Prospects of promoting MMC across the public construction sector: A systematic review against the diffusion of innovation theory

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Abstract: Despite the calls to transform construction and the potential of the Modern Methods of Construction (MMC) to address traditional construction concerns, the global construction industry is yet to embrace the benefits. The purpose of this review is to theoretically explain MMC low uptake in the public sector by exploring the relative pressure points that are contributing to clients' indecision. The study argues the five functional constructs of the Diffusion of Innovation Theory (DOI) against MMC attributes. A systematic review of sixty-seven articles through a Preferred Reporting Item for Systematic Review and Meta-analysis (PRISMA) led to key arguments that explicate the lesser drive for MMC adoption. Results reveal that past literature is plurally discarding the dynamics between supply and demand, decision-making, and contracting business models. An improved understanding of these dynamics would, therefore, support research efforts in disclosing the necessary considerations that can promote clients' favourable innovation-decisions. This study echoes past calls and act as a departure point for future research to assess MMC beyond its technical attributes from a theoretical lens to better understand how construction innovations flow in the public construction sector.

Introduction

Background

Since the last decade, the Modern Methods of Construction (MMC) has been acquiring significant interest, among the industry's key stakeholders, due to the belief that MMC can meet project goals more effectively than traditional construction methods. However, despite its demonstrated benefits, the uptake of MMC is still minimal, constituting to less than 8% of the construction market in the United Kingdom (KPMG, 2016; Branson, 2020), and around 2% globally (Taylor, 2015). The growing body of knowledge related the low uptake to technical and non-technical attributes accompanying MMC (El-Abidi and Ghazali, 2015; Oti-Sarpong, 2020). The study examines existing literature against the five functional constructs of an innovation's attributes in the Diffusion of Innovation theory (DOI). Those constructs are explained by Rogers (2003) as characteristics that predict the prospects of an innovation's adoption across a specific social system. Reviewing vast literature towards extracting decision-making factors aided by the DOI theory serves as departure point for empirical investigations that can explain the interdependency of the decision-making factors influencing wider uptake and offering a clear guidance to the needed future research directions and trends (Reychav and Aguirre-Urreta, 2014).

This study follows a rigours systematic approach in its attempt to bridge the gap in our current knowledge. Initially, the review examines literature relevant to MMC. Secondly, the study clusters the determinants into five functional constructs, namely; complexity, compatibility, trialability, relative advantage, and observability. These themes provide basis for the MMC market to be well-informed on the causes behind the lag in achieving the required economy of scale and offers the means to examine the readiness of

their business models to better penetrate a specific construction market. Finally, the research concludes by identifying the needed changes and considerations necessary in future efforts with respect to achieving consistency between both supply and demand towards enhancing MMC prospects in the industry.

The innovation: Modern Methods of Construction

The Modern Methods of Construction (MMC) minimises onsite activities by shifting fundamental costly and time-consuming construction practices offsite. In turn, it positively influences projects' quality, safety, and productivity (Arif and Egbu, 2010; Abdul Nabi and El-adaway, 2021; Iacovidou et al., 2021). However, the uptake of such methods is still very primitive worldwide (Taylor, 2020). Being described as the vehicle that can meet the targets set, MMC emerged in the past decade to become one of the government's main interests (MHCLG, 2017). Such emergence and focus are mainly due to MMC's capability to address the aspects where traditional methods extensively fail, like meeting deadlines, minimising waste, reducing environmental impacts, ensuring more cost certainty, and achieving better quality and safety (MHCLG, 2019a). Broadly, MMC definition varies among recent studies to describe volumetric structures, like modules and pods, and nonvolumetric components, like panels and foldable enclosures (Ginigaddara et al., 2022). To address MMC terminological confusions, MHCLG (2019b) published a definition framework linking MMC activities to seven different categories. In summary, definitions of existing literature indicate multiple meanings and approaches; however, these are commonly unified in describing MMC as a practice nominated to drive a faster, cheaper, and safer built environment.

The social system: Public construction sector

Public clients are organisations that operate on local, national, and regional levels to benefit the public by procuring services and goods without having their profit margin as the sole driver for their activities (Hartmann et al., 2008). Private and public clients differ in nature and demand; for instance, public clients handle higher pressure from external influences and conditions than private clients. Private clients tend to focus more on their interests (Sutrisna and Goulding, 2019), while public clients aim toward public welfare. Antoniou (2020) reports the importance of public clients in promoting innovation in line with the national procurement regulations, categorising public procurement as a potential driver and facilitator of innovation. This can be explained by the magnitude of public clients' growth proportion in new construction works, reaching a staggering £2.7 bn compared to £750 million in the private sector in 2018 (Taylor, 2020). Such focus enables harvesting public clients' abilities to drive the overall industry in accepting and adopting innovation (Kuitert et al., 2019). The choice to focus on public clients means that authors will not be bounded by specific individual or organisational agendas and will rather favour the innovation as perceived by the vast majority (Lindblad and Karrbom Gustavsson, 2021). To approach this, understanding the decision making processes is key to reinforce our understanding on these clients, starting from the standpoint that clients' ability to drive industry change is based on the acceptance of an innovation among their decision-makers and the alignment of the innovation with their resources and interests (Havenvid et al., 2016). So, what are the determinants influencing MMC's adoption-decision among public client organisations?

Research Gap

The diffusion of innovation theory by Rogers (2003) details critical constructs deemed effective when investigating innovation adoption against a decision-making process. The constructs have been utilised by a variety of recent studies looking at innovations

in construction like BIM (Xu et al., 2020), sustainability (Mead et al., 2020), and 3D printing (Besklubova et al., 2021); such an approach details the influence of innovation's characteristics on their innovation-decision. However, the same constructs have not yet been utilised in the MMC context from past relevant research efforts, with an overall limited interest to relate MMC to theories (Ehwi et al., 2022). This study, therefore, is the first client-oriented review relative to investigating MMC's characteristics towards extracting the decision-making factors that are undermining wider adoption. DOI can serve, overall, as a comprehensive model that enables researchers to adequately study the adoption of an innovation in construction.

