified that the instrument contains six domains and 40 items related to technology diffusion and that their judgment on the degree of relevance of each item to the measured domains was needed. It was indicated that their reviews should be based on the definition grouping and relevant terminologies that were provided to them. Reviewers ranked each questionnaire item on a 4-point scale, where 1 is irrelevant to the measured domain, and 4 is highly relevant to the measured domain. Prior to calculating the content validity index (CVI), the relevance rating was recorded as 1 (relevance scale of 3 or 4) or 0 (relevance scale of 1 or 2). CVI = (Number of Experts Rating "Highly Relevant" + Number of Experts Rating "Somewhat Relevant")/Total Number of Experts. The number of experts who agree on an item divided by the total number of experts yields the Item Content Validity Index (I-CVI). Based on I-CVI, the Scale Content Validity Index/Average (S-CVI/Ave) is calculated by averaging the I-CVI values for each item.

Apart from the variable "lack of confidence," which scored .5, all other items obtained an item-level content validity index of 1. The scale-level content validity index based on the average of the 40 items was .98. A content validity index at or above .8 validates the instrument (Yusoff, 2019). See Table 2. This meticulous validation process applied to produce the final questionnaire before administration enhanced the content's validity and aligned with the fundamental tenets of Rogers' (Rogers, 2003) technology diffusion theory.

The questionnaire's structure unfolds as a two-fold narrative. The first domain, which has demographic questions, reveals the participants' professional profiles by delineating their industry positions, experience, and design-build (DB) competence. This foundational context lays the groundwork for the second dimension, in which participants' modular construction experiences illuminate the narrative of adoption (Ribeiro et al., 2022). During the course of the questionnaire administration, participants' responses are reduced to a five-point Likert scale ranging from 1 representing "strongly disagree" to 5 indicating "strongly agree." This scale choice, supported by Chang's (1994) observations, finds a balance between granularity and participant clarity, deftly avoiding the perils of response confusion or the "laziness phenomenon." The design of the questionnaire resembles a crucible in which methodological precision and the dynamism of technology diffusion coexist. A nuanced recalibration, synthesized and theoretically enriched content, imparts vitality to the instrument to evaluate barriers in modular design-build projects.

Sampling and data collection

When establishing a technique that is characterized by accuracy and ethical soundness, the careful selection of participants and meticulous data collection organization is of utmost importance. Purposive sampling is a method that is grounded in the naturalistic inquiry philosophy (Patton, 1990). It serves as a guiding principle, ensuring that the selection of participants for a research study is aligned with the specific requirements and demands of the study. The intentional selection of purposive sampling drawn from LinkedIn search recognizes the distinct composition of participants within the United Kingdom. The participant selection strategy was intentionally inclusivity. To ensure a diverse representation, participants came from varied organizational categories, industry positions, and experience levels. This decision was made because various professional practices engage in modular deployment and, thus, prioritizing those from construction-focused organizations and essential positions, such as Construction Managers, Designers, Quantity Surveyors, and Project Managers, were expected to yield insights. To increase the depth of the study and enrich the dataset, a variety of experiences were considered, incorporating design and build and modular prior or no-prior utilization. Such broad data capture facilitated a comprehensive snapshot of the construction industry. This methodological framework acknowledges the inherent value of key situations, typical examples, convenience, and maximal variety in augmenting the depth and breadth of insights obtained. In the context of data collecting, the process naturally evolves since participants themselves serve as conduits for broadening the study's range. The growth of this study, like a snowball effect,

