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Establishing interrelationships and dependencies of Critical Success Factors for Implementing Offsite Construction in the UK.

Purpose

The United Kingdom (UK) construction sector is transforming with increasing confidence in Offsite construction (OSC) solutions following its accrued benefits. To sustain this momentum, exploring viable strategies to promote successful OSC implementation is a top priority. This paper aims to identify and establish interrelationships and logical dependencies of Critical Success Factors (CSFs) for implementing Offsite construction (OSC) on building projects in the UK.

Design/methodology/approach

This study utilised a qualitative research approach. Following a critical review of extant literature, brainstorming and focus group sessions were carried out with OSC experts in the UK construction industry to identify and contextualise CSFs for OSC implementation. Interpretive structural modelling (ISM) and Matrix Impact Cross-Reference Multiplication Applied to a Classification (MICMAC) were used to analyse and model the interrelationships between the contextualised CSFs'.

Findings

The study identified eighteen CSFs for implementing OSC on projects in the UK positioned on seven hierarchical levels and clustered into dependent, linkage, and independent factors. The top five CSFs established were client commitment, top management support, adequate OSC knowledge and experience, flexible leadership, and flexible business models. These were located at the base of the ISM model, possessing the highest driving powers in facilitating the successful implementation of OSC on projects.

Originality

This study established a hierarchical interrelationship and the importance of the CSFs influencing the successful implementation of OSC. This would assist OSC clients and project teams in identifying and prioritising particular areas for strategic actions, which offer advantages in pursuing successful OSC project outcomes in the UK. Previous research on OSC implementation in the UK had not examined CSFs' interrelationships.

Keywords: Offsite construction, implementation, construction industry, interpretive structural modelling, critical success factor, prefabricated construction, modular construction, modular integrated construction, modern methods of construction, United Kingdom.

1. INTRODUCTION

An industry-wide push for the construction industry's performance in terms of process and product improvements has led to the accelerating adoption of innovations like Offsite Construction (OSC) (Vernikos et al., 2014; Masood et al., 2023; Van Oorschot et al., 2020; Zhang et al., 2021; Ginigaddara et al., 2022). Many countries are fast adopting OSC as it has been touted as an enabler to boost the realisation of automation and sustainability objectives of the construction industry (Masood et al., (2023; Van Oorschot et al., 2020) in addition to other benefits widely reported (Shahzad et al., 2023; Obi et al., 2022; Hong et al., 2016; Kamali and Hewage, 2016). The global OSC market is projected to reach USD 1.9 trillion in 2025 from USD 820 billion in 2020 (AGCS, 2021). However, the uptake and implementation levels vary from country to country. Countries like Japan, Sweden, Germany, and the Netherlands have increasingly consolidated the adoption of OSC, especially in the building sector, to improve housing supply. For instance, China is raising the proportion of OSC projects to 30% over the next decade (Jiang, 2018). In the United States of America (USA), the future of its construction industry is being promoted against the backdrop of OSC implementation (Razkenari et al., 2020). Like other countries, OSC is also gaining increasing attention in the United Kingdom (UK), especially across residential housing developments (Vernikos et al., 2014; Taylor, 2020). About thirty percent of the new homes recently built in the UK are said to have adopted one form of the OSC methods (Young et al., 2020). OSC has the potential to tackle many of the shortcomings of the UK construction sector, offering many tangible benefits to clients and users alike (Build Offsite 2012).

Various strategic actions are being implemented to support OSC uptake in the construction sector. For instance, incentivising the implementation of pre-manufactured housing, amongst others, has been proposed (Farmer, 2016). In 2017, the Secretary of State for Communities and Local Government proposed an accelerated Construction programme with offsite manufacturing techniques to meet the country's rising housing and infrastructure needs (Parliament UK, 2018). Also, the Chancellor of the Exchequer made commitments to support offsite construction across suitable capital programmes in various vital ministries in the country in the Autumn Budget of 2017. Similarly, in 2018, the Construction Sector Deal focused on meeting Offsite manufacturing technologies' objectives to help minimise wastage and inefficiencies in construction performances (Gov UK, 2019). Most recently, in January 2023, the Crown Commercial Service awarded a new agreement for offsite construction, which aims to support the public sector to innovate, drive efficiency and continue to work towards their carbon net-zero targets (Crown Commercial Service, 2023). These actions suggest successful OSC implementation at sector and project levels is a priority for the government; hence, the need for effective implementation cannot be overemphasised. The UK government research and development investment has extended focus from implementing OSC for housing delivery to other non-residential buildings (such as hospitals, schools, and prisons) and infrastructure (such as transport). It is claimed that the OSC building elements and structures are worth around £2-3 Billion per year and account for around 7% of the total UK construction sector (Taylor, 2009; UK Commission for Employment and Skills (UKCES), 2015; KPMG, 2016). The UK Prefabricated Buildings Industry Report shows that the OSC market in the UK is expected to grow at a compound annual growth rate CAGR of approximately 4.5%, mainly driven by the increasing investments in the UK's OSC sector (Mordor Intelligence, 2023). This construction market in the UK is transforming with increasing confidence in OSC solutions (Mordor Intelligence, 2023). Hence, the need for effective implementation strategies to improve performance and delivery cannot be overemphasised.

Compared to traditional projects, employing OSC has its peculiarities. OSC implementation is often supply-driven and involves setting up appropriate structures and resources, including re-engineering organisational supply chains in implementing OSC method(s) successfully on a project (Masood et al., 2023; Hosseini et al., 2018; Pan et al., 2007). Unfortunately, OSC implementation practices in the UK construction industry have remained fragmented and underdeveloped, sometimes resulting in more expensive solutions at sector and project levels (Goulding and Rahimian, 2019). Certain factors identified as Critical Success Factors (CSFs) (Wuni et al., 2020b; Jung et al., 2021) are required to ensure successful OSC implementation and maintain OSC practices' sustainability on projects. These are the specific elements/actions that must be considered essential elements of a management system that lead directly to successful outcomes. They are employed to achieve the strategic and operational goals of the project and, hence, have a significant impact on project management success. Surprisingly, studies on CSFs for OSC implementation are rare. A few studies, such as Li et al. (2018), Pan et al. (2007), Wuni et al. (2020b), Jung et al. (2021) and Shahzad et al. (2023), made attempts to provide a list of CFS associated with OSC. However, there are some limitations to their studies. Firstly, many of the CSFs identified were generic to OSC practices and often focused on OSC adoption. Secondly, many studies identified the CSFs without adequately exploring possible interactions and logical dependencies between them or modelled the factors in a hierarchical structure for client and project teams' easier understanding. According to Mao et al. (2018) and Wuni and Shen (2019a), the factors influencing OSC success do not exist in isolation but behave like an ecosystem with logical interdependences. Thirdly, many studies employed a quantitative approach to identifying- and analysing the CSFs and were not investigated within the UK context. According to Pan et al. (2007), providing practical guidance is a viable strategy to help project stakeholders become aware and understand the factors necessary to support successful OSC implementation. This paper aims to identify and establish interrelationships and logical dependencies of Critical Success Factors (CSFs) for implementing Offsite Construction (OSC) on building projects in the UK. The study findings would provide insights on CSFs for OSC implementation on projects that clients and project teams can use to set up bespoke strategies and management measures to maintain its sustainability of practice in the UK.

2. OFF-SITE CONSTRUCTION AND CRITICAL SUCCESS FACTOR: A LITERATURE REVIEW

Offsite construction (OSC) is considered an innovation as it changes the character and nature of delivering structures, allowing a significant portion of construction project activities to be carried out in a more controlled indoor environment, enabling standardisation and mass production (Van Oorschot et al., 2020; Masood et al., 2023). It requires parts of the building to be fabricated in a factory and then transported to the location where they are installed into a permanent position (Jiang et al., 2018; Hu et al., 2019). Existing literature establishes many terms such as Offsite Production, Offsite Manufacturing, Modern Methods of Construction (MMC), industrialised building systems and Prefabrication that have been used to describe Offsite construction (OSC). It also documents state of the art in OSC research and practice in the last decade, identifying benefits, challenges, methods, and drivers of OSC uptake (Taylor, 2022; Li et al., 2014; Jiang et al., 2018; Goulding and Rahimian, 2019; Wuni and Shen, 2019b; Razkenari et al., 2020; Correia et al., 2020; Wu et al. 2021). Literature suggests a series of methods are available when implementing OSC (see Arif and Egbu, 2010; Arif et al., 2017), and many construction projects employ one or more of these methods in their delivery. It is reported that OSC methods offer opportunities to substantially improve cost, time, quality, health and safety, environmental and circularity performances (Razkenari et al., 2020; Kamali and Hewage, 2016; Obi et al., 2022). OSC is not new to the UK construction industry (i.e. used since the Second World War to help meet the demand for housing). However, it has faced many challenges associated with implementation, generating a widening negative perception among clients and users (Arif et al., 2017). OSC implementation differs significantly from onsite construction processes as it involves undertaking most operations in advance (Razkenari et al., 2020). It further requires key stakeholders (authorities, town planners, developers, designers, contractors, manufacturers, and suppliers) to work closely throughout the project cycle executing specific workflows covering design, construction, operation, and maintenance tasks (Zhai et al., 2014). The peculiarities associated with OSC implementation prompt the need to identify and further understand what CSFs can support effective and sustainable OSC implementation practices on projects, especially for a country like the UK seeking to exploit all the benefits it could offer.

Critical Success Factors (CSFs), as defined by Obi et al. (2021), are essential elements in a management system that directly lead to successful outcomes. They are specific elements/actions that must be considered and employed to achieve the strategic and operational goals of the project. Hence, have a significant impact on project management success. In the last decade, existing literature documents a variety of possible CSFs for OSC practices (see Table 1). Lau (2011), in a study on OSC in Hong Kong, China, and Singapore, highlighted seven CSFs for managing modular production design in the context. Ismail et al. (2012) highlighted 12 CFSs for industrialised building system (IBS) project implementation in Malaysia. Azhar et al. (2013) investigated 12 critical factors and constraints for selecting modular construction over conventional stick-built techniques. Karmar et al. (2014) explored 19 CSFs for adopting IBS construction in Malaysia. O'Connor et al. (2014) identified 21 CSFs for implementing optimum and maximum industrial modularisation in the engineering, procurement, and construction (EPC) industries. Choi et al. (2016) identified 21 CSFs for implementing industrial modular projects. Li et al. (2018) identified 23 CSFs for project planning and control in China's prefabrication housing production (PHP). Ojoko et al. (2018) highlighted 10 CSFs for industrialised building system implementation in Nigeria. Wuni and Shen (2019a) identified 35 CSFs for modular integrated construction projects in Hong Kong. Wuni and Shen (2020a) identified 9 CSFs for managing the early stages of prefabricated prefinished volumetric construction projects in Hong Kong. Further research by Wuni et al. (2020b) identified 25 CSFs for implementing Modular integrated construction in Hong Kong. Zhang et al. (2021) established 15 CSFs for OSC adoption in Hong Kong. A recent study by Jung et al. (2021) highlighted 20 CSFs for OSC adoption in South Korea. Al-Aidrous et al. (2022) investigated essential factors enhancing industrialised building implementation in Malaysian residential projects. A list of 24 commonly cited CSFs identified across the studies were considered possible CSFs for OSC implementation, as shown in Table 1. These studies provided valuable contributions to the OSC/CSF literature. Still, the list in these studies requires further contextual investigation and validation within the UK context, which this study would address. Furthermore, it is also essential to understand how these factors interrelate, which would provide the needed clarity to develop appropriate strategies and guidance.