A review of relevant literature revealed a limited number of studies relating to theories in general but particularly in the MMC context. A variety of reviews discuss the barriers, challenges, benefits, and advantages of the adoption of MMC, particularly in the last decade. Such reviews, however, apply little focus on the adoption stance, with the lack of utilising theories that can help determine the critical factors acting as the pressure points responsible for the low MMC uptake across the sector; the most recent reviews are listed in **Table 1**. Moreover, relevant literature is discreet in comprising a study that investigates the influence of the innovation's characteristics on the clients' decision-making process from a theoretical lens. The approach followed in this research feeds into the MMC research with contemporary arguments and justifications of the low uptake of these methods. The diffusion of innovation theory offers constructs to measure the potential uprise of an innovation and the prospects of its adoption. This paper is an eye-opener to the various factors influencing wider adoption through a systematic review. The theory illustrates that its constructs influence the decision-making process and assist in better MMC acceptance among the decision-making units (see Figure 1).

The importance of this study is evidenced in recent studies that emphasise the need for comparable research to effectively investigate enhancing MMC prospects for better adoption (Abdul Nabi and El-adaway, 2020; Oti-Sarpong et al., 2022; Darlow et al., 2022; Ayinla et al., 2022). As a result of the direction of recent studies in underpinning the lack of research to explain MMC's low adoption and the lack of utilisation of theories to aid research in explaining and understanding innovation adoption in construction, the authors deem this study as timely. The lack of a similar systematic review is delimiting a thorough exploration and an accessible evidenced-based inference of the attributes that can explain the unfavourable decision-making towards MMC despite a spectrum of demonstrated benefits. This paper, hereby, intend to contribute to existing construction innovation research by investigating the influence of MMC characteristics on its adoption, as explained in Rogers (2003) theory.

This study hereby attempts to explore the prospects of enhancing MMC uptake in the public construction sector. The main aim of this paper is to capture the decision-making factors that are playing a distinct role in influencing MMC adoption across the construction sector. The novelty of this paper is in extracting and classifying the decision-making factors that are proving to be critical by recent research efforts. It is logical to state that the change in the determinants of the variables identified can influence change in the innovation-decision, based on the interrelation of the MMC perceived attributes with demand's decision-making processes.

Methodology

This study adopts a systematic review method to study existing literature. Such methodology enables researchers and scholars to conceptualise and pave the road for a practical qualitative analysis of previous works (Popay et al., 2006). Moreover, it offers

credible data in answering key research questions approached by the extensive literature review, a substantiated and focused database, and a clear inclusion-exclusion criterion (Tranfield et al., 2003). Scopus database is chosen in this study because it covers vast peer-reviewed journals compared to other similar databases (Chadegani et al., 2017). In addition, due to the broad reach of relevant resources in the Scopus database, data is deemed sufficient for review without involving other databases. **Table 2** details the parameters of the inclusion-exclusion criteria restricting the search.

The systematic review methodology allows the authors of this paper to compile publications relevant to MMC from a variety of peer-reviewed sources. Such choice of methodology, albeit rare in the same context, enables contemporary observations on how MMC research efforts offer an opportunity to explore underlying decision-making factors responsible for the low uptake of MMC across the sector. The selection of the keywords chosen relied on previously published MMC research (Ahn et al., 2020a; Zhang et al., 2020; Liu et al., 2022; Yang et al., 2022), utilising comparable words of identification to describe MMC. The search focuses on the terms “Modern Methods of Construction (MMC)” OR “Offsite Construction (OSC)” OR “Industrialized Building Systems (IBS)” OR “Offsite Manufacturing (OSM)” OR “Modular” OR “Volumetric” OR “Design for Manufacturing and Assembly (DfMA)” OR “Modular Integrated Construction (MiC)”. Due to the generalisation of the terminology associated with MMC, it is worth mentioning that all articles included are exclusively within the construction context. The first Scopus database search date is April 5, 2021. The use of systematic review methodology has been described as a lengthy process that requires significant time and human resources, and the mean lead time from start to publication has been determined as 67.3 weeks (Borah et al., 2017). The initial Scopus search presents 9,546 articles showing vast contributions between the years 2015-2020 and a plummet

of published works before 2010 (see Figure 2); therefore, only studies after 2010 are included in this review, offering an adequate exploration for research from the past decade. Moreover, a recent systematic review of MMC research by Ehwi et al. (2022), revealed the limited use of similar qualitative studies that offers a clear exploration of MMC, reinforcing confidence that the analysis period between the end of 2021 and 2022, no studies have yet contributed to address the same prevailing gap in research similarly as this paper, which substantiates the sustained value associated with this paper.

The articles are then analysed through a thematic content analysis method that is described as a structured criterion of analysis that identifies trends throughout organising large amounts of literature (Finfgeld-Connett, 2014). Content analysis is a prevailing method within the growing body of research that collects and organises data toward capturing underlying trends (Elo and Kyngäs, 2008). This approach helps add consistency to the different wordings of the collected studies towards common themes and genres, better explaining MMC through the collective presentation of the attributes orchestrating its adoption. Rogers (2003) explain that innovations may be formed from clusters, where a cluster of multiple ideas would form an innovation. In the formation of the themes, findings are categorised based on their relevancy (Finfgeld-Connett, 2014), which is dictated by the trends among them (Braun and Clarke, 2012), as repetitive trends and patterns are grouped into themes and are then inductively linked to their corresponding construct (Braun et al., 2022).