Table 2. Validation of questionnaire instrument

Variables	Expt. 1	Expt. 2	Expert in agreement	I-CVI	UA
RELATIVE ADVANTAGE					
Uncertainty Risk	1	1	2	1	1
Ascertaining Benefits	1	1	2	1	1
Limited Chances for Repeatability	1	1	2	1	1
COMPATIBILITY					
Client Attitude	1	1	2	1	1
Limited Experience	1	1	2	1	1
Understanding Cost of Supply Chain	1	1	2	1	1
Lead-in Time	1	1	2	1	1
Dominance of Traditional Construction	1	1	2	1	1
Fragmentation of the industry	1	1	2	1	1
Conventional Mindset	1	1	2	1	1
Lack of Technical Guidance	1	1	2	1	1
Resistance to Change	1	1	2	1	1
Capital Cost	1	1	2	1	1
Lowest Bid Price	1	1	2	1	1
Obtaining Finance	1	1	2	1	1
Past Sentiments	1	1	2	1	1
TRIALABILITY					
Lack of Tested Supply Chain	1	1	2	1	1
Need for Large Crane	1	1	2	1	1
Unsuitability for Smaller Projects	1	1	2	1	1
Limited Understanding	1	1	2	1	1
Design Inflexibility	1	1	2	1	1
Immature modular System	1	1	2	1	1
Lack of Standard Components	1	1	2	1	1
Uncertainty of Demand and Supply	1	1	2	1	1
OBSERVABILITY					
Monotony of Structure	1	1	2	1	1
Blandness and Uniformity of Outlook	1	1	2	1	1
Fear of City Standardization	1	1	2	1	1
Impaired Aesthetics	1	1	2	1	1
COMPLEXITY					
Lack of Customizability	1	1	2	1	1
Logistic Cost	1	1	2	1	1
Reluctance and skepticism	1	1	2	1	1
Lack of Confidence	0	1	1	.5	0
Lack of Skills	1	1	2	1	1
Complex Interfacing	1	1	2	1	1
Geographical Constraints	1	1	2	1	1
GOVERNMENT AND ORGANISATIONAL ENVIRONMENT					
Organizational Mechanisms	1	1	2	1	1
Lack of Policy	1	1	2	1	1
Lack of Government Support	1	1	2	1	1
Absence of Subsidies	1	1	2	1	1
Lack of Regulatory Framework	1	1	2	1	1
PROPORTIONAL RELEVANCE	0.975	1	S-CVI/Ave	0.9875	
Average proportion judged as relevance across 2 experts	0.9875		S-CVI/UA		.98

I-CVI Item level content validity index.
S-CVI/Ave Scale-level content validity index using average method.
S-CVI/UA Scale level content validity index universally agreed.

aligns with the principles of naturalistic inquiry and allows participants to actively influence the direction of the research (Gerdes & Conn, 2001). The fostering of a participant-driven "flow" is a change from the traditional approaches of researcher-directed or randomized sampling. Motivated by ethical considerations, the initiation of this endeavor involves the dissemination of invitations to 50 potential participants via electronic means using Linked-in and e-mail. The cover letter that accompanies the questionnaire demonstrates a commitment to openness by encouraging participation while also ensuring the protection of individual rights such as privacy, anonymity, confidentiality, and the option to withdraw. Offering anonymity on the questionnaire reduced social pressure and thus may likewise reduce social desirability bias (Chung & Monroe, 2003). As the process of collecting data progresses, each individual response contributes to a tapestry that is formed by the amalgamation of many experiences and views. These observations converge to form a comprehensive understanding of the obstacles that impede using modular technology in Design-Build projects. Once the number of participants exceeds 30, a diverse range of opinions begins to emerge, providing valuable insights for the upcoming stages of research. The 38 completed responses were deemed satisfactory because it satisfied a normally distributed sample (Field & Miles, 2009). In alignment with the commitment to thoroughness and precision, the use of quantitative power statistics of .8 or higher serves as a valuable measure in assessing the dependability of the research findings, therefore affirming the accuracy of the collected data. A power statistic of .8 or higher avoids Type I and Type II statistical errors (Sheppard, 1999). The strict adherence to ethical guidelines emphasizes the methodology's dedication to scholarly quality, guaranteeing that participants' perspectives are respected while also making a valuable contribution to the wider field of knowledge on modular building.

Analysis method

The questionnaire results were analyzed using the statistical package for social scientist (SPSS-21) software. The internal consistency and reliability of the five-point Likert Scale were tested using a Cronbach alpha of .7. The Relative Importance Index (RII) was used to rank the barriers in each group. Higher values of RII indicate that the perceived barrier is more problematic than lower RRI. RII was evaluated in Microsoft Excel 2016 using the following equation:

$$RII = \frac{\sum_{i=1}^{5} w_i x_i}{\sum_{i=1}^{5} x_i} \quad (1)$$

Where: w_i = the weighting to the ith response ($w_i = 0,1,2,3,4$ for $i = 1,2,3,4,5$ respectively)

x_i = the frequency of the i^{th} response; i = the response category index = 1,2,3,4,5 ranging from strongly disagree to strongly agree.