Table 1

3. METHODOLOGY

The researchers leaned towards an interpretivist philosophical stance and adopted an exploratory qualitative research approach in which knowledge is grounded on the collective opinions of experts (Fellows and Liu, 2015; Obi et al., 2021). The research initially used a systematic search approach to identify relevant literature from which possible CSFs that could impact OSC implementation can be identified. To achieve this, the researchers considered databases such as Scopus and Web of Science, often used for OSC research (Obi et al., 2022). A search string with keywords such as "success factor," "Critical success factor", "Offsite construction", OR "prefabricated", OR "modular", OR "offsite manufacturing", OR "Offsite production" OR "offsite manufacture" OR " Modular integrated construction" was used. Though not exhaustive, these keywords were considered adequate. The search was limited to peer-reviewed published articles in English that discussed CSFs in OSC, published between 2011 and 2022 and highly cited. The authors also ensured that the selected articles cut across studies from varying country contexts. These restrictions help identify 20 highly cited articles on CSFs relevant to the study. As espoused by Wuni and Shen (2019a), a sample of 16 articles is adequate for a systematic literature review. From these retrieved articles, the 24 most frequently appearing CSFs that may impact OSC implementation were extracted, as shown in Table 2. Subsequently, the ISM technique to establish interactions, model, and categorise the CSFs for OSC implementation in the UK.

3.1 Interpretive Structural Modelling (ISM) Approach

The Interpretive Structural Modelling (ISM) method is a qualitative and interpretive approach based on the insights of experts who decide which and how factors are related to resolving complex problems (Awuzie and Abuzeinab, 2019). It analyses the interactions among factors to define their interconnections and map the complexity of their relationships into a multi-level hierarchically structural model (Sushil, 2017). Studies such as Jung et al. (2021) and Marinelli et al. (2022) have employed ISM and MICMAC in their research of OSC practices. In this context, ISM is used to particularly establish interrelationships and logical dependencies of CSFs for OSC in a hierarchal model leveraging on experts' knowledge and experience. The resultant model would facilitate an easier understanding of the broader landscape of the influence of these CSFs. The ISM procedure presented is similar to those employed in previous studies (Awuzie and Abuzeinab, 2019; Obi et al., 2021; Jung et al., 2021). The ISM methodology consists of the following key steps:

- Define the variables and determine contextual relationships.
- Develop the structural self-interaction matrix (SSIM) based on contextual relationships.

- Develop a reachability matrix.
- Conduct a level partitioning of the factors.
- Develop the interpretive structural model of CSFs for OSC implementation.
- Categorise the factors using a MICMAC analysis, which uses a power and dependence matrix to cluster variables into Independent, Linkage, dependent, and Autonomous clusters (Jung et al. 2021; Obi et al. 2021).
    - Autonomous cluster- consists of factors with low driving power and dependence and hence are relatively disconnected from the system.
    - Dependent cluster- consists of factors with strong dependence but weak driving power. They largely depend on other factors from the base of the system.
    - Linkage cluster- consists of factors with strong driving power and dependence. They influence some factors in the system while also being influenced by other factors, often making them unstable.
    - Independent cluster- consists of factors with strong driving power and low dependence. The factors have the strongest capability and hence demand the most attention.
- Review and validate process and model.

ISM is expert-dependent, and the focus on experts' perceptions is to gain an in-depth understanding of the CSFs' interrelationships. The authors used brainstorming and focus group discussions at various stages within the ISM to gather expert views. These methods are ideal for facilitators to build on participants' responses to generate insights and confirm the CSFs being discussed (Saunders et al., 2016). The experts' views were thematically analysed and used as input into the ISM process. The participants were selected through purposive sampling, widely accepted in OSC research (Masood et al., 2023). The practitioners were selected who were construction professionals who have worked or are working with organisations actively promoting OSC practices in the UK and are affiliated with the offsite Hub or building offsite. The participants (academics and practitioners) were selected based on their knowledge, expertise, and experience in OSC practices in the UK. The study sample included a mix of designers, architects, OSC academics/researchers, client advisors/project managers, manufacturers/suppliers, and contractors responsible for OSC project development and implementation. This mix aimed to ensure a spread of opinions from a blend of possible key OSC project stakeholders in the UK. Table II provides details of the twelve experts who participated in the study. Twenty-three participants were initially contacted to participate, but only twelve participated. Four OSC experts (one OSC contractor, Client advisor, designer, and academic) participated in the brainstorming session. The brainstorming sessions allowed the identification and contextualisation of a list of CSFs from UK experts' view. Subsequently, a focus group discussion was conducted involving eight experts to determine contextual relationships between the 18 contextualised CSFs. The second focus group allowed for the structured walkthrough and validation of the model developed. The participants included two suppliers/manufacturers, two contractors, two OSC designers, one Client OSC advisor and one OSC Academic. Three of the participants were previously involved in the brainstorming session.

Table 2: Participant's profile

A summary of the main steps employed in this study is presented in Figure I

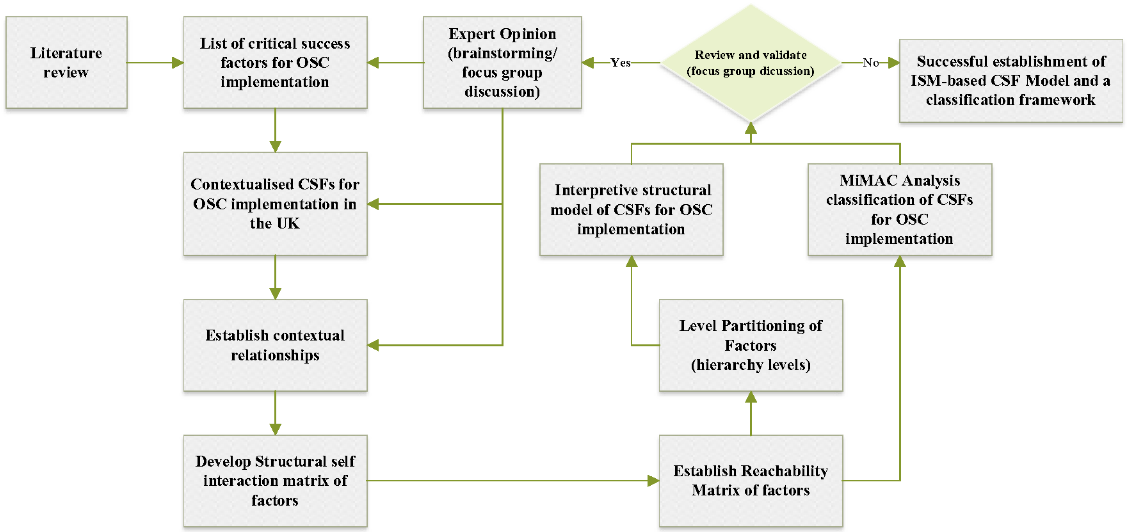

Figure I: Methodological Process

The following sections of the paper present the ISM results and findings.

4. RESULTS

The results from the ISM are presented in this section.

4.1 Contextualisation of CSFs for OSC Implementation

In the brainstorming session, experts were asked to list and describe CSFs for OSC implementation in the UK. Participants echoed many of the CSFs previously identified from the literature. They specifically mentioned flexible OSC business models, equitable trust and buy-in, OSC database, and flexible leadership approach, which were new contributions. Experts were presented with the CSF lists from the literature alongside their suggestions. They discussed and debated the criticality of the factors in the UK context. They refined the list by removing factors they considered not critical. They renamed some factors and merged others. To achieve consensus, authors ensured to confirm participants agreed with each factor put forward as a CSF for consideration in the study through a vote. Those on which consensus was not initially reached were reconsidered, reworded, and voted on again. The consensus was not based on unanimity but considered above two-thirds of the participant's agreement. Through these sessions, eighteen factors were consolidated (See Table III).

4.2 Determining the Reachability Matrix and Partition Levels of the CSFs Identified

Contextual relationships among the CSFs were defined from expert opinions through focus group discussions. Experts were required to define the relationships between the identified CSFs (CSF1, CSF2 . . . CSF18) using the term "influences" for links. The nature of the relationship between any two factors (i and j) is defined as follows:

- V: Factor i influences factor j,
- A: Factor j influences factor i,
- X: Factor i and j influence each other.
- O: No relationship exists between factors i and j.

This allowed the coding of experts' opinions into matrices. Based on the contextual relationship defined by the experts, the SSIM is developed. The symbols V, A, X and O in the SSIM were then converted into a binary matrix by substituting "1", where experts confirmed a relationship and "0", where no relationship exists. Consequently, the initial reachability matrix was derived, and further checks for transitivity relationships were explored.

Transitivity (depicted as 1*) dictates that if factor "CSF1" influences a factor "CSF2" and the factor "CSF2" influences factor "CSF3", then Factor "CSF1" may also be said to influence factor "CSF3". The transitivity was confirmed with experts, and the final reachability matrix was developed. A level partitioning iteration was undertaken to assign levels to CSFs using the data in the final reachability matrix. When a factor's reachability (the factor itself and other variable (s) that it may enhance) and intersection set are seen as the same, a level is assigned to that factor and removed from the factor list. This iteration process is known as level partitioning and was repeatedly undertaken until all the levels for each factor in the list were determined.

4.3 Interpretive Structural Model of CSFs for OSC Implementation

The ISM model (see Figure II) structure was developed from the level iterations by arranging the partition levels obtained for each CSF from top to bottom and plotting the relationship between the factors. In Figure II, the ISM model portrays the CSFs that influence the successful implementation of OSC on projects ranked in seven levels. CSFs on level 7 are the most critical; hence, they are a high priority for consideration, and level 1 is the least critical in the factor system. Figure II shows all the relationships among the CSFs at the same level and hierarchical levels. Red-coloured arrows show the direction of influence from one level to another. Hence, CSFs at one level facilitate the successful realisation of CSFs on the level to which the arrow points. The brackets show CSFs on the same level. Level directional relations were depicted in green or grey colour legends. A green colour legend shows that the CSFs at that level have bilateral relationships, facilitating each other. A grey colour shows no relationship or influence. Adequate OSC knowledge and experience (CSF 16), Top management support (CSF 11) and Client commitment (CSF 10) located on level 7 are linked with bi-directional relationships, and all directly facilitate CSFs on level 6. Flexible leadership approach (CSF 13) and Flexible OSC business models (CSF 14) located on level 6 have no relationship. However, both directly facilitate CSFs on level 5. Collaborative procurement methods (CSF 9) and Early team involvement (CSF 17) at Level 5 are linked and have bi-directional relationships. They all directly facilitate CSFs on Level 4. Equitable trust and buy-in (CSF 12), Effective communication and collaboration (CSF 15), Robust and accessible project information (CSF 5) and Use of data-driven (CSF 4) are located on level 4. These CSFs have bilateral relationships and directly facilitate CSFs on level 3. At level 3 are Effective planning and scheduling (CSF 1), Process and product Standardisation (CSF 3) and Robust and accessible OSC database (CSF 2). These CSFs have bilateral relationships and directly facilitate CSFs on Level 2. Early design freeze (CSF 6), Effective risk management (CSF 8) and Effective supply chain management (CSF 7) at level 2 have a bilateral relationship and all together directly facilitate CSFs on Level. Continuous learning and improvement (CSF 18) are located at level 1 and depend on all The CSFs from the base of the ISM for its actualisation.