Research Findings

Figure 3 describes the inclusion process of relevant articles through a PRISMA diagram. The diagram reveals the importance of screening to ensure that non-relevant

articles or duplicates are excluded. The collected 67 articles comprise studies from 34 different peer-reviewed journals like Engineering, Construction and Architectural Management, Automation in Construction, Journal of Construction Engineering and Management, Journal of Management in Engineering, Construction Management and Economics, and Building Research and Information. Such journals were ranked by Wing (1997) as pioneers in publishing scholarly construction studies with an exclusive focus on the field of construction management. The same journal ranking has been acknowledged as impactful by recent systematic reviews (Wang et al., 2023). Figure 4 shows a more detailed process of the review methodology. Moreover, Figure 5 and Figure 6 show the network occurrence of the keywords within the included articles across the five areas of research and the co-authorship relatedness network of collaboration respectively.

The number of included articles may be professed as a small sample of secondary data; however, this number appears to be above the average when comparing it with other systematic reviews in the construction context. For instance, Sonkor and García de Soto (2021) included 55 articles when exploring digitalisation, Raouf and Al-Ghamdi (2019) used 68 articles when assessing previous work on green buildings, both Ayodele et al. (2020) and Tetteh and Chan (2019) included 53 articles for workforce turnover and construction joint ventures respectively, and Luo et al. (2017) used 74 articles to study complexity in construction projects. Thus, the number adopted in this study can be deemed sufficient to provide a knowledgeable exploration of MMC literature from the past decade.

Discussion

To aid efforts in explaining the low MMC market uptake, this study utilises the DOI theory by relating the five critical functional constructs. Rogers (2003) argues that an innovation standing out in these constructs has better prospects to being widely adopted. This section reports the arguments made by classifying MMC literature under each of the DOI functional constructs of a) complexity, b) compatibility, c) trialability, d) relative advantage, and e) observability. These arguments led to the emergence of a variety of variables relative to each of the five constructs in the utilised theory. Hence, the following subsections discuss the emerging themes according to their materiality to the five constructs.

Complexity

In the innovation context, complexity is the extent to which an innovation can be challenging to use, understand, or faultlessly utilise (Rogers, 2003). This subsection introduces discussions within existing literature describing difficulties experienced by users associated with MMC like a) technical complexities, b) design complexities, and c) delivery complexities.

Technical complexities

The literature argues that fire resistance in MMC is more complex than traditional methods. Tažiková (2020) emphasises the need to address MMC elements in alignment with existing fire protocols and in their ability to halt the spread from the "origin and development of fire". They align with Liew (2019), conveying the expression ‘compartmentalisation’ to describe the need to limit fire spread between modules. The same study indicates that all fire materials and regulations are like those utilised in conventional methods. The spread complexity lies in the gaps formed by wall and slab connections. Due to longstanding minimum data, Evernden (2012) reports that

concerns will remain regarding the fire performance in MMC structures. Addressing such complexity within the market, the government has recently published the 'Building Safety Bill', which states strict regulations and guidelines to halt the spread of fire (MHCLG, 2021). Hence, halting the spread of fire is perceived as more complex than traditional methods.

Literature also identifies thermal comfort as a variable within the complex construct compared to traditional methods. Rodrigues (2013) underscores that thermal comfort considerations are not being given the necessary attention for an effective cooling strategy due to the nature of MMC designs. As mitigation, Tažiková (2020) proposes the use of thermal insulations in external walls. Similarly, Iuorio (2019) proposes that MMC designs must consider passive strategies as an option to control internal temperatures. Additionally, a case study focusing on UK MMC dwellings emphasised the need for a combination of existing technologies to mitigate thermal complexities (Rodrigues et al., 2016). A Ministry of Housing, Communities & Local Government report confirms the same concerns in the public sector, inferring the need for retrofit regulations and mitigation measures within all newly built homes (MHCLG, 2019c). Hence, overheating within MMC is an innovation complexity that can influence wider adoption.

Ensuring MMC offers a waterproof solution is described by literature as a complex task compared to traditional methods. The nature of MMC in having gaps between the panels and modules creates challenges for an effective waterproofing mechanism that requires novel solutions (Orlowski et al., 2018). Chen (2017) reports similar views on the complexity of waterproofing, indicating that high-quality welding can mitigate gaps to ensure such issues are treated at the unit joints. The gaps are customarily formed due to the lack of sufficient stiffness of the beams-column joint, yet increasing the

stiffness might reduce the initial ductility. Hence, waterproofing is an MMC-associated complexity compared to traditional methods.

Design complexities

The selection process between the different options of MMC that best corresponds to the project's specifications is being described as another complex task compared to traditional methods. Due to the variety of existing MMC solutions, selecting an appropriate MMC option is not as straightforward. Sutrisna (2019) informs a case study where significant disruptions emerged after an MMC option was a second choice, causing costly design changes, onsite disruptions, and prolonged deliveries. Moreover, Gbadamosi (2020) indicates the importance of MMC selection in influencing clients' procurement decisions, as many factors impact their decision like the appropriateness in meeting their vision and need, supply chain capabilities to each type, and the price accuracy among the options. MMC systems vary and differ in types; For instance, there are Structural Insulated Panels, Cross Laminated timbers, and Ceramic Panels (Tažiková et al., 2020). Such systems are categorised into different genres, where each has its bespoke characteristics, functionalities, suitability, and level of offsite usage (Piroozfar and Farr, 2013). The magnitude of which MMC is being utilised and adopted influences its benefits like waste reduction, directly proportional to the type of system chosen (Pacultová et al., 2019). Typically, the type of system being used is linked to the actual functionality of the end structure. For instance, volumetric approaches are used in repetitive services like kitchens and bathrooms (Kempton, 2010). Hence, the selection of MMC for an outcome-based approach can be perceived as a complexity over traditional methods.