The one-sample t-test was used to test the hypothesis at the 95% significance confidence level, where $p \leq .05$ indicates that the difference between the true mean (μ) and the comparison value (m0 = 3) is equal to zero. A comparison value of 3 or more is interpreted to signify that those participants did not disagree that a particular factor is considerably significant to the use and nonuse of modular approaches. The independent T-test (at $p \leq .05$) was used to determine the confidence interval for the responses. The following hypotheses were tested:

H1: *Disparity exists between designers' and construction professionals' perceptions of the technology diffusion factors affecting modular construction uptake.*

Table 3. Demographics of the sample

Personal Profile	Categories	Per cent
Organization Type	Design	31.6
	Construction	68.4
Industry Role	Construction Manager	57.9
	Quantity Surveyor	13.2
	Project Manager	7.9
	Engineer	7.9
	Architect	2.6
	Contractor	2.6
	Building Services	2.6
	Engineer	2.6
	Other	2.6
Industry Experience	0–5 years	60.5
	6–10 years	15.8
	11–15 years	7.9
	16+ years	15.8
Design & Build Experience	Yes	71.1
	No	28.9
Modular Experience	Yes	63.2
	No	36.8

H2: *Disparity exists between the perception of adopters and non-adopters of the technology diffusion factors affecting modular construction uptake.*

Analysis and discussion

Population demographic profile

Table 3 shows the demographic characteristics of the 38 respondents. Accordingly, most participants originate from design organizations, with more than half representing construction management professionals having 0–5 years of industry experience, working on a design-build project, and prior experience with modular construction. The Cronbach alpha for this study is .903, a value deemed acceptable (Bonett & Wright, 2015).

The relative importance of the perceived barriers

Within the ever-evolving field of construction innovation, the process of adopting modular building techniques is not an isolated endeavor hindered by conventional obstacles. Instead, it is closely intertwined with the core concepts of innovation diffusion theory. This discussion examines the primary obstacles identified in Table 4, which include the conventional mind-set, the dominance of traditional construction practices, resistance to change, historical sentiments, and the focus on the lowest bid price. Notably, the five top-ranked factors align with the technological compatibility category. These factors are the main hindrances that impede the smooth integration of modularization. Nevertheless, it is important to note that these barriers are not standalone entities but rather interconnected with the dominant attitudes and opinions inside the sector. The interdependent connection between barriers and attitudes offers significant insights into the complex issue of compatibility in the diffusion of technology. This analysis provides a nuanced comprehension of the intricate