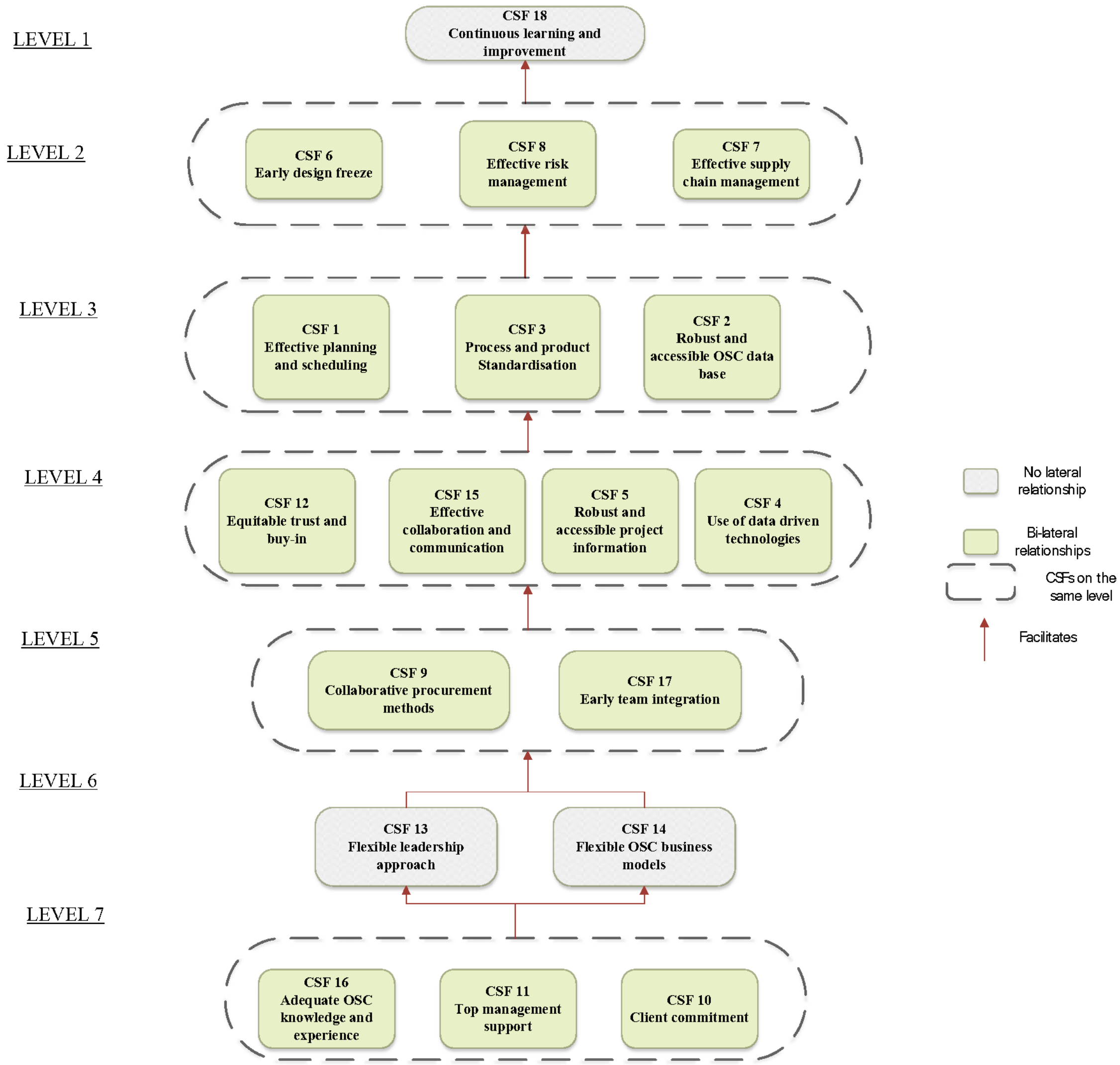

Figure II: Interpretive structural model of CSFs for implementing OSC.

4.4 MICMAC Analysis Of CSFs For OSC Implementation

A MICMAC analysis was also performed using data from the final reachability matrix to classify the CSFs into dependent, linkage, and independent clusters. No CSF was located in the autonomous cluster (see Figure III). From Figure III, the loading of the factors is presented as follows:

- Independent cluster: Seven factors comprising CSFs 10, 16, 11,13, 14, 9 and 17 are loaded into this cluster.
- Linkage cluster: Four factors, comprising CSFs 12,4,5 and 15 loaded into this cluster.
- Dependent cluster: Seven factors comprising CSFs 1,2,3, 6,7, 8, and 18 loaded into this cluster.

The loading of the CSFs indicated that all the factors identified were essential to successful OSC implementation on projects.

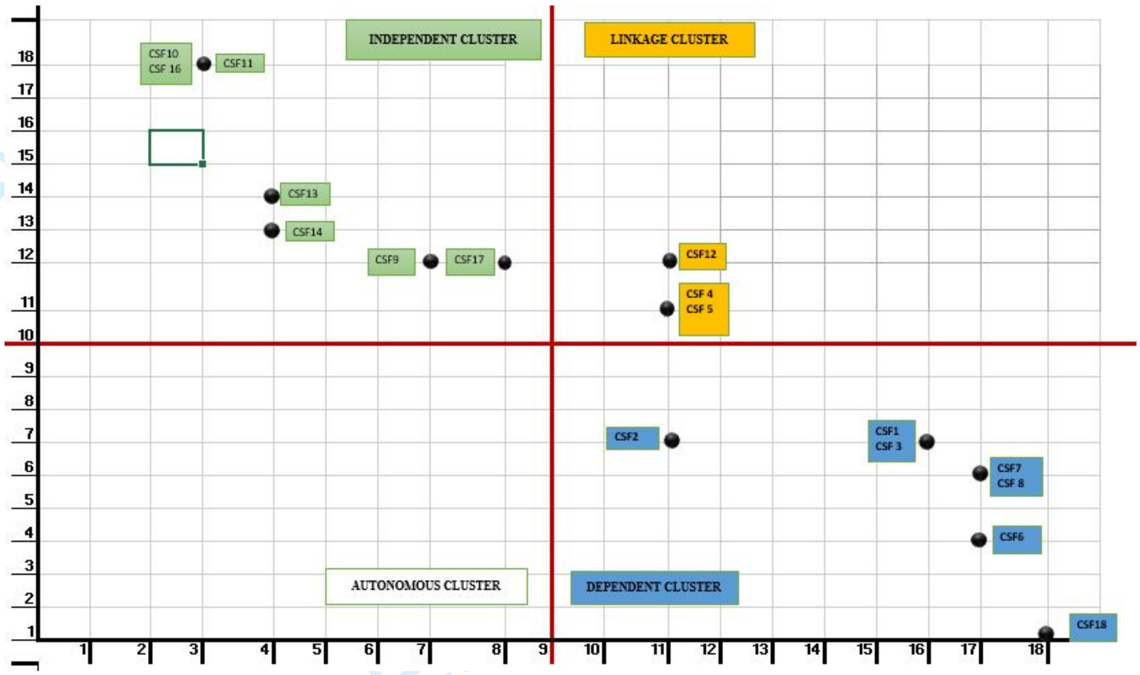

Figure III: MICMAC categorisation of CSFs for OSC implementation

The authors and experts performed a structured walkthrough to identify contextual inconsistencies and validate the ISM model. Experts further commented on the MIMAC categories following the loading. They espoused that the CSFs loaded in the independent cluster were leadership-related, requiring top-level management decisions and actions. On linkage factors, experts opined that the loading of the factors was focused on technology-enhanced information management approach for efficient collaborative practices. Regarding the dependent cluster, the experts opined that the CSFs loaded in this cluster were focused on planning, monitoring, and improving operations across teams on the OSC project. Drawing on an interpretive structural model, clustering of the CSFs, and agreeing with expert opinions, the authors labelled each cluster: Leadership, technology-enhanced collaborative working and operational management. The framework suggests that leadership and technology-enhanced collaborative working-related CSFs influence operational management-related CSFs. Hence, more focus should be directed towards leadership and technology-enhanced collaborative working. On these findings, a CSF classification framework for OSC implementation in the UK, as depicted in Figure IV, was proposed. Bespoke strategies that offer advantages in pursuing successful outcomes should be developed in these areas.

Figure IV: CSF classification framework for OSC implementation

5 DISCUSSION

The overall success of OSC implementation on projects in the UK construction sector is driven by five top CSFs: Top Management Support, Client Commitment, Adequate OSC knowledge and Experience of the Project Team, Flexible Leadership Approach and Flexible Business Models. These five CSFs emphasise the need to understand clients' nature and impact and top management's contributions to decision-making within the OSC process. In addition, there is a need to engage the right set of professionals in the teams the leadership style and business models should be selected appropriately for the OSC project. These findings are mostly consistent with earlier studies conducted by Jung et al. (2021), apart from persistent policies and incentives and early research on modularisation. The differences may have emerged following expert views from South Korea. However, it differs from the top five CSFs identified by Wuni et al. (2020b) except for adequate OSC knowledge and experience. Such differences may be associated with surveying 40 experts' views from various regions, including America, Asia and Europe, while CSFs relationships are not interpretive based. The eighteen CSFs identified from this study are further discussed under the headings of their associated classifications.

5.1 Leadership-related CSFs

Successful OSC implementation in a project requires a robust leadership framework, starting with the client and then the project team. The leadership related CSFs identified from the study are discussed below.

5.1.1 Client Commitment

The client's early commitment to the concept of OSC creates a level of trust that OSC could deliver the preconceived vision for the project, paving the way for effective communication of proposed project requirements. Clients should understand the value of OSC and be informed about its techniques to be more likely to commit to its use firmly. From the outset, client commitment to OSC significantly impacts a well-defined client requirement, substantially assuring rigour in the project budget, programme, and scope (Kamali and Hewage. 2016; Choi et al., 2016). The client is the vision bearer; hence, early client commitment to OSC ensures the appropriate resource types, stakeholders, and levels of expertise, ultimately mitigating gaps in capabilities as projects develop. As such, regular strategies to disseminate OSC updates should be made available and accessible for potential and current OSC clients, stakeholders, and influencers such as local councils and governments to ensure they are well informed of the benefits of OSC.

5.1.2 Top Management Support

Top management in client and contracting organisations are committed financially and politically, ultimately delivering governance and leadership that impacts the project. To effectively make timely and appropriate decisions for the project, the top management on all sides needs to be aware of the OSC requirements. Ideally, from RIBA Stage 0 but up to RIBA Stage 2 (as all parties may not be onboard at RIBA Stage 0) (RIBA, 2020), they need to align the project with the strategy of the client's organisation and that of the funding partners. They must define project success measures and be flexible to authorise and support the people, process, and structure for effective OSC implementation. Therefore, they should have the experience to understand and mitigate risks, learning lessons from past experiences as they make decisions that influence project management and product success (Choi et al., 2016).

5.1.3 Adequate OSC Knowledge and Experience

Manufacturing projects typically differ from traditional construction schemes as they are predominantly product-focused rather than project-focused (Goulding and Raihmen, 2019). Understanding the OSC expectations and requirements demands adequate OSC knowledge and experience from those saddled to deliver the project (Wuni and Shen, 2019a; 2019b). These include the Client, contractor, consultants, and manufacturing/supply team. Each team's adequate knowledge and experience are helpful in advising, teaching, and making effective decisions that support the OSC process. Previous studies (Jiang et al., 2018; Li et al., 2018; Wuni and Shen, 2019a) highlighted the perceived concerns over the lack of trained and experienced OSC workforce, including clients, contractors, manufacturing and design teams. The need to embrace OSC product-oriented processes and approaches may require the workforce to be retrained with assembly skills and manufacturing principles. As such, there is a need to up-skill the OSC workforce within each team to embrace the uniqueness of OSC delivery (Goulding and Rahimian, 2019). Strategies such as occupational training and higher degree apprenticeships for continuous learning and upskilling in OSC practice should be encouraged. Built environment academic programs, in addition to higher education institutions, can be drivers of accelerated knowledge of OSC practices through their curriculum.