MMC design phase is being reported as more complex compared with conventional methods. Sutrisna (2019) indicates that freezing the preliminary design can result in more time certainty, fewer costs, and better quality. However, due to the clients' general nature in preferring maximum input from their end, standardisation may be an unpreferred alternative. Notably, Isaac (2016) reports the ability to exploit MMC features and add more flexibility for clients by integrating a mechanism where more components can be installed to offer more options for the demand side. Coherently, studies like Yang (2021) and Dowsett (2019) report significant disruptions and reworks associated with client amendments impacting an economically profitable standardisation (Antoniou and Marinelli, 2020). However, mitigation measures can be approached by early engagement and better communication between the key stakeholders, where collaboration is critical for a smooth procurement and acceptance of standardisation (Goulding et al., 2012). In the context of public clients, the UK government published the 'Construction Playbook', which states various policies that include taking measures so that designs would not limit innovation (Cabinet Office, 2020). Hence, the MMC design stage is associated with complexities limiting better diffusion of MMC across the public sector.

Decisions of whether MMC is accepted as an alternative worth the investment are at the project and organisational levels, creating a need for early stakeholder collaboration to overhaul any misalignments (Ofori-Kuragu and Osei-Kyei, 2021). Such collaboration should be initiated at an early stage to minimise any changes and errors occurring at the design stage (Wasim, Han, et al., 2020), which can avoid potential future issues throughout such an early involvement (Gao et al., 2020). However, the lack of guidelines may limit achieving constructive collaboration in MMC projects (Wasim, Vaz Serra, et al., 2020). Nevertheless, Hairstans (2018) reports that different attributes are

to be considered to enhance collaboration, such as sharing common concerns, effective planning and reporting, effective intervention with the government, and knowledge of MMC aspects among the key stakeholders. Pablo (2020) defines collaboration in MMC as a "commitment" toward a "manufacturing mentality". Hence, a governed collaboration towards innovation can facilitate its adoption across the construction sector.

Delivery complexities

The transportation and appropriateness of the routes leading to sites may not be a significant factor for traditional methods. However, due to MMC's offsite nature, the transportation phase is influenced by vehicle capacity, location, lifting equipment, and highway regulations, subsequently impacting the decision to choose MMC (Sutrisna and Goulding, 2019). Empirically, the findings indicate the significance of the MMC transportation phase in terms of including complexities that conflict with MMC's abilities to minimise environmental risks (Tavares et al., 2019). The study suggests reducing the distance from the factory to the site and environmentally contemplating the least energy-intensive transportation mode. Salama (2017) conveys that transportation is an integral phase of MMC project delivery. This phase can impact the modules' dimensions, where transportation agencies must consider the "futuristic needs" for suitable infrastructure and better highway regulations. Hence, the transportation phase draws environmental and mobility concerns that may be perceived as complexities associated with MMC compared to traditional methods.

Another new task arguably less regarded in traditional methods is the assembly phase in MMC, being described as a more complex task. Linking assembly with design, Yuan (2018) argues that the design stage of MMC buildings must be determinedly integrated with the assembly stage to achieve a resilient outcome and increase the success rate

of the overall process. To achieve this alignment, the assembly should focus on the "fixation mechanism" that can ensure a "clean and fast" assembly process (Martínez et al., 2013). Similarly, Liew (2019) recommends connecting techniques to ensure better rigidity, integrating a modular tracking system as a technological approach to achieve a more accessible, faster, and more controlled assembly phase. Empirically, Enshassi (2019) reports severe misalignments and gaps within the modules, columns, and plates during the assembly phase due to discarding tolerance values with inefficient geometry management. A study proposes advanced analysis simulation approaches like Monte Carlo (Rausch et al., 2019) and BIM-OfA assessment system (Gbadamosi et al., 2019). Such technological tools can analyse the tolerance and detect any assembly misalignments. From the client's point of view, damages during the installation process can vitally impact the smoothness required between onsite and offsite processes (Yang et al., 2021). Hence, MMC is associated with new tolerance requirements acting as complexities within the assembly phase.

Compatibility

Compatibility is described as the degree of consistency of the innovation with existing activities, practices, or habits well known within the industry (Rogers, 2003). This subsection reports arguments of existing literature on how MMC is a) compatible with building regulations, b) compatible with contracts, c) compatible with work styles, d) compatible with the surrounding, and e) compatible with warranties and guarantees.

Compatibility with building regulations

Compared to traditional construction, which involves an environment subject to dynamic and dangerous conditions, Ahn (2020b) reports significant safety risk reduction associated with offsite solutions due to their controlled nature. Elsewhere, safety within

construction is also significantly enhanced after introducing Design for Manufacturing and Assembly (DfMA) principles, explained by labour reduction throughout several potentially dangerous activities (Wasim, Vaz Serra, et al., 2020). Empirically, a case study reports that an overall approach is being considered by firms offering MMC solutions to meet “stringent” outcomes in safety towards attracting public attention and consideration (Sutrisna and Goulding, 2019). Overall, MMC tend to acquire an acceptable appraisal of meeting safety in construction due to its straightforward phases, which align exclusively with Hackitt (2018). This governmental publication states a strict need to enhance building safety across the UK. Hence, maintaining effective safety measures can act as a compatible driver to adopt the modern methods.

Compatibility with contracts

On the contractual side, clients prefer standard contracts as validated and traditionally used agreements securing their interests with fixed terms. In contrast, MMC may require fundamental amendments to the commonly known terms (Charlson and Dimka, 2021). Duncheva (2019) reports that a collaborative contract must exist to govern the key activities offsite due to fewer onsite activities. Charlson (2021) highlights the inapplicability of the procurement methods adopted in procuring traditional projects, which requires new contracting approaches to change the current mindset to better align with modern methods. The same study reports that both academic and governmental sectors identify existing contract forms as potential inhibitors, negatively impacting the decision to procure MMC projects. Hence, studies collected reflect the incompatibility of standard contract forms with MMC practices, where bespoke amendments may be required to ensure better consistency.