Table 4. One sample t-test, factor relative importance and rank

Variables Test Value = 3	t	Mean	Sig. (2-tailed)	Std. Deviation	95% Confidence Interval Lower	 Upper	RII	Rank
Relative Advantage								
Uncertainty Risk	−3.698	2.45	.001	.921	−.86	−.25	1.45	39
Ascertaining Benefits	4.263	3.68	.000	.989	.36	1.01	2.68	10
Limited Chances for Repeatability	−2.217	2.63	.033	1.025	−.71	−.03	1.63	38
Compatibility								
Client Attitude	1.762	3.26	.086	.921	−.04	.57	2.26	19
Limited Experience	3.765	3.53	.001	.862	.24	.81	2.53	13
Understanding Cost of Supply Chain	.662	3.11	.512	.981	−.22	.43	2.11	23
Lead-in Time	3.932	3.74	.000	1.155	.36	1.12	2.74	6
Dominance of Traditional Construction	6.429	4.18	.000	1.136	.81	1.56	3.18	2
Fragmentation of the industry	3.340	3.50	.002	.923	.20	.80	2.50	14
Conventional Mindset	7.638	4.24	.000	.998	.91	1.56	3.24	1
Lack of Technical Guidance	2.124	3.42	.040	1.222	.02	.82	2.42	17
Resistance to Change	8.849	4.05	.000	.733	.81	1.29	3.05	3
Capital Cost	4.386	3.68	.000	.962	.37	1.00	2.68	10
Lowest Bid Price	5.376	3.79	.000	.905	.49	1.09	2.79	4
Obtaining Finance	−1.916	2.68	.063	1.016	−.65	.02	1.68	37
Past Sentiments	3.876	3.79	.000	1.255	.38	1.20	2.79	4
Trialability								
Lack of Tested Supply Chain	.681	3.11	.500	.953	−.21	.42	2.11	23
Need for Large Crane	1.880	3.34	.068	1.122	−.03	.71	2.34	18
Unsuitability for Smaller Projects	−.488	2.92	.628	.997	−.41	.25	1.92	32
Limited Understanding	.312	3.05	.756	1.038	−.29	.39	2.05	29
Design Inflexibility	3.782	3.74	.001	1.201	.34	1.13	2.74	6
Immature modular System	.000	3.00	1.000	.697	−.23	.23	2.00	30
Lack of Standard Components	.442	3.08	.661	1.100	−.28	.44	2.08	25
Uncertainty of Demand and Supply	.552	3.08	.584	.882	−.21	.37	2.08	25
Observability								
Monotony of Structure	4.120	3.71	.000	1.063	.36	1.06	2.71	9
Blandness and Uniformity of Outlook	2.607	3.45	.013	1.058	.10	.80	2.45	15
Fear of City Standardization	.433	3.08	.668	1.124	−.29	.45	2.08	25
Impaired Aesthetics	1.245	3.24	.221	1.188	−.15	.64	2.24	20
Complexity								
Lack of Customizability	−1.356	2.76	.183	1.076	−.59	.12	1.76	35
Logistic Cost	1.483	3.21	.146	.875	−.08	.50	2.21	22
Reluctance and skepticism	5.281	3.74	.000	.860	.45	1.02	2.74	6
Lack of Confidence	1.653	3.24	.107	.883	−.05	.53	2.24	21
Lack of Skills	3.258	3.63	.002	1.195	.24	1.02	2.63	12
Complex Interfacing	−1.653	2.76	.107	.883	−.53	.05	1.76	35
Geographical Constraints	−4.668	2.32	.000	.904	−.98	−.39	1.32	40
Government and Organisational Environment								
Organizational Mechanisms	−.842	2.87	.405	.963	−.45	.19	1.87	33
Lack of Policy	2.607	3.45	.013	1.058	.10	.80	2.45	15
Lack of Government Support	−1.045	2.82	.303	1.087	−.54	.17	1.82	34
Absence of Subsidies	.517	3.08	.608	.941	−.23	.39	2.08	25
Lack of Regulatory Framework	−.172	2.97	.864	.944	−.34	.28	1.97	31

dynamics that either hinder or facilitate the adoption of modular construction methodologies.

According to Wuni and Shen (2020) research, the impediments that hinder the extensive use of modular construction may be attributed to societal norms and attitudes. The decision-making processes that underpin the acceptance of innovative approaches are guided by attitudes shaped by the fundamental elements of innovation diffusion theory, including relative advantage, compatibility, complexity, trialability, and observability. The notion of relative advantage encompasses the degree to which an invention is judged to exceed its predecessors. In the realm of modular building, the primary obstacle comes in properly conveying its advantages over conventional techniques, therefore overcoming the constraints presented by the prevailing mind-set and deeply ingrained traditional construction practices. In contrast, compatibility is dependent on the extent to which an invention corresponds with the values, previous experiences, and requirements of potential users. The presence of resistance to change and historical attitudes highlights the existence of hurdles that indicate a lack of alignment between the modular approach and established standards, hence impeding its smooth integration. Alternatively, incentives and regulations can be implemented to promote guarantees, warranties, and certifications for MC products, thereby providing lenders and consumers with the same level of confidence as conventional construction methods.