5.1.4 ***Flexible Business Model(s)***

OSC business organisations significantly facilitate effective implementation through their business model (Goulding et al., 2015; Pan et al., 2012; Jones et al., 2019). OSC solutions to clients are often based on the strength of the contractor's business models. For instance, a contractor offering modular products may suggest modular solutions to clients even if a panelised or hybrid method may be more appropriate. The lack of flexible business models is one of the issues affecting effective OSC implementation at the project level (Goulding et al., 2015). Business model innovation/transformation is a way for OSC businesses to become more responsive to meet client's requirements and satisfaction (Antikainen and Valkokari, 2016). Such transformation may involve a joint venture with other OSC contractors or between contractor and manufacturer offering pods or panelised solutions, complementing solutions to a client's requirements.

5.1.5 Flexible Leadership Approach

There is a shift in focus from project management to project leadership to achieve success (Pilkienė et al., 2018; Müller, 2018; Howell et al., 2004). This study confirms this, where project leadership is in Level 6 and the independent category. With the complexity of OSC projects, the dynamics are high as they cannot be assessed in just one direction (Ahola et al., 2014). Hence, the leadership style must be appropriate for each stage of the process. Flexibility in the dynamics of temporary shifts in leadership between project managers and team members for accomplishing desired tasks in the OSC process can be envisaged. Clients and project managers may consider a shared and balanced leadership approach (see Müller et al., 2018). For instance, in this approach, the project manager may delegate leadership responsibilities during the manufacturing stage to the lead supplier because of their wealth of experience in the requirements for attaining success in that stage.

5.1.6 Early Team Involvement

The success of OSC involves great collaboration between manufacturers, suppliers, and contractors from a very early stage. Clients and contractors need to engage with an offsite manufacturer/supplier early, for instance, at RIBA Stage 2, so that the right parameters for design ahead of planning and manufacturing can be implemented. This would give the key teams- design, manufacturing, and construction enough time to assess the project and provide advice to support effective decision-making on the design, platform strategies and resource planning (such as cost and time planning) (Wuni et al., 2020b, Wuni and Shen, 2020a; Choi et al., 2016)). It also facilitates better integration across teams, mitigating blockers such as design-related issues, commercial, and manufacturing at early and crucial stages of the project. However, this may require shifting from the current popular procurement models (traditional or design and build) to embracing more collaborative models.

5.1.7 Collaborative Delivery Methods

Practitioners alluded that fundamental problems arise when the client selects a preferred manufacturer but is then employed by a reluctant contractor, and the link between client and manufacturer is lost. Procurement methods should be promoted, such as integrated project delivery, alliance partnering, integrated project insurance, and framework agreement, considering the complexity of OSC delivery (Razkenari et al., 2019). These procurement methods allow vital players such as designers, manufacturers, suppliers, and contractors to be engaged earlier and appropriately in the process (ideally between RIBA Stage 0 and Stage 2) (RIBA, 2020).

5.2 Technology-Enhanced Collaborative Working

Successful OSC implementation requires collaborative practices effectively supported by appropriate technologies. The related CSFs identified from the study are discussed below:

5.2.5 Equitable Trust and Buy-In

OSC involves numerous stakeholders working together to implement the project, requiring the need to buy into common goals (Goulding and Raihmen 2019). A committed stake in the project enables all risk elements and gains to be fairly distributed between partners. However, commitment (i.e. project timescale and beyond) comes from a place of mutual trust and mutual accountability (Faris et al., 2022). Therefore, OSC teams must be open, honest, and willing to share important information with themselves that reflects the real situation. Building and maintaining a good reputation through reciprocity, fairness and professionalism at the individual and organisational level is a crucial indicator influencing the decision to trust (Khalfan et al. 2007). Clear and well-defined objectives, measurable deliverables, and attainable timeframes are essential to allow various teams to manage expectations efficiently. Consensus, regular updates on progress, transparency, effective change management practices, contractual agreement, opportunity for future work, recognition of efforts, feedback, and effective complaints handling should be considered (Faris et al. 2022; Manu et al. 2015).

5.2.2 Effective Communication and Collaboration

OSC implementation requires increased interactions and close collaboration among key stakeholders (e.g. developers, designers, contractors, manufacturers, and suppliers) to execute specific workflows that cover design, construction, operation, and maintenance tasks (Zhai et al., 2014). The contract development should clearly define communication channels, systems, protocols, procedures, and roles to enable effective communication. In addition, online collaboration tools that link the project commercials with the supply chain, logistics, design, programme, and monitoring should be implemented for successful collaboration. There are numerous tools for communication and collaboration employed by respective companies involved in OSC, and there may be instances where these tools are incompatible. This should not be a blocker, as specialist systems usually have gateways and other protocols to allow interaction with conventional/market-leading collaboration tools.

5.2.6 Use of Digital-Driven Technologies

Technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), Machine learning (Ml) and Blockchain may be considered relevant (Wang et al., 2020; Hou et al., 2020; Xiao et al., 2022) and effective for creating and managing OSC project information. These technologies facilitate effective coordination and exchange of project information among OSC professionals, providing faster access to reliable data and details, supporting project control and real-time monitoring of work progress, transportation, and assembly (Altaf et al., 2018). Data-driven technology will promote a platform for capturing information that supports industry-wide modular coordination and standardised design components. This will lead to product and process performance standards for offsite construction and support effective decision making, especially associated with design, manufacturing, construction, and lifecycle process analysis. However, some studies identified industry lags in implementing such concepts in real-time in the OSC process (Arif et al., 2017; Ginigaddara et al., 2022).

5.2.7 Robust and Accessible Project Information

To effectively run the OSC project and meet the expectations of the client, all related information to the project should be accurate, comprehensive, and accessible to those that need it, such as the designer, manufacturer, client, and contractors (Jung et al., 2021; Wuni et al., 2020b). Limitations of sharing data and information compromise the speed and quality of the project. This fluidity of information needs to expand between manufacturer, logistic and assembly platforms to avoid any misalignment with schedule, design, and risks. Recent advances in information technologies facilitate convenient access, storage, and analysis of large amounts of project information such as drawings, reports, certificates, spreadsheets, or any other document across various teams throughout the facility's lifecycle. Accordingly, many features of digitalisation like building information modelling (BIM), Blockchain, Artificial intelligence (AI), Internet of Things (IoT) and Digital twins (DT) will play a very significant role in creating a dynamic platform to ensure transparency and traceability of OSC project information.

5.3 Operational Management

Successful OSC implementation requires managing activities that can directly impact various operations within the OSC stages. The related CSFs identified from the study are discussed below.

5.3.1 OSC Database

A robust and accessible OSC database gives the project team clear access to data records from various OSC projects and companies. These may include supplier information data on design, cost, and module standards informing a consistent approach for evaluating project performance, benchmarking, and predicting possible performance scenarios of current and future OSC projects. With such data, standardisation and effective planning and scheduling can be achieved.

5.3.2 Process and Product Standardisation

The use of standardised designs and processes encourages repeatability. Modularity in building elements and processes from design to closeout is fundamental to achieving economies of scale (O'Connor et al., 2014). Higher productivity in the manufacturing industry partly results from standardised products on assembly lines (Wuni et al., 2020b). With standardisation, effective planning and surety of lead times can be determined.

5.3.2 Planning and Scheduling

Planning and scheduling project resources and optimising logistics within the process to avoid delays (transport and owner) are essential to ensure project coordination and performance (Choi et al. 2016). Effective planning is highly critical, considering the high complexity and relationships well beyond conventional construction processes (Goulding and Rah, 2019; Razkenari et al., 2019). A seamless process that integrates manufacturing and construction, taking advantage of offsite production and onsite work, should be well thought out before execution.

5.3.3 Early Design Freeze

A design freeze is a deadline for making all the major design decisions for a construction project. This allows the design team to set and work within set dates and procurement milestones. Understanding early design freeze, especially for the client team, is necessary to avoid design changes later in the process (Choi et al., 2016). When such a freeze is not considered, design changes are imminent. This will require extensive reworking of drawings to fit a manufacturer's module sizes or, in some cases, multiple module sizes produced, which impacts cost-effectiveness.

5.3.4 Effective Supply Chain and Risk Management

The OSC project's supply chain includes a variety of sectors, such as design, engineering, and manufacturing, that have interdependent relationships (Jung et al., 2021) and hence require effective management. Such management will involve identifying potential problematic areas and implementing strategies to prevent or minimise their occurrences within the chain and on the project. Tools that support effective coordination between these various sectors must be put in place (Masood et al., 2023). This allows cross-teams to create and utilise information on various project activities, improving construction productivity, enhancing competitive advantage, and satisfying the client requirements at the lowest possible cost (Li et al., (2017). This would proactively help in risk identification and prevention throughout the OSC process.

5.3.5 Continuous Learning and Improvement

Project performance should be continuously improved through performance analysis and appropriate benchmarking practices. Promoting a learning culture at organisation and project levels through workshops and seminars can also support staff and team knowledge on OSC processes. The study agrees that continuous learning and improvement are critical for improving OSC implementation practices, and this has been advocated for through research and industry practice. However, the ISM reveals that achieving this factor requires several other factors discussed first to be put in place.

6 CONCLUSION

OSC is increasingly becoming a preferred method over the traditional construction approach for many projects in the UK. Improving OSC implementation practices at the project level is critical to realising the objectives and expectations of key stakeholders. This research investigated the interrelations and logical dependencies of CSFs for OSC implementation on projects in the UK. An interpretive structural model of eighteen CSFs influencing OSC implementation is developed. The model defined seven levels of importance for the eighteen CSFs and showed their directional and bilateral relationships. A CSF classification framework has also been developed to benefit clients and project teams involved in OSC implementation on building projects in the UK. The MICMAC analysis categorised CSFs according to driving and dependence power into three clusters, and all five driving CSFs were mostly consistent with previous studies.

The study contributes to the establishment of relationships among the CSFs, especially for OSC implementation, which has not been previously investigated, particularly within the UK context. It also developed a classification framework for CSFs in OSC implementation: Leadership, Technology-enhanced collaborative working and operational management. It validated previous research findings that argued CSFs have logical dependencies and interrelationships contributing to existing knowledge in OSC success factor literature. OSC client and project teams can also leverage the CSFs identified in this research as a valuable reference for further contextual investigations in their country contexts. The model and the classification framework can assist client and project teams develop bespoke strategies to mitigate poor OSC implementation performances and promote better leadership and collaborative practices. However, clients, designers, contractors, and manufacturers need to understand the nature and impact of their input in decision-making and actions within the OSC process. Their commitment to achieving success should start with refocusing priorities from CSFs at the top of the model that are often outcomes of other influencing factors to those at the base. Investment of resources in establishing systems that can facilitate timely engagement of the right set of OSC workers/professionals, leadership style, and business models appropriate to deliver client needs must take priority to drive successful OSC implementation.