Compatibility with work styles

Alwan (2017) indicates that involving researchers in an MMC project results in a compelling delivery, reflecting the role that education can play in sustaining innovation. Notably, Ginigaddara (2021a) suggests that upskilling could save most traditional skills from being 'diminished'. Similarly, Pablo (2020) discusses the significance of gaining new skills, describing that upskilling is as vital as demonstrating current skills. Education can play a significant role in spreading essential knowledge throughout the sector (Taylor, 2020), whereas Goulding (2012) reports the ability to integrate technologies such as Virtual Reality (VR), which can enable learners to experience real-life scenarios. In terms of social value, upskilling would reduce the dependency on foreign workers (Akmam Syed Zakaria and Amtered El-Abidi, 2021), by increasing local opportunities. However, the skills required to meet the sector's needs are still limited in research and application (Ginigaddara et al., 2021b). The limited training towards mastering emerging skills, such as assemblers (Hairstans and Smith, 2018), might negatively influence clients' decision to adopt this innovation (Ginigaddara et al., 2021a). The same was argued by Nasirian (2019), stating a linkage between performance and the skill level and the need for new hiring policies to promote upskilling in MMC environments. Empirically, Rahman (2014) reports that the outcome of studying organisations reflects that those lacking experience in MMC has indicated triple the number of factors representing their fear of adoption. Thus, ensuring effective education, upskilling, and training are vital to achieving better MMC compatibility.

Compatibility with the surrounding

Martínez (2013) reports the vital aspect of finishes in MMC projects, indicating that their abilities to resist corrosion and physical impacts to meet existing standards are strictly linked to workers' skills in providing the desired finishes. Iuorio (2019) discusses that finishes are vital and have variable meanings for clients. Ofori-Kuragu

(2021) reports a potential direction of where finishes required can benefit the clients in providing a product that looks "less modular", revealing a new paradigm for which clients can exploit MMC values whilst sustaining the traditional preferred finish. Such finishes are considered acceptable in terms of durability, yet data should exist to report the number of years that such finishes can last (Isaac et al., 2016). To contribute to making MMC a future credible alternative, preventing defects is a critical approach that will result in the users' enjoyable experience (Švajlenka and Kozlovská, 2020). Despite Gao (2020) reporting a case of 73% fewer defects recorded in MMC, defect issues still exist within MMC projects and are identified as quality issues with the components, worker-related misoperation, and an ineffective assembly inspection (Yu et al., 2019). Hence, MMC meets the finishes compatibility required compared to what is offered by the traditional methods.

Compatibility with warranties and guarantees

MMC has a vital potential to be acknowledged as an "ecological and healthy housing alternative" for users' sincere satisfaction (Švajlenka and Kozlovská, 2020). The values and assurances customers are provided, like accreditations and warranty schemes, strengthen their decision to adopt MMC (Goulding et al., 2015). Such warranties comfort buyers on longer terms and act as commitments towards possible risks. Taylor (2020) reports that public clients seek MMC providers offering solutions that comply with the "Buildmark Warranty Scheme", which substantiates the linkage between client satisfaction and warranty schemes in the compatibility context.

Trialability

Trialability is described as the ability for the innovation to be tested, trailed, or well experimented with before adoption (Rogers, 2003). This subsection introduces

aspects of relevance that emerge under the trialability genre in the MMC literature such as experimented functionality and certainty in the existence of long-term trialability data.

Experimented functionality and accessibility

Functionality and long term maintenance are public client concerns that have proven essential in past experiences; for instance, a public UK Country Council identifies maintenance as an aspect that impacts their choice and influences their decision to procure MMC projects (Piroozfar et al., 2012). As an advantage, Kempton (2010) discusses the findings of an MMC study for three years, indicating that the results favour MMC in terms of requiring less maintenance. However, the same study indicates that such a period is not enough for clients to perceive MMC as a well-tested and durable option. Moreover, Gbadamosi (2020) reports that modules must consider conservation in their design, emphasising the need for an easily accessible product. The same is stated by Isaac (2016), reporting that more capacity can be considered when designing for services, as this can be significantly beneficial in case of any future maintenance needs, additional installation of components, or changes by the clients. Finally, Iuorio (2019) suggests using visualising and simulation software to substantiate further the ease of clients' visualisation of maintenance issues within MMC components, verifying its effectiveness in the context of trialability. Hence, the functionality and maintenance in MMC act as long-term data influencing the ability of clients to acquire trialability assurances.

Assurance

The offsite nature of MMC projects tends to minimise uncertainties that act as "practical decision supportive approaches" in determining and quantifying risks (Hasan and

Lu, 2021). However, Ofori-Kuragu (2021) reports that MMC can still hold blurriness in its emergence, and uncertainty exists across MMC key processes. Despite that MMC cultivates more certainty than traditional methods, uncertainties influencing its trialability exist. Yang (2021) empirically categorises those uncertainties into manufacturing; like machine breakdowns, demand; like the ability to deal with change orders, and supply; like lead times for transportation and assembly. In dealing with those, Taylor (2020) describes MMC as "illusive" due to being associated with blur uncertainties and lack of proper trialability that, in return, is influencing its adoption. Therefore, more data is required to assure MMC is well experimented with, particularly towards dealing with sudden disruptions and uncertainties.

Relative advantage

Relative advantage is the extent to which an innovation can be superior to existing traditionally adopted practices (Rogers, 2003). This subsection introduces arguments where MMC is foreseen to have advantages over traditional methods in a) meeting sustainability goals, b) SMEs involvement, c) effective digitalisation, d) cost reduction, and e) productivity improvements.

MMC meets sustainability goals

The ability of MMC to uptake innovative and intelligent possibilities contributes to significant sustainability goals (Goulding et al., 2015). Švajlenka (2018) reports that the increasingly expanding suburban sustainable clusters are imposing pressure on clients for efficient housing alternatives, where MMC is being seen as an attractive option acting as a potential choice within this transformation. Ofori-Kuragu (2021) highlights case studies where investments in manufacturing facilities demonstrate sustainability, encouraging investors to board the innovation. To achieve satisfactory results in

project delivery, Alwan (2017) reports the need to engage clients in the loop of economic, social, and ecological values that can be extracted by abiding with MMC principles due to the sustainability standards being offered. In the context of public clients, various governmental publications are issued to strengthen public procurement practices and ensure the prioritisation of sustainable options (Government, 2013; MHCLG, 2018; Public Health England, 2020). Thus, harvesting the sustainability values accompanied by MMC is a relative advantage compared to traditional methods.