The impression of complexity plays a crucial role in the process of adoption, as it refers to the level of difficulty involved in understanding and adopting modular solutions. For example, determining who is responsible for rehiring due to delays and the risks and title transfers associated with module delivery and unit-size programming where multiple levels of examinations are required contributes to uncertainty on the part of customers and project professionals. The aforementioned perspective has a direct influence on the level of resistance toward change, as a perceived increase in complexity can amplify skepticism and hesitation. It is crucial to address and reduce the impression of complexity in order to minimize the resistance that is sometimes experienced while implementing a new system or process. The notion of trialability, which refers to the degree to which an invention may be tried on a smaller scale, carries significant implications in the context of modular construction as it allows for the experimentation of individual components before their full deployment – hence reducing concerns associated with untested methodologies. Moreover, the concept of observability, which refers to the extent to which an invention is visible, plays a crucial role in influencing opinions. The objective at hand is to enhance the prominence of successful modular initiatives, enabling prospective adopters to directly encounter the advantages and, therefore, alleviate doubts or hesitations. This is necessary as individual's perceptions of the usefulness and ease of use of a particular technology influence their intent to employ it and actual user behavior (Davis et al., 1989).

The significance of these characteristics becomes apparent when considering the contrast between obstacles and attitudes in the context of modular construction. The observability difficulty is highlighted by the historical difficulties encountered in the implementation of prefabrication solutions. These setbacks have had a lasting impact on the industry's awareness, sometimes overshadowing the potential advantages of modular construction. The prioritization of the lowest bid price, along with considerations about cost-effectiveness, corresponds to the concept of relative advantage. In order to address this matter, it is necessary to emphasize the extensive and enduring benefits associated with modular approaches, therefore altering the impression of relative superiority in favor of modular construction.

The complex interplay between obstacles and attitudes is prominently observed in the domain of financial considerations. The significant financial obligation associated with substantial initial capital expenses, as emphasized by Rahman (2014), aligns with the concept of complexity, which involves a substantial upfront expenditure that may seem overwhelming, but ultimately provides a range of long-lasting benefits. The complicated and untested nature of a system might combine with opposition to change, leading stakeholders to display caution in investing. However, the inherent modularity not only poses difficulties but also provides an opportunity for trialability. The utilization of small-scale implementations can effectively demonstrate the practical advantages of modular building, therefore mitigating the uncertainties associated with its complexity. This is achieved through replicability, which promotes learning and facilitates a feedback cycle that uses the knowledge gained from one module to enhance the next, resulting in improved risk mitigation and delivery quality with each iteration. This principle of modularization, in which the whole is greater than the sum of its parts, enables testing prior to full-scale deployment and ensures quicker deployment, thereby enhancing learning, reducing costs, and enhancing safety and efficiency (Flyvbjerg, 2021).

Furthermore, there has been a notable change in the industry's viewpoint, as it has gradually acknowledged the inherent worth of modular building. This movement in perspective is in line with the notion of compatibility. The transformation of these attitudes relies on the efficient communication of the compatibility between modular techniques and the current values and requirements of the construction industry. The alignment with a larger industry strategy facilitates the mitigation of hurdles presented by established traditional construction supremacy, thereby enabling a wider adoption. Culturally, there will be reluctance until manufacturers and consumers perceive MC as a worthwhile investment.

Comparison of perceptions of design and construction professionals

As identified by Bagozzi et al. (1992), the evaluation of utility and efficacy in modular construction is influenced by human variations and system characteristics. Table 5a highlights the significance of observability diffusion characteristics in highlighting the differences between design and construction experts when utilizing modular construction techniques. Eight criteria ranked higher among construction professionals than designers, indicating their heightened attention to specific aspects. However, the remaining 32 criteria were evaluated identically by both design and construction professionals, indicating significant differences among stakeholders regarding the importance of modularization's obstacles.

Interestingly, aesthetics account for fifty per cent of the criteria that revealed significant disparities between design and construction experts. This indicates a disparity in the acceptability and adoption of modular construction, which is partly influenced by concerns that modular projects compromise design and result in a decline in aesthetic appeal. Professionals in the construction industry place a greater emphasis on aesthetic factors than their design counterparts, indicating a concern that architectural creativity is constrained and can lead to configuration monotony during the operational phase (Wuni & Shen, 2020). It is essential to note, however, that this emphasis on aesthetics by designers may be a result of their lack of experience with modular construction and not necessarily a reflection of the inherent rigidity of the approach.