There are a few limitations associated with this research. The finding reflects only the UK local context as the evaluated CSFs for OSC implementation were developed based on UK OSC experts' views. Hence, the priority list in the study may differ for other countries which require further investigations. The ISM model has not been validated on real-life OSC projects. Therefore, future studies can test the model in real-life settings to evaluate its performance against success criteria for OSC project success. In addition, the model was premised on qualitative interpretations and was not statistically validated. It is then recommended that future studies examine the contextual relations of each CSF with respect to the OSC stages and use quantitative approaches such as Structural equation modelling (SEM) and regression analysis.

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Establishing interrelationships and dependencies of Critical Success Factors for ~~the~~ ~~Implementation~~implementing ~~of~~ Offsite Construction in the UK.

Purpose

The United Kingdom (UK) construction sector is transforming with increasing confidence in Offsite construction (OSC) solutions following its accrued benefits. To sustain this momentum, exploring viable strategies to promote successful OSC implementation is top priority. This paper aims to identify and establish interrelationships and logical dependencies of Critical Success Factors (CSFs) for implementing Offsite construction (OSC) on building projects in the UK.

Design/methodology/approach

This study utilised a qualitative research approach. Following a critical review of extant literature, brainstorming and focus group sessions were carried out with OSC experts in the UK construction industry to identify and contextualise CSFs for OSC implementation. Interpretive structural modelling (ISM) and Matrix Impact Cross-Reference Multiplication Applied to a Classification (MICMAC) were used to analyse and model the interrelationships between the contextualised CSFs'.

Findings

The study identified eighteen CSFs for implementing OSC on projects in the UK positioned on seven hierarchical levels and clustered into dependent, linkage, and independent factors. The top five CSFs established were client commitment, top management support, adequate OSC knowledge and experience, flexible leadership, and flexible business models. These were located at the base of the ISM model possessing the highest driving powers in facilitating the successful implementation of OSC on projects.

Originality

This study established a hierarchical interrelationship and the importance of the CSFs influencing the successful implementation of OSC. This would assist OSC clients and project teams ~~identify~~ in identifying and ~~prioritise~~ prioritising particular areas for strategic actions, which offer advantages in pursuing successful OSC project outcomes in the UK. Previous research on OSC implementation in the UK had not examined CSFs' interrelationships.

Keywords: Offsite construction, implementation, construction industry, interpretive structural modelling, critical success factor, prefabricated construction, modular construction, modular integrated construction, modern methods of construction, United Kingdom.

1. INTRODUCTION

An industry-wide push for the construction industry's performance in terms of process and ~~products~~ product improvements has led to the accelerating adoption of innovations like Offsite Construction (OSC) (Vernikos et al., 2014; Masood et al., 2023; Van Oorschot et al., 2020; Zhang et al., 2021; Ginigaddara et al., 2022). Many countries are fast adopting OSC as it has been touted as an enabler to boost the realisation of automation and sustainability objectives of the construction industry (Masood et al., (2023; Van Oorschot et al., 2020) in addition to other benefits widely reported (Shahzad et al., 2023; Obi et al., 2022; Hong et al., 2016; Kamali and Hewage, 2016). The global OSC market is projected to reach USD 1.9 trillion in 2025 from USD 820 billion in 2020 (AGCS, 2021). However, the uptake and implementation levels vary from country to country. Countries like Japan, Sweden, Germany, and the Netherlands, have increasingly consolidated the adoption of OSC, especially in the building sector, to improve housing supply. For instance, China is raising the proportion of OSC projects to 30% over the next decade (Jiang, 2018). In the United States of America (USA), the future of its construction industry is being promoted against the backdrop of OSC implementation (Razkenari et al., 2020). Like other countries, OSC is also gaining increasing attention in the United Kingdom (UK) ~~OSC~~, especially across residential housing developments (Vernikos et al., 2014; Taylor, 2020). About thirty percent of the new homes recently built in the UK are said to have adopted one form of the OSC methods (Young et al., 2020). OSC has the potential to tackle many of the shortcomings of the UK construction sector, offering many tangible benefits to clients and users alike (Build Offsite 2012). Various strategic actions are being implemented to support OSC uptake in the construction sector. For instance, incentivising the implementation of pre-manufactured housing, amongst others, has been proposed (Farmer, 2016). In 2017, the Secretary of State for Communities and Local Government proposed an accelerated Construction programme with offsite manufacturing techniques to meet the country's rising housing and infrastructure needs (Parliament UK,~~.~~ ~~(~~2018). Also, the Chancellor of the Exchequer made commitments to support offsite construction across suitable capital programmes in various vital ministries in the country in the Autumn Budget of 2017. Similarly, in 2018, the Construction Sector Deal focused on meeting Offsite manufacturing technologies' objectives to help minimise wastage and inefficiencies in construction performances (Gov ~~.~~UK, 2019). Most recently, in January 2023, the Crown Commercial Service awarded a new agreement for offsite construction, which aims to support the public sector to innovate, drive efficiency and continue to work towards their carbon net-zero targets (Crown Commercial Service, ~~(~~2023). These actions suggest successful OSC implementation at sector and project levels ~~are~~ is a priority for the government; hence the need for effective implementation cannot be overemphasised. The UK government research and development investment has extended focus from implementing OSC for housing delivery to other non-residential buildings (such as hospitals, schools, and prisons) and infrastructure (such as transport). It is claimed that the OSC building elements and structures are worth around £2-3 Billion per year and account for around 7% of the total UK construction sector (Taylor, 2009; UK Commission for Employment and Skills~~,~~ (UKCES), 2015; KPMG, 2016). The UK Prefabricated Buildings Industry Report shows that the OSC market in the UK is expected to grow at a CAGR of approximately 4.5%, mainly driven by the increasing investments in the UK's OSC sector (Mordor Intelligence, 2023). This construction market in the UK is transforming with increasing confidence in OSC solutions (Mordor Intelligence, 2023). Hence the need for effective implementation strategies to improve performance and delivery cannot be overemphasised.

Compared to traditional projects, employing OSC has its peculiarities. OSC implementation is often supply-driven and involves setting up appropriate structures and resources, including re-engineering organisational supply chains in implementing OSC method(s) successfully on a project (Masood et al., 2023; Hosseini et al., 2018; Pan et al., 2007). Unfortunately, OSC implementation practices in the UK construction industry have remained fragmented and underdeveloped, sometimes resulting in more expensive solutions at sector and project levels (Goulding and Rahimian, 2019). Certain factors identified as Critical Success Factors (CSFs) (Wuni et al., 2020b; Jung et al., 2021) are required to ensure successful OSC implementation and maintain OSC practices' sustainability on projects. These are the specific elements/actions that must be considered essential elements of a management system that leads directly to successful outcomes. They are employed to achieve the strategic and operational goals of the project and, hence, have a significant impact on project management success.

Surprisingly, studies on CSFs for OSC implementation are rare. A few studies found ~~studies~~, such as Li et al. (2018), Pan et al. (2007), Wuni et al. (2020b), Jung et al. (2021) and Shahzad et al. (2023), made attempts to provide a list of CFS associated with OSC. However, there are some limitations to their studies. Firstly, many of the CSFs identified were generic to OSC practices and often focused on OSC adoption. Secondly, many studies identified the CSFs without adequately exploring possible interactions and logical dependencies between them or modelled the factors in a hierarchical structure for client and project teams' easier understanding. According to Mao et al. (2018) and Wuni and Shen (2019a), the factors influencing OSC success do not exist in isolation but behave like an ecosystem with logical interdependences. Thirdly, many studies employed a quantitative approach to identifying- and analysing the CSFs and were not investigated within the UK context. According to Pan et al. (2007), providing practical guidance is a viable strategy to help project stakeholders become aware and understand the factors necessary to support successful OSC implementation. This paper aims to identify and establish interrelationships and logical dependencies of Critical Success Factors (CSFs) for implementing Offsite Construction (OSC) on building projects in the UK. The study findings would provide insights on CSFs for OSC implementation on projects that clients and project teams can use to set up bespoke strategies and management measures to maintain its sustainability of practice in the UK.

2. OFF-SITE CONSTRUCTION AND CRITICAL SUCCESS FACTOR: A LITERATURE REVIEW

~~2. LITERATURE REVIEW~~

~~2.1 Off- Site Construction And Critical Success Factor~~

Offsite construction (OSC) is considered an innovation as it changes the character and nature of delivering structures allowing a significant portion of construction project activities to be carried out in a more controlled indoor environment, enabling standardisation and mass production (Van Oorschot et al., ~~(~~2020; Masood et al., ~~(~~2023). It requires parts of the building to be fabricated in a factory and then transported to the location where they are installed into a permanent position (Jiang et al., 2018; Hu et al., 2019). Existing literature establishes many terms such as Offsite Production, Offsite Manufacturing, Modern Methods of Construction (MMC), industrialised building systems and Prefabrication that have been used to describe Offsite construction (OSC). It also documents the state of the art in OSC research and practice in the last decade identifying benefits, challenges, methods, and drivers of OSC uptake (Taylor, 2022; Li et al., 2014; Jiang et al., 2018; Goulding and Rahimian, 2019; Wuni and Shen, 2019b; Razkenari et al., 2020; Correia et al., 2020; Wu et al. 2021). Literature suggests a series of methods are available when implementing OSC (see Arif and Egbu, 2010; Arif et al., 2017), and many construction projects employ one or more of these methods in their delivery. It is reported that OSC methods offer opportunities to substantially improve cost, time, quality, health and safety, environmental and circularity performances (Razkenari et al., 2020; Kamali and Hewage, 2016; Obi et al., 2022). OSC is not new to the UK construction industry (i.e. used since the Second World War to help meet the demand for housing). However, it has faced many challenges associated with implementation, generating a widening negative perception among clients and users (Arif et al., 2017). OSC implementation differs significantly from onsite construction processes as it involves undertaking most operations in advance (Razkenari et al., 2020). It further requires key stakeholders (authorities, town planners, developers, designers, contractors, manufacturers, and suppliers) to work closely throughout the project cycle executing specific workflows covering design, construction, operation, and maintenance tasks (Zhai et al., 2014). ~~It further requires key stakeholders (authorities, town planners, developers, designers, contractors, manufacturers, and suppliers) to work closely throughout the project cycle and execute specific workflows covering design, construction, operation, and maintenance tasks (Zhai et al., 2014).~~ The peculiarities associated with OSC implementation prompt the need to identify ~~further~~ and further understand what CSFs can support effective and sustainable OSC implementation practices on projects, especially for a country like the UK seeking to exploit all the benefits it could offer.