Piroozfar (2012) reports a vital reduction in the carbon footprint recorded in an MMC-constructed building compared to a traditional one, despite that the latter has less energy usage. Similarly, Monahan (2011) reflects that 51% less embodied carbon is recorded in an offsite constructed house. Moreover, Iuorio (2019) discusses the term ‘Low Carbon Agenda’ as the new direction by the industry to prioritise carbon reduction among multi-stakeholders. Nevertheless, a compelling argument emerges as Liu (2019) points out that 95% of the carbon emissions are recorded in the component-prefabrication phase. Similar outcomes are described by Tavares (2019), stating that 80% of the carbon recorded was in the material production, recommending the use of less energy-intensive material. Hence, MMC can act as a potential option for clients keen to reduce environmental impacts, facilitating wider adoption.

MMC is a potential solution to plummet construction waste due to its more controlled essence (Pacultová et al., 2019). MMC adoption is also an "essential way to minimise waste" in construction projects (Ajayi and Oyedele, 2018). Compared to conventional methods, MMC offers 90% less waste (Ofori-Kuragu and Osei-Kyei, 2021). In achieving those substantial rates, Gao (2020) emphasises the role of designers to minimise wastes generated by MMC projects, as the design stage can mitigate waste-intensive activities. Monahan (2011) notes that proper management can minimise MMC waste

to as little as 2kg per square meter. Notably, Alwan (2017) indicates that government policy to tax waste generated in traditional construction is inefficient, as contractors tend to pass those taxes to clients, which proves that such inflated taxes increase the overall costs without any environmental benefits. Therefore, the ability of MMC to meet existing waste-reduction needs, and align with governmental publications like that issued by the Department for Environment Food and Rural Affairs (2021), to substantially and effectively reduce waste in crucial construction activities acts as an advantage for better adoption.

SMEs involvement

Pablo (2020) documents two case studies reflecting SMEs' successful results in delivering MMC projects; despite substantial transformation costs and the initial capital, the study spotlights the possibility for SMEs to board the MMC sector and overcome all the limitations. Knowing the increasing need to aggregate SMEs in the construction sector, MMC can act as the potential pathway where smaller companies can extract further advantages. However, the advantages of SMEs entering the MMC market will require that the conditions are rebalanced in a way that helps SMEs gain better ground (Dowsett et al., 2019). To achieve this, Gbadamosi (2020) argues that more focus on increasing the adoption of MMC in the construction sector will lead to economies of scale and enable better SME involvement by lowering the entry points. Thus, supporting SMEs is a critical advantage of MMC over traditional construction practices.

Effective digitalisation

Martinez (2021) presents a study that tests CCTV security cameras in governing MMC processes, reporting 92% more accuracy, eliminating human errors, and minimising time-consuming manual works through machine learning algorithms that fall within the

advanced digitalisation of activities. Moreover, Moon (2020) reports that MMC is applicable for a “Computerized Numerical Control” system that replaces engineers and designers in time-consuming activities, like producing shop drawings. Furthermore, Malik (2019) reports that optimising existing technologies within MMC manufacturing processes result in considerable annual savings due to integrating technological advancements to monitor waste in the key processes. Furthermore, Iuorio (2019) reports a case study where MMC contractors utilise Virtual Reality (VR) to communicate with clients, enabling personnel with less experience to be included in the design phase. Towards more familiar technologies, Building Information Modelling (BIM) is enhancing planning, manufacturing, and operations in MMC projects (An et al., 2020). Experimentally, Yang (2021) reports that the positive interaction between BIM and customisable emerging technologies reveals vast economical, technical, and social values in the MMC sector. Another vital digital approach is visualisation, proving more ease of resource allocation and optimum simulation (Rohani et al., 2014). Notably, Sutrisna (2018) discusses that such visualisation is accompanied by more transparency which is crucial for clients. Therefore, MMC offer a better environment for technological advancements acting as a critical relative advantage for its adoption.

Cost reduction/savings

Goulding (2015) states that MMC projects acquire a feasible and firm ability to present “cost-effective" solutions in the MMC context. Practically, Wasim (2020) records vital savings after comparing an offsite MMC approach and a traditional onsite project. Savings result from fewer labour requirements, which is described as “the most relevant and influencing economic factor” (Akmam Syed Zakaria and Amtered El-Abidi, 2021). Hasan (2021) supports this argument by stating that labour costs could reach a staggering half of the total project’s cost. Coherently, O’Connor (2014) reports that cost is

the main factor that drove a client to choose the MMC option for three projects. Moreover, Švajlenka (2018) discusses that initial MMC are attractive, but future lifecycle savings tend to be even more appealing. Aligning with the said, Pan (2011) reports a case study where 25% cost reduction is achieved, describing the statement of MMC being more expensive than conventional methods as a “myth”. Hence, the ability of MMC to reduce project costs acts as a relative advantage in its perceived characteristics.

Productivity improvements

Wasim (2020) reports that imperative enhancements in productivity that, in return, result in vast savings are directly linked to MMC. An empirical study indicates that one way to influence a decision to accept MMC is to consider the staggering values associated with its deployment. The findings reflect an 18% increase in resource utilisation and a 400% improvement in labour productivity, substantiating vital productivity enhancements (Goh and Goh, 2019). Being one of the attributes of most concern to clients (Akmam Syed Zakaria and Amtered El-Abidi, 2021), productivity increased only by 1% over 20 years in the traditional sector, where MMC can boost those statistics (Gbadamosi et al., 2020). In addition, productivity in MMC projects has not yet reached its peak, as Yang (2021) reports that current output rates can easily be yielded if intelligent technologies are deployed, as these are proven to be effective with MMC’s productivity improvements. Thus, productivity enhancement is a vital relative advantage in MMC compared to the traditional construction methods.