Inadequate comprehension of the processes involved in modular construction is one of the fundamental obstacles, as it impedes the accurate interpretation of industry-specific benefits. As a result, organizations continue to resist innovation and modular construction. Uniqueness in form contributes to aesthetics (Nanay, 2016), but contractors vying for

Table 5. Independent sample T-test

Variable	F	Sig.	T	Significance 2-tailed	Mean difference	95% confidence interval Lower	Upper
a - Design and construction professionals							
Reluctance and skepticism adopting modular	3.360	.075	−2.048	.048	−.590	−1.174	−.006
Difficulty ascertaining Benefits	23.116	.000	−2.567	.023	−1.000	−1.838	−.162
Design Inflexibility	18.779	.000	−2.931	.011	−1.321	−2.287	−.354
Absence of Subsidies	.533	.470	−3.324	.002	−.968	−1.559	−.377
Monotony of Structure	4.155	.049	−2.706	.016	−1.038	−1.852	−.225
Blandness and Uniformity of Outlook	9.871	.003	−2.542	.023	−1.019	−1.875	−.163
Fear of City Standardization	1.624	.211	−3.080	.004	−1.090	−1.807	−.372
Impaired Aesthetics	.558	.460	−3.775	.001	−1.347	−2.071	−.623
b - Modular experience							
Uncertainty of Supply & Demand	.863	.359	2.689	.011	.785	.193	1.376
Lack of Policy	.045	.359	2.569	.015	.906	.191	1.621
Lack of Government Support	1.291	.263	2.892	.006	1.027	.307	1.747

contracts tend to favor standard, cost-effective, and repeatable alternatives over highly customized ones. Detailed designs in modular construction can limit the learning curve, and the integration of complex modules may incur additional revision costs when issues arise (Flyvbjerg, 2021).

In a design-build context, contractors exert greater influence over the design process, allowing them to influence building processes, pricing, and the complexity of modular components (Heaton et al., 2022). In evaluating the remaining factors, design professionals consider technical obstacles to be more significant than their construction counterparts. This discrepancy results from the fact that an underdeveloped modular system restricts opportunities for reproducibility, whereas complex interfacing is advantageous when modular construction is employed.

Human variations and system characteristics influence the evaluation of utility and usability in modular construction. The disparities between design and construction professionals, particularly with regard to aesthetics and technical barriers, illustrate the difficulties inherent in adopting and embracing modular construction. In order to overcome these obstacles, a deeper comprehension of the advantages and limitations of modular construction, the encouragement of innovative thought, and the resolution of concerns regarding design flexibility and customization are required. By bridging the knowledge divide and encouraging collaboration among stakeholders, the industry can unlock modular construction's maximum potential and promote its widespread adoption.

Collaboration in modular projects

In the domain of modular construction implementation, effective collaboration between designers and manufacturers is the key to success, as it preserves design adaptability throughout the construction process. Table 5b distinguishes between professionals with and without modular expertise to identify the forces affecting modular adoption, highlighting two regulatory hurdles and one industry impediment to modular development.

Surprisingly, the emphasized adoption determinants are more important for individuals who have not had modular experience, reflecting concerns about weak government support and policy in this area. Existing studies (Javid, 2017) and governmental pronouncements (Minister of State for Housing, 2019) confirm that government aid for modular projects is easily accessible. Notable policy reforms highlight the UK's commitment to modular building (Wuni & Shen, 2020). This paradox of increased concern among the uninitiated is effectively addressed by grounding perceptions in factual information, dispelling myths, and emphasizing the evolving landscape of support and policy reform that underpins the UK's promising trajectory of modular construction. Resolving ambiguities about modular compliance with building rules is also critical, needing regulatory harmonization to expedite uptake (Housing Communities Local Government Committee, 2019). According to the suggestions of Mostafa et al. (2020), inclusive regulations that permit both modular and conventional methods provide a route that is consistent with carbon emission objectives and housing needs. The government must create an all-encompassing regulatory framework sensitive to each method's individual details and benefits.

Table 5b reveals hurdles to modular acceptability that are beyond the industry's control. Variability in supply and demand, self-employment predominance, unskilled labor, and resource scarcity all contribute to inefficiencies (Farmer, 2016). The latter's vulnerability to macroeconomic upheavals and environmental catastrophes emphasizes their significance. Nonetheless, in the absence of informed rules and regulations, government action, and awareness campaigns, these conditions continue to be impediments to modular expansion. Finally, addressing these roadblocks and external issues is critical for promoting widespread usage and acceptance of modular construction. Early cooperation, effective policy change, inclusive laws, and increased awareness all contribute to a sound, sustainable future in the modular building sector.