Critical Success Factors (CSFs), as defined by Obi et al. (2021), are essential elements in a management system that directly lead to successful outcomes. They are specific elements/actions that must be considered and employed to achieve the strategic and operational goals of the project and, hence, have a significant impact on project management success. In the last decade, existing literature documents a variety of possible CSFs for OSC practices (see Table 1). Lau (2011), in a study on OSC in Hong Kong, China, and Singapore, highlighted seven CSFs for managing modular production design in the context. Ismail et al. (2012) highlighted 12 CFSs for industrialised building system (IBS) project implementation in Malaysia. Azhar et al. (2013) investigated 12 critical factors and constraints for selecting modular construction over conventional stick-built techniques. Karmar et al. (2014) explored 19 CSFs for adopting IBS construction in Malaysia. O'Connor et al. (2014) identified 21 CSFs for implementing optimum and maximum industrial modularisation in the engineering, procurement, and construction (EPC) industries. Choi et al. (2016) identified 21 CSFs for implementing industrial modular projects. Li et al. (2018) identified 23 CSFs for project planning and control in China's prefabrication housing production (PHP). Ojoko et al. (2018) highlighted 10 CSFs for industrialised building system implementation in Nigeria. Wuni and Shen (2019a) identified 35 CSFs for modular integrated construction projects in HongkongHong Kong. Wuni and Shen (2020a) identified 9 CSFs for managing the early stages of prefabricated prefinished volumetric construction projects in Hong Kong. Further research by Wuni et al. (2020b) identified 25 CSFs for implementing Modular integrated construction in HongkongHong Kong. Zhang et al. (2021) established 15 CSFs for OSC adoption in HongkongHong Kong. A recent study by Jung et al. (2021) highlighted 20 CSFs for OSC adoption in South Korea. Al-Aidrous et al. (2022) investigated essential factors enhancing industrialised building implementation in Malaysian residential projects. A list of 24 commonly cited CSFs identified across the studies were considered possible CSFs for OSC implementation, as shown in Table 1. These studies provided valuable contributions to the OSC/-CSF literature. Still, the list in these studies requires further contextual investigation and validation within the UK context, which this study would address. Furthermore, it is also essential to understand how these factors interrelate, which would provide the needed clarity to develop appropriate strategies and guidance.

Table 1

3. METHODOLOGY

The researchers leaned towards an interpretivist philosophical stance and adopted an exploratory qualitative research approach in which knowledge is grounded on the collective opinions of experts (Fellows and Liu, 2015; Obi et al., 2021). The research initially used a systematic search approach to identify relevant literature from which possible CSFs that could impact OSC implementation can be identified. To achieve this, the researchers considered databases such as Scopus and Web of Science, often used for OSC research (Obi et al., 2022). A search string with keywords such as "success factor," "Critical success factor", "Offsite construction", OR "prefabricated", OR "modular", OR "offsite manufacturing", OR "Offsite production" OR "offsite manufacture" OR " Modular integrated construction" was used. Though not exhaustive, these keywords were considered adequate. The search was limited to peer-reviewed published articles in English that discussed CSFs in OSC, published between 2011 and 2022 and highly cited. The authors also ensured that the selected articles cut across studies from varying country contextsAuthors also ensured articles selected cut across studies from across varying country contexts. These restrictions help identify 20 highly cited articles on CSFs relevant to the study. As espoused by Wuni and Shen (2019a), a sample of 16 articles is adequate for a systematic literature review. From these retrieved articles, the 24 most frequently appearing CSFs, that may impact OSC implementation were extracted, as shown in Table 2. Subsequently, the ISM technique to establish, interactions, model and categorise the CSFs for OSC implementation in the UK.

3.1 Interpretive Structural Modelling (ISM) Approach

The Interpretive Structural Modelling (ISM) method is a qualitative and interpretive approach based on the insights of experts who decide which and how factors are related to resolving complex problems (Awuzie and Abuzeinab, 2019). It analyses the interactions among factors to define their interconnections and map the complexity of their relationships into a multi-level hierarchically structural model (Sushil, 2017). Studies such as Jung et al. (2021) and Marinelli et al. (2022) have employed ISM and MICMAC in their research of OSC practices. In this context, ISM is used to particularly establish interrelationships and logical dependencies of CSFs for OSC in a hierarchal model leveraging on experts' knowledge and experience. The resultant model would facilitate an easier understanding of the broader landscape of the influence of these CSFs. The ISM procedure presented is similar to those employed in previous studies (Awuzie and Abuzeinab, 2019; Obi et al., 2021: Jung et al., 2021). ~~the~~ The ISM methodology consists of the following key steps:

- Define the variables and determine contextual relationships.
- Develop the structural self-interaction matrix (SSIM) based on contextual relationships.
- Develop a reachability matrix.
- Conduct a level partitioning of the factors.
- Develop the interpretive structural model of CSFs for OSC implementation.
- Categorise the factors using a MICMAC analysis which uses a power and dependence matrix to cluster variables into Independent, Linkage, dependent, and Autonomous clusters (Jung et al. 2021; Obi et al. 2021).
    - Autonomous cluster- consists of factors with low driving power and dependence and hence are relatively disconnected from the system.
    - Dependent cluster- consists of factors with strong dependence but weak driving power. They largely depend on other factors from the base of the system.
    - Linkage cluster- consists of factors with strong driving power and dependence. They influence some factors in the system while also being influenced by other factors, which can often make them unstable.
    - Independent cluster- consists of factors with strong driving power and low dependence. The factors have the strongest capability and hence demand the most attention.
- Review and validate process and model.

ISM is ~~expert dependent~~ expert-dependent, and the focus on experts' perceptions is to gain an in-depth understanding of the CSFs' interrelationships. The authors used brainstorming and focus group discussions at various stages within the ISM to gather expert views. These methods are ideal for facilitators to build on participants' responses to generate insights and confirm the CSFs being discussed (Saunders et al., 2016). The experts' views were thematically analysed and used as input into the ISM process. The participants were selected through purposive sampling, which is widely accepted in OSC research (Masood et al., 2023). The practitioners were selected ~~whom~~ were construction professionals who have worked or are working with organisations actively promoting OSC practices in the UK and are affiliated with the offsite Hub or building offsite ~~were selected~~. The participants (academics and practitioners) were selected based on their knowledge, expertise, and experience in OSC practices in the UK. The study sample included a mix of designers, architects, OSC academics/researchers, client advisors/project managers, manufacturers/suppliers, and contractors responsible for OSC project development and implementation. This mix aimed to ensure a spread of opinions from a blend of possible key OSC project stakeholders in the UK. Table II provides details of the twelve experts who participated in the study. Twenty-three participants were initially contacted to participate, but only twelve participated. Four OSC experts (one OSC contractor, Client advisor, designer, and academic) participated in the brainstorming session. The brainstorming sessions allowed the identification and contextualisation of a list of CSFs from UK experts' view. Subsequently, a focus group discussion was conducted involving eight experts to determine contextual relationships between the 18 contextualised CSFs. The second focus group allowed for the structured walkthrough and validation of the model developed. The participants included two ~~supplier~~ suppliers/manufacturers, two contractors, two OSC designers, one Client OSC advisor and one OSC Academic. Three of the participants were previously involved in the brainstorming session.

Table 2: Participant's profile

A summary of the main steps employed in this study is presented in Figure ~~1~~ I

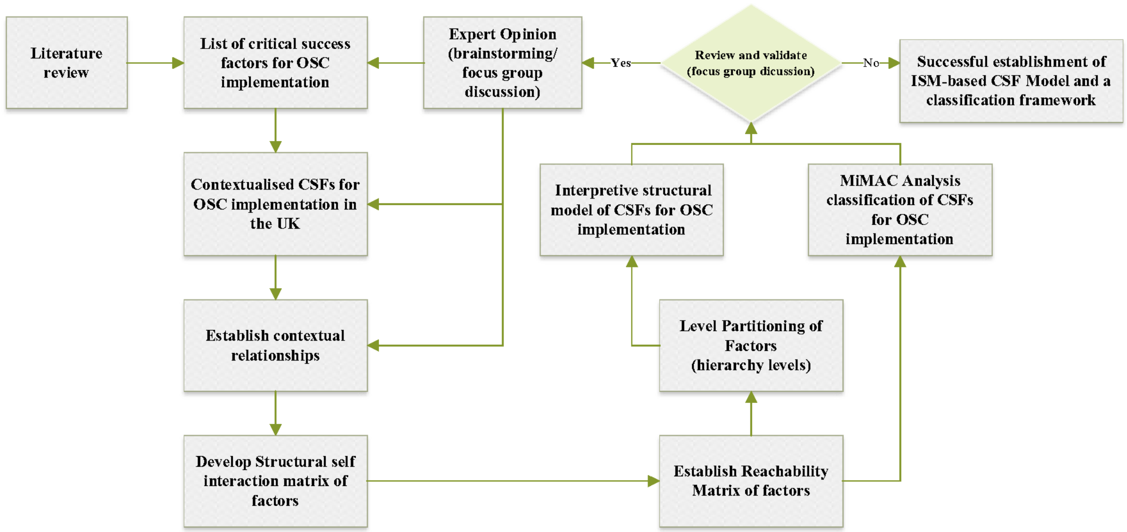

Figure I: Methodological Process

The following sections of the paper present the ISM results and findings.

4. RESULTS

The results from the ISM are presented in this section.

4.1 Contextualisation of CSFs for OSC Implementation~~Contextualisation Of of CSFs For OSC Implementation~~

In the brainstorming session, experts were asked to list and describe CSFs for OSC implementation in the UK. Participants echoed many of the CSFs previously identified from the literature. They specifically mentioned flexible OSC business models, equitable trust and buy-in, OSC database, and flexible leadership approach, ~~with~~ which were new contributions. Experts were presented with the CSF lists from the literature alongside their suggestions. They discussed and debated the criticality of the factors in the UK context. They refined the list by removing factors they considered not critical. They renamed some factors and merged others. To achieve consensus, authors ensured to confirm participants agreed with each factor put forward as a CSF for consideration in the study through a vote. Those on which consensus was not initially reached were reconsidered, reworded, and voted on again. The consensus was not based on unanimity but considered above two-thirds of the participant's agreement. Through these sessions, eighteen factors were consolidated (See Table III).

4.2 Determining The Reachability Matrix And Partition Levels Of The CSFs Identified~~.~~

Contextual relationships among the CSFs were defined from expert opinions through focus group discussions. Experts were required to define the relationships between the identified CSFs (CSF1, CSF2 . . . CSF18) using the term "influences" for links. The nature of the relationship between any two factors (i and j) is defined as follows:

- V: Factor i influences factor j,
- A: Factor j influences factor i,
- X: Factor i and j influence each other.
- O: No relationship exists between factors i and j.
- ~~V: if If factor iI influence influences factor j,~~
- ~~A: factor j influences factor iI,~~
- ~~X: if If factor i and j influence each other.~~
- ~~O: no No relationship exists between factors i and j.~~

This allowed the coding of experts' opinions into matrices. Based on the contextual relationship defined by the experts, the SSIM is developed. The symbols V, A, X and O in the SSIM were then converted into a binary matrix by substituting "1", where experts confirmed a relationship and "0", where no relationship exists. Consequently, the initial reachability matrix was derived, and further checks for transitivity relationships were explored. Transitivity (depicted as 1*) dictates that if factor "CSF1" influences a factor "CSF2" and the factor "CSF2" influences factor "CSF3", then Factor "CSF1" may also be said to influence factor "CSF3". The transitivity was confirmed with experts, and the final reachability matrix was developed. A level partitioning iteration was undertaken to assign levels to CSFs using the data in the final reachability matrix. When a factor's reachability (the factor itself and other variable (s) that it may enhance) and intersection set are seen as the same, a level is assigned to that factor and removed from the factor list. This iteration process is known as level partitioning and was repeatedly undertaken until all the levels for each factor in the list were determined.