Observability

Observability is described as the ability of potential adopters to observe the emergence and adoption of the innovation by other peers, which can trigger their adoption

(Rogers, 2003). This subsection reflects MMC observability through discussing the exposure of MMC effectiveness through publicly available data, and terminological communicability.

Effective exposure

Sutrisna (2020) reports findings confirming that MMC can act as a “source of competitiveness”, contributing to enhancements that might influence its adoption. Mandicak (2017) suggests that contractors should better promote MMC and ensure potential customers are well-aware of its values to harvest the associated values. Physical activities like showrooms, factory visits, and magazines reflect the portfolios and key specialities rather than relying only on social media. Moreover, Goulding (2012) reports that incorporating emerging technologies like Augmented Reality (AR), which is feasible in MMC projects due to its controlled nature, can ‘trigger’ interaction and creates a margin for more competitiveness. Arguably, Hairstans (2018) reports the need for a vital understanding of MMC's functionalities and values for wider uptake from both clients and end-users. This understanding is conveyed as a barrier due to the lack of "publicly available data" that results in MMC being perceived as an ineffective alternative (Pan and Sidwell, 2011). Hence, triggering competitiveness for better observability can enhance the adoption of MMC as an emerging innovation being adopted by construction peers.

Terminological communicability

There is a need to harmonise MMC terminologies that will enable better application (Nawi et al., 2019). Piroozfar (2013) indicates that current definitions are being used in different meanings, emphasising the vital need for new readings that can raise MMC awareness, enabling more coherence and, thus, more observability of the key

benefits. Moreover, blurriness is associated with current terminologies, where Ofori-Kuragu (2021) states the necessity to explicitly articulate “what exactly MMC is” and identify implications potentially associated with accepting such methods. To initiate a state of rationalisation within the industry for better observability, a standard definition for MMC and its principles must be developed and accepted. Kempton (2010) reports that the current definitions are complicated and lack their purpose. Similarly, Pablo (2020) indicates that the terminology is being used "interchangeably", as the definition is formulating a debate that requires academia to "re-brand" such terminology to approach a term with more rational (Taylor, 2020). Thus, existing terms and notions can create confusion, limiting an explicit observation of the adoption of MMC across the construction industry.

Facilitating MMC adoption

The above innovation discussions captured the variables and determinants that feed into clients' perception of MMC as an effective alternative, Figure 7 shows the captured variables against each functional construct in a hierarchical framework. This section argues the approaches necessary to utilise the identified variables under MMC’s perceived attributes to reinforce innovation-decisions across the sector.

Reinventing contractor business models

Goulding (2015) suggests that for better MMC uptake and acceptance, contractors’ business models must develop to embrace change through new ways of working. Such an approach should drive clients to accept the high potential of added values brought by contractors (Gao et al., 2020). Nevertheless, models based on old building code revisions, payment schedules, and land banking can be amended to reduce the influence of old mindsets in limiting innovation (Hairstans and Smith, 2018). Iuorio

(2019) recommends creating business models that promote sharing knowledge and enhancing collaboration. For instance, a case study reports a conventional building that is later reconsidered to MMC due to effectively communicating MMC values, creating a direct linkage between the ability of suppliers to drive clients' decisions toward a perceived innovation (Ahn et al., 2020b). Therefore, reinventing contractor business models can facilitate clients' adoption of MMC as an innovation.

Effective planning tends to drive procurement favouring MMC compared to traditional methods by resolving potential conflicts and sudden interruptions (Liew et al., 2019). To approach this from an MMC mindset, Rohani (2014) indicates that traditional planning and scheduling activities are unsuitable for MMC projects, where an MMC-demonstrated planning is to be approached. Moreover a study stressing the importance of Work Breakdown Structure in hierarchically planning MMC projects draws that integrating such approaches can result in a "synchronisation" of both offsite and onsite activities (Sutrisna et al., 2018). Such synchronisation aligns with Liu (2017) suggestion of a schedule that can increase certainty between the outset and delivery, detailing all resources and potential delays. In an extensive case study that included 191 modules, findings stress the need to integrate technological software that simulates MMC processes towards "high-level planning" (Taghaddos et al., 2014). Similarly, Martinez (2021) emphasises the need for embedding technologies to effectively calculate key attributes, where results indicate 92% accuracy when measuring person-hours than specific MMC tasks. Hence, MMC offers effective planning capabilities to facilitate MMC diffusion as a practical innovation.

A need is emerging for a strategy to manage risks as an approach that can increase confidence in adopting MMC by identifying and accordingly mitigating construction risks. However, a study reports the vulnerability of MMC logistics and suggests using

technological frameworks to increase predictability (Yang et al., 2021). Arguably, Rausch (2019) informs that the risk of rework arises as one of the clients' main concerns when addressing issues like tolerance and misalignments in MMC developments. However, by initiating statistical distributions, such risks can be effectively mitigated. Nevertheless, the use of technology should be associated with proper experience, as Yu (2019) reports in a case study where the use of new technological tools increased risks due to the contractor's lack of familiarity. Therefore, it is logical to state that developing business models that are considering the determinants of clients' decision-making would aid the prospects of MMC uptake by reinforcing supply's approaches to penetrate a specific construction market.