Implications of the findings

The complex interaction between obstacles, attitudes, and the key principles of innovation diffusion theory has far-reaching ramifications for the modular building sector as well as the growth of theoretical knowledge in this area. These results serve as a guiding beacon in the changing environment of building innovation, putting light on the many constraints that limit the mainstream integration of modularization. Practitioners and stakeholders benefit from these insights by effectively overcoming hurdles ranging from traditional thinking to financial concerns. These implications go beyond theory, and they resonate significantly with the real growth of the modular building sector. Recognizing the critical role of attitudes in adoption choices allows us to address resistance and skepticism at their source. The compatibility between modular methods and industrial principles provides a means to overcome traditional obstacles and embrace the revolutionary potential of modular construction. This transition represents a comprehensive innovation culture, catalyzing change and cultivating a receptive ecology for modular methods.

Theoretical progress is also evident since these findings improve our understanding of how innovation takes root inside a sector. The combination of the concepts of innovation diffusion theory – relative advantage, compatibility, complexity, trialability, and observability – strengthens the basis for forecasting, explaining, and controlling the adoption process. Furthermore, these findings provide light on the processes driving technological compatibility, bringing nuance to the discussion of innovation uptake. In practice, these results are relevant to enterprises looking to promote and advertise their goods, as well as guiding public policy choices on technology uptake. The research emphasizes the importance of attitudes and perceptions in affecting the effectiveness of new technologies in breaking through technological hurdles. It emphasizes the importance of professional positions in decision-making, providing insights for successful strategies. To genuinely support broad adoption, the construction sector must establish a collaborative environment that encourages information sharing. The creation of platforms, digital markets, and innovation hubs that bring together various stakeholders fosters an atmosphere in which ideas flow freely, resources are pooled, and modular construction adoption increases jointly. To achieve effective implementation, practitioners must identify facilitators and areas for development, matching their efforts with the momentum that these insights have created.

Conclusions and recommendations

The study's results provide significant insights into the obstacles that impede the integration of modular buildings within the construction sector. In contrast to traditional constraints, stakeholder perceptions have a more significant impact. This study utilizes the framework of technology diffusion theory to examine the influential aspects that contribute to the convergence of modular construction with the values, prior experiences, and requirements of prospective adopters. The study revealed that stakeholders' opinions of modular construction are influenced by several factors, including the prevalence of conventional mindsets, deeply ingrained traditional practices, reluctance to change, historical attitudes, a focus on bid price, and a general sense of distrust. Moreover, the influence of professional positions serves as a mediator in the differentiation between individuals who have adopted a certain practice or technology and those who have not. This is particularly evident in the case of less experienced professionals. Despite the inherent advantages of modular buildings, such as increased manufacturing quality, efficiency, and timely assembly, the construction industry continues to express skepticism owing to previous issues with prefabrication and a conservative approach toward adopting innovative practices. In order to overcome these obstacles, it is suggested that a customized framework or industry-specific proposal be created to recognize the non-linear diffusion dynamics that are inherent in the deployment of modular construction. The proposed strategy should include a wider array of procurement indicators and KPIs, including early engagement with modular subcontractors within the framework of design-build procurement. In addition, it is crucial to provide project managers with decision frameworks that may assist customers in evaluating the appropriateness of modular construction for their projects. While recognizing the constraints of technological acceptability modeling, the findings of this research play a fundamental role in promoting the use of modular construction. In order to facilitate the process of industrial transformation, it is crucial to address and overcome barriers to adoption while also implementing a complete strategy that promotes cooperation among customers, contractors, and designers. Acknowledging the non-linear character of diffusion dynamics in this context is important. Through the active questioning and collaborative pursuit of a constructive environment that is more effective, environmentally friendly, and characterized by novel approaches, we may use the benefits of modular construction to enhance social well-being in both the present and the future.

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No potential conflict of interest was reported by the author(s).

Data statement

Data in this research are presented in the manuscript.

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