4.3 Interpretive Structural Model of CSFs for OSC Implementation~~Interpretive Structural Model Oof of CSFs Ffor for OSC Implementation~~

The ISM model (see Figure II) structure was developed from the level iterations by arranging the partition levels obtained for each CSF from top to bottom and plotting the relationship between the factors. In Figure II, the ISM model portrays the CSFs that influence the successful implementation of OSC on projects ranked in seven levels. CSFs on level 7 are the most critical; hence high priority for consideration, and level 1 is the least critical in the factor system. Figure II shows all the relationships among the CSFs at the same level and hierarchical levels. Red-coloured arrows show the direction of influence from one level to another. Hence CSFs at one level facilitate the successful realisation of CSFs on the level to which the arrow points. The brackets show CSFs on the same level. Level directional relations were depicted in green or grey colour legends. A green colour legend shows that the CSFs at that level have bilateral relationships, facilitating each other. A grey colour shows no relationship or influence. Adequate OSC knowledge and experience (CSF 16), Top management support (CSF 11) and Client commitment (CSF 10) located on level 7 are linked with bi-directional relationships, and all directly facilitate CSFs on level 6. Flexible leadership approach (CSF 13) and Flexible OSC business models (CSF 14) located on level 6 have no relationship. However, both directly facilitate CSFs on level 5. Collaborative procurement methods (CSF 9) and Early team involvement (CSF 17) at Level 5 are linked and have bi-directional relationships. They all directly facilitate CSFs on Level 4. Equitable trust and buy-in (CSF 12), Effective communication and collaboration (CSF 15), Robust and accessible project information (CSF 5) and Use of data-driven (CSF 4) located on level 4. These CSFs have bilateral relationships and directly facilitate CSFs on level 3. At level 3 are Effective planning and scheduling (CSF 1), Process and product Standardisation (CSF 3) and Robust and accessible OSC database (CSF 2). These CSFs have bilateral relationships and directly facilitate CSFs on Level 2. Early design freeze (CSF 6), Effective risk management (CSF 8) and Effective supply chain management (CSF 7) at level 2 have a bilateral relationship and all together directly facilitate CSFs on Level. Continuous learning and improvement (CSF 18) are located at level 1 and depends on all The CSFs from the base of the ISM for its actualisation.

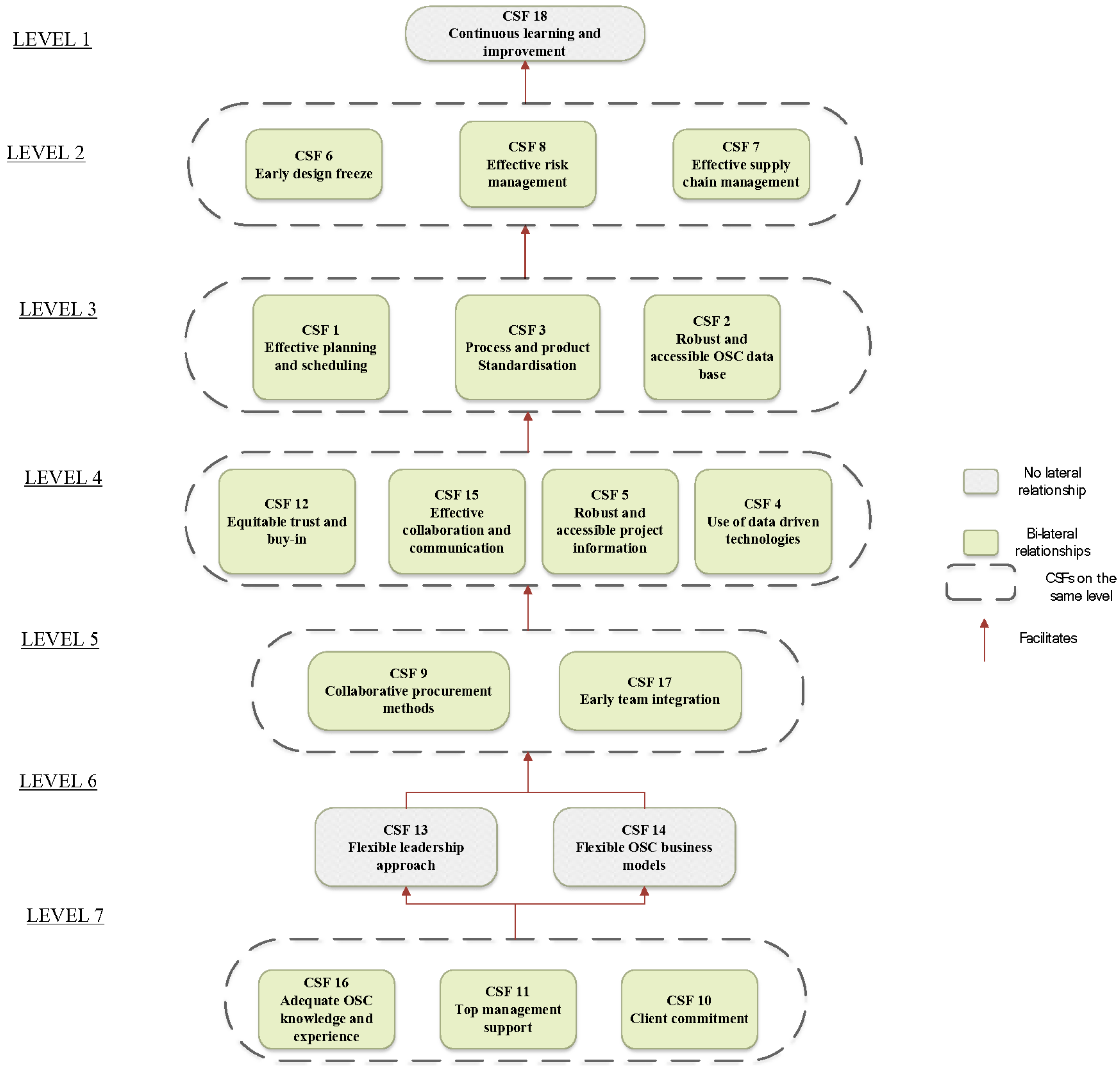

Figure II: Interpretive structural model of CSFs for implementing OSC.

4.4 -MICMAC Analysis Of CSFs For OSC Implementation

A MICMAC analysis was also performed using data from the final reachability matrix to classify the CSFs into dependent, linkage, and independent clusters. No CSF was located in the autonomous cluster (see Figure III). From Figure III, the loading of the factors is presented as follows:

- Independent cluster: Seven factors comprising CSFs 10, 16, 11,13, 14, 9 and 17 are loaded into this cluster.
- Linkage cluster: Four factors, comprising CSFs 12,4,5 and 15 loaded into this cluster.

- ~~dependent~~ Dependent cluster: Seven factors comprising CSFs 1,2,3, 6,7, 8, and 18 loaded into this cluster.

The loading of the CSFs indicated that all the factors identified were essential to successful OSC implementation on projects.

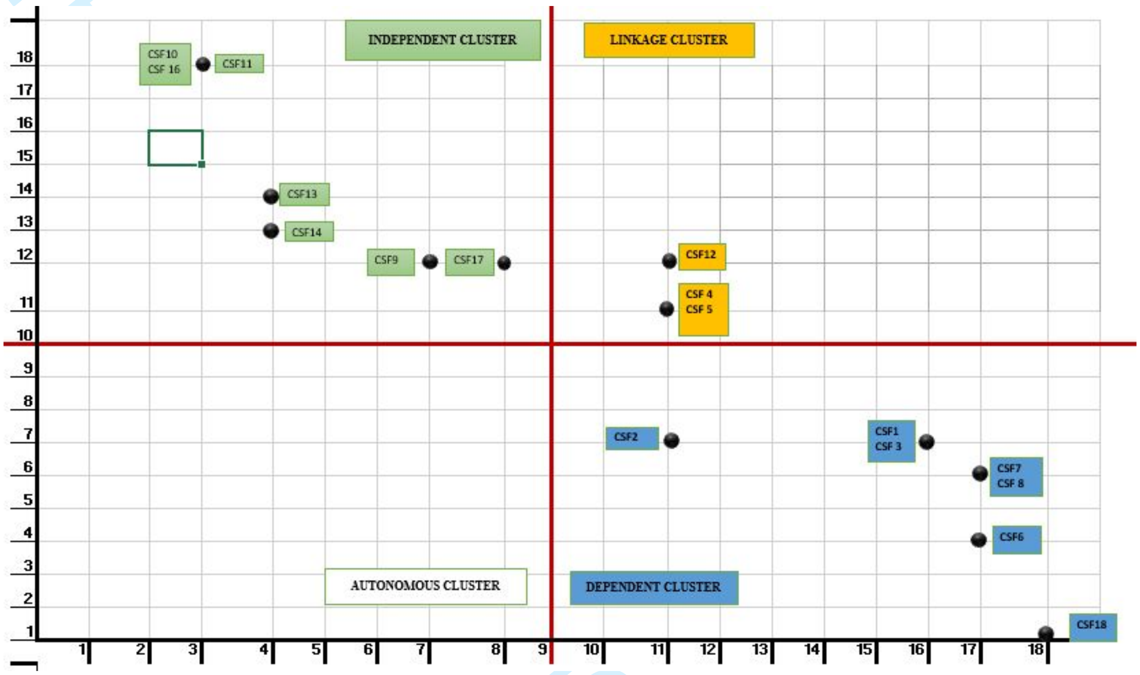

Figure III: MICMAC ~~cCategorisation~~ categorisation of CSFs for OSC implementation

The authors and experts performed a structured walkthrough to identify contextual inconsistencies and validate the ISM model. Experts further commented on the MIMAC categories following the loading. They espoused that the CSFs loaded in the independent cluster were leadership-related, requiring top-level management decisions and actions. On linkage factors, experts opined that the loading of the factors was focused on technology-enhanced information management approach for efficient collaborative practices. Regarding the dependent cluster, the experts opined that the CSFs loaded in this cluster were focused on planning, monitoring, and improving operations across teams on the OSC project. Drawing on an interpretive structural model, clustering of the CSFs, and agreeing with expert opinions, the authors labelled each cluster: Leadership, technology-enhanced collaborative working and operational management. The framework suggests that leadership and technology-enhanced collaborative working-related CSFs influence operational management-related CSFs. Hence, more focus should be directed towards leadership and technology-enhanced collaborative working. On these findings, a CSF classification framework for OSC implementation in the UK, as depicted in Figure IV, was proposed. Bespoke strategies that offer advantages in pursuing successful outcomes should be developed in these areas.~~The authors and experts performed a structured walkthrough to identify contextual inconsistencies and validate the ISM model. Experts further commented on the MIMAC categories following the loading. They espoused that the CSFs loaded in the independent cluster were leadership related~~ leadership-related, ~~requiring top-level management decisions and actions. On linkage factors, experts opined that the loading of the factors was focused on information management to support collaborative practices, which needed to be technology underpinned technology-underpinned towards achieving efficiency. Regarding the dependent cluster, the experts opined that the CSFs loaded in this cluster were operation focus~~ operation-focused ~~and supported focused on planning, monitoring, and improving operations across teams on the OSC project. Drawing on an interpretive structural model, clustering of the CSFs, and agreeing with expert opinions, the authors labelled each cluster: Leadership, technology-enhanced collaborative working and operational management. The framework suggests that Leadership~~ leadership ~~and technology-enhanced collaborative working related~~ working-related ~~CSFs influence operational management-related CSFs. Hence more focus should be directed towards Leadership~~ leadership ~~and~~

~~technology-enhanced collaborative working. On these findings, a CSF classification framework for OSC implementation in the UK, as depicted in Figure IV, was proposed. Bespoke strategies that offer advantages in pursuing successful outcomes should be developed in these areas.~~

Figure IV: CSF classification framework for OSC implementation

5 DISCUSSION

The overall success of OSC implementation on projects in the UK construction sector is driven by five top CSFs: Top Management Support, Client Commitment, Adequate OSC knowledge and Experience of the Project Team, Flexible Leadership Approach and Flexible Business Models. These five CSFs emphasise the need to understand clients' nature and impact and top management's contributions to decision-making within the OSC process. In addition, there is a need to engage the right set of professionals in the ~~and~~ teams, the leadership style and business models should be selected ~~appropriate~~ appropriately for the OSC project. These findings are mostly consistent with earlier studies conducted by Jung et al., (2021), apart from persistent policies and incentives and early research on modularisation. The differences may have emerged following expert views from South Korea. However, it differs from the top five CSFs identified by Wuni et al., (2020b) except for adequate OSC knowledge and experience. Such differences may be associated with a survey of 40 experts' views from various regions, including America, Asia and Europe ~~and~~ while CSFs relationships are not interpretive based. The eighteen CSFs identified from this study are further discussed under the headings of their associated classifications.