Characteristics of Public clients

Gao (2020) reports concerns within projects if MMC knowledge was not fundamentally present among parties involved "from downstream up to the design stage". Similarly, Wasim (2020) reports the vital need for coordination among stakeholders, especially in the early design phase for a practical application. Kim (2016) describes MMC as a simple initial design, ensuring fewer but standardised components, which will require prior knowledge to avoid design risks. Such risks are described as "a domino effect", impacting phases that follow in a lack of an adequate understanding of the fundamental principles (Sutrisna and Goulding, 2019). Moreover, Tan (2020) reports that MMC can be approached by different disciplines where architects should have extensive managerial experience, especially in logistics and assembly. The lack of proper MMC knowledge is empirically confirmed to result in vital design reworks, imposing delays and expenses due to the disconnection between the designs and the offsite systems used, traced back directly to the clients (Duncheva and Bradley, 2019). The same argument is emphasised by Antoniou (2020), noting the need for public authorities to

ensure employees are familiar with offsite processes towards “reinforcing their commitment”. In this regard, Alwan (2017) states that “behind every good project is an educated client", aligning with Evernden (2012) argument that MMC principles will not reach their full potential if clients are not yet familiar with the contemporary manufacturing practices. Therefore, the above discussions add more balance to the research direction by emphasising the need to reveal how clients’ characteristics are influencing their own MMC adoption-decision.

Conclusion

The proliferation of MMC studies, particularly the past decade, is associated with the tendency to focus on the technical aspects rather than how these aspects influence decision-making processes that would aid MMC adoption in the construction sector. It is logical to hypothesise that the adopted research trends, albeit increasing, are limited in the sense of investigating the relational structures in how supply can influence demand, and vice versa, to the extent that made this review the first to explore the increasing attention on MMC, suggesting that previous work is context-specific and disjointed, requiring an overarching need for more generalisation and empirical investigation.

Public clients play a vital role in driving industry change towards accepting and embracing innovation. MMC can offer solutions beyond only meeting public demand but also benefiting the overall construction sector. Therefore, a better understanding of MMC approaches can highlight the pressure points that influence clients' adoption. By focusing on the client-oriented stance rather than the regular innovation-oriented approach reflected by literature, this study identified the decision-making factors deemed critical in their influence on the innovation-adoption decision. This systematic review

extracts and critically analyses work from the past decade to uncover the prospects of the diffusion of MMC as an innovation, constituting as a contribution to studies looking at the adoption of innovation in construction.

This study draws on significant practices that can facilitate public clients' acceptance to embrace MMC as a practical construction alternative against the five functional constructs of the innovation theory. The classification of the decision-making factors in line with Rogers theory provides insights into the actions needed to enhance MMC adoption rate in the construction sector. In essence, these insights can aid both supply; by highlighting the need to reinvent their business models to align with demand's decision-making processes, and demand; by highlighting the need to investigate the influence of public clients' characteristics on their own decision-making. The focus on both the former and the latter are underpinned by this study as areas considered underrepresented in existing literature. Results suggest that despite MMC acquiring relative advantages compared to traditional methods, it still lacks sufficient coherence in its characteristics by being associated with various complexities, contradicting existing norms, relating ambiguous observability, and attaining insufficient long-term trialability data. Such characteristics are explained to limit the prospects of MMC diffusion across the public sector's social system.

Future research paradigm of focusing on MMC technical attributes is expected to radically shift towards focusing on organisation's decision-making and contractor business models as the key gaps in relation to their influence on the low MMC uptake. This paper can be recognised as a robust foundation for future empirical investigations that would assess the explored determinants under each of the MMC attributes. A linkage is, therefore, required between the determinants and the low MMC uptake within the industry through revealing the decision-making process of clients. Limitations of this

study can be argued to be the small sample of secondary data (67 articles), which is justified by the inability to include vast MMC literature in one systematic review paper. Moreover, keywords utilised to capture recent literature may be associated with bias toward countries that are famous to adopt these wordings, i.e. United Kingdom, and the authors acknowledge that the use of additional keywords to describe the same context, undoubtedly, would have resulted in a much bigger exposure to articles from other countries. The choice of wordings to how MMC is differently interpreted across regions may have created a stance of imbalance among the collected articles, where this may provide scope for further research to consider these limitations toward more efforts in the same direction.

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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Table 1: List of previous systematic reviews on MMC

Resource	Title	MMC focus
Yao (2014)	A Systematic Review on Supply Chain Management in Prefabricated House-Building Research	Supply Chain Management
Akinradewo (2021)	Modular method of construction in developing countries: the underlying challenges	MMC in Developing Countries
Lima (2021)	Sustainability in the construction industry: A systematic review of the literature	Sustainability
BuHamdan (2021)	Generative systems in the architecture, engineering and construction industry: A systematic review and analysis	Digitalisation
Luo (2021)	A systematic overview of prefabricated construction policies in China	Policies
Zhang (2021)	Assessment of Feasibility, Challenges, and Critical Success Factors of MiC Projects in Hong Kong	Critical Success Factors

Loizou (2021)	Quantifying Advantages of Modular Construction: Waste Generation	Waste Management
Qi (2021)	A systematic review of emerging technologies in industrialised construction	Digitalization
Ekanayake (2021)	Identifying supply chain capabilities of construction firms in industrialised construction	Supply Chain Management
Ehwi (2022)	Offsite Manufacturing Research: A Systematic Review of Methodologies Used	Methodologies
Hou et al. (2022)	Towards a more extensive application of off-site construction: a technological review	Technological Processes
Kedir and Hall (2021)	Resource efficiency in industrialized housing construction: A systematic review of current performance and future opportunities	Sustainability

Table 2: The Inclusion/Exclusion Criteria

Criteria	Inclusion	Exclusion
Type	Journal Articles	Conference papers, book chapters, reviews, policy analysis, dissertations,
Condition	MMC related challenge, case study, empirical study, benefit, driver, contemporary issue, application, principle, phase	Secondary data analysis, non-construction related
Language	English	Other languages
Dates	2010-2021	-
Sector	Construction, Construction and Project Management	Non-construction related, Mathematical Computational, Biology-related MMC,

Dentistry, Pharmacology, Developmental Biology, Medicine