5.1 ~~Leadership Related~~Leadership-Rrelated CSFs

Successful OSC implementation in a project requires a robust leadership framework starting with the client and then the project team.

5.1.1 Client Commitment

The client's early commitment to the concept of OSC creates a level of trust that OSC could deliver the preconceived vision for the project, paving the way for effective communication of proposed project requirements. Clients should understand the value of OSC and be informed about its techniques to be more likely to commit to its use firmly. From the outset, client commitment to OSC significantly impacts a well-defined client requirement, substantially assuring rigour in the project budget, programme, and scope (Kamali and Hewage, 2016; Choi et al., 2016). The client is the vision bearer; hence early client commitment to OSC ensures the appropriate resource types, stakeholders, and levels of expertise, ultimately mitigating gaps in capabilities as projects develop. As such regular strategies to disseminate OSC updates should be made available and accessible for potential and current OSC clients, stakeholders, and influencers such as local councils and governments to ensure they are well informed of the benefits of OSC.

5.1.2 Top Management Support

Top management in client and contracting organisations are committed financially and politically, ultimately delivering governance and leadership that impacts the project. To effectively make timely and appropriate decisions for the project, the top management on all sides needs to be aware of the OSC requirements. Ideally, from RIBA Stage 0 but up to RIBA Stage 2 (as all parties may not be onboard at RIBA Stage 0) (RIBA, 2020), they need to align the project with the strategy of the client's organisation and that of the funding partners. They must define project success measures and be flexible to authorise and support the people, process, and structure for effective OSC implementation. Therefore, they should have the experience to understand and mitigate risks, learning on lessons from past experiences ~~(Choi et al., (2016)~~ as they make decisions that influence project management and product success (Choi et al., 2016).

5.1.3 Adequate OSC Knowledge a~~A~~nd Experience

Manufacturing projects typically differ from traditional construction schemes as they are predominantly product-focused rather than project-focused (Goulding and Raihmen, 2019). Understanding the OSC expectations and requirements demands adequate OSC knowledge and experience from those saddled to deliver the project (Wuni and Shen, 2019a; 2019b). These include the Client, contractor, consultants, and manufacturing/supply team. Each team's adequate knowledge and experience are helpful ~~to make~~in making effective decisions and advise, teach, and support the OSC process. Previous studies (Jiang et al., 2018; Li et al., 2018; Wuni and Shen, 2019a) highlighted the perceived concerns over the lack of trained and experienced OSC workforce, including clients, contractors, ~~and~~ manufacturing and design teams. The need to embrace OSC product-oriented processes and approaches may require the workforce to be retrained with assembly skills and manufacturing principles. As such, there is a need to up-skill the OSC workforce within each team to embrace the uniqueness of OSC delivery (Goulding and Rahimian, 2019). Strategies such as occupational training, and higher ~~and~~ degree apprenticeships for continuous learning and upskilling in OSC practice should be encouraged. Built environment academic programs ~~further~~ in addition to ~~and~~ higher education institutions can be drivers of accelerated knowledge of OSC practices through their curriculum.

5.1.4 *Flexible Business Model(s~~S~~)*

OSC business organisations significantly facilitate effective implementation through their business model (Goulding et al., 2015: Pan et al., 2012; Jones et al., 2019). OSC solutions to clients are often based on the strength of the contractor's business models. For instance, a contractor offering modular products may suggest modular solutions to clients even if a panelised or hybrid method may be more appropriate. The lack of flexible business models is one of the issues affecting effective OSC implementation at the project level (Goulding et al., 2015). Business model innovation/transformation is a way for OSC businesses to become more responsive to meet clients' requirements and satisfaction (Antikainen and Valkokari, 2016). Such transformation may involve a joint venture with other OSC contractors or between contractor and manufacturer offering pods or panelised solutions, complementing solutions to a client's requirements.

5.1.5 Flexible Leadership Approach

There is a shift in focus from project management to project leadership to achieve success (Pilkienė et al., 2018: Müller, 2018: Howell et al., 2004). This study confirms this, where project leadership is in Level 6 and the independent category. With the complexity of OSC projects, the dynamics are high as they cannot be assessed in just one direction (Ahola et al., 2014). Hence the leadership style must be appropriate for each stage of the process. Flexibility in the dynamics of temporary shifts in leadership between project managers and team members for accomplishing desired tasks in the OSC process can be envisaged. Clients and project managers may consider a shared and balanced leadership approach (see Müller et al., 2018). For instance, in this approach, the project manager may delegate leadership responsibilities during the manufacturing stage to the lead supplier because of their wealth of experience in the requirements for attaining success in that stage.

5.1.6 Early Team Involvement

The success of OSC involves great collaboration between manufacturers, suppliers, and contractors from a very early stage. Clients and contractors need to engage with an offsite manufacturer/supplier early, for instance, at RIBA Stage 2, so that the right parameters for design ~~and~~ ahead of planning and manufacturing can be put in place. This would give the key teams- design, manufacturing, and construction enough time to assess the project and provide advice to support effective decision-making on the design, platform strategies and resource planning (such as cost and time planning) (Wuni et al., 2020b, Wuni and Shen, 2020a; Choi et al., 2016)). It also facilitates better integration across teams, mitigating blockers such as design-related issues, commercial, and manufacturing at early and crucial stages of the project. However, this may require shifting from the current popular procurement models (traditional or design and build) to embracing more collaborative models.

5.1.7 Collaborative Delivery Methods

Practitioners alluded that fundamental problems arise when the client selects a preferred manufacturer but is then employed by a reluctant contractor, and the link between client and manufacturer is lost. Procurement methods should be promoted, such as integrated project delivery, alliance partnering, integrated project insurance, and framework agreement considering the complexity of OSC delivery (Razkenari et al., 2019). These procurement methods allow vital players such as designers, manufacturers, ~~/~~suppliers, and contractors to be engaged earlier and appropriately in the process (ideally between RIBA Stage 0 and Stage 2) (RIBA, 2020).

5.2 Technology-~~E~~enhanced Collaborative Working Related ~~Csfs~~CSFs~~.~~

Successful OSC implementation requires collaborative practices effectively supported by appropriate technologies.

5.2.5 Equitable Trust ~~And~~and Buy-In

OSC involves numerous stakeholders working together to implement the project, requiring the need to buy into common goals (Goulding and Raihmen 2019). A committed stake in the project enables all risk elements and gains to be fairly distributed between partners. However, commitment (i.e. project timescale and beyond) comes from a place of mutual trust and mutual accountability (Faris et al., 2022). Therefore, OSC teams must be open, honest, and willing to share important information with themselves that reflects the real situation. Building and maintaining a good reputation through reciprocity, fairness and professionalism at the individual and organisational level is a crucial indicator influencing the decision to trust (Khalfan et al. 2007). Clear and well-defined objectives, measurable deliverables, and attainable timeframes are essential to allow various teams to manage expectations efficiently. Consensus, regular updates on progress, transparency, effective change management practices, contractual agreement, opportunity for future work, recognition of efforts, feedback, and effective complaints handling should be considered (Faris et al. 2022; Manu et al. 2015).

5.2.2 *Effective Communication ~~And~~and Collaboration*

OSC implementation requires increased interactions and close collaboration among key stakeholders (e.g. developers, designers, contractors, manufacturers, and suppliers) to execute specific workflows that cover design, construction, operation, and maintenance tasks (Zhai et al., 2014). The contract development should clearly define communication channels, systems, protocols, procedures, and roles to enable effective communication. In addition, online collaboration tools that link the project commercials with the supply chain, logistics, design, programme, and monitoring should be implemented for successful collaboration. There are numerous tools for communication and collaboration employed by respective companies involved in OSC, and there may be instances where these tools are incompatible. This should not be a blocker, as specialist systems usually have gateways and other protocols to allow interaction with conventional/market-leading collaboration tools.

5.2.6 *Use ~~O~~of Digital-Driven Technologies*

Technologies such as Building Information ~~Modeling~~Modelling (BIM), the Internet of Things (IoT), Machine learning (Ml) and Blockchain may be considered relevant (Wang et al., 2020; Hou et al., 2020; Xiao et al., 2022) and effective for creating and managing OSC project information. These technologies facilitate effective coordination and exchange of project information among OSC professionals, providing faster access to reliable data and details, supporting project control and real-time monitoring of work progress, transportation, and assembly (Altaf et al., 2018). Data-driven technology will promote a platform for capturing information that supports industry-wide modular coordination and standardised design components. This will lead to product and process performance standards for offsite construction and support effective decision making especially associated with design, manufacturing, construction, and lifecycle process analysis. However, some studies ~~identifiedy~~identified ~~that the~~ industry lags in implementing such concepts in real-time in the OSC process (Arif et al., 2017; Ginigaddara et al., 2022).

5.2.7 *Robust ~~A~~and Accessible Project Information*

To effectively run the OSC project and meet the expectations of the client, all related information to the project should be accurate, comprehensive, and accessible to those that need ~~them~~it, such as the designer, manufacturer, client, and contractors (Jung et al., 2021; Wuni et al., 2020b). Limitations of sharing data and information compromise the speed and quality of the project. This fluidity of information needs to expand between manufacturer, logistic and assembly platforms to avoid any ~~miss alignment~~ misalignment with schedule, design, and risks. Recent advances in information technologies facilitate convenient access, storage, and analysis of large amounts of project information such as drawings, reports, certificates, spreadsheets, or any other document across various teams throughout the facility's lifecycle. Accordingly, many features of digitalisation like building information modelling (BIM), Blockchain, Artificial intelligence (AI), Internet of Things (IoT) and Digital twins (DT) will play a very significant role in creating a dynamic platform to ensure the transparency and traceability of OSC project information.

5.3 Operational Management related CSFs

Successful OSC implementation requires managing activities that can directly impact various operations within the OSC stages.

5.3.1 OSC Database

A robust and accessible OSC database provides the project team with clear access to data records from various OSC projects and companies. These may include supplier information data on design, cost, and module standards informing a consistent approach for evaluating project performance, benchmarking, and predicting possible performance scenarios of current and future OSC projects. With such data, standardisation and effective planning and scheduling can be achieved.

5.3.2 Process ~~And~~ and Product Standardisation

The use of standardised designs and processes encourages repeatability. Modularity in building elements and processes from design to closeout is fundamental to achieving economies of scale (O'Connor et al., 2014). Higher productivity in the manufacturing industry partly results from standardised products on assembly lines (Wuni et al., 2020b). With standardisation, effective planning and surety of lead times can be determined.

5.3.2 Planning ~~And~~and Scheduling

Planning and scheduling project resources and optimising logistics within the process to avoid delays (transport and owner) are essential to ensure project coordination and performance (Choi et al. 2016). Effective planning is highly critical, considering the high complexity and relationships well beyond conventional construction processes (Goulding and Rah, 2019; Razkenari et al., 2019). A seamless process that integrates manufacturing and construction taking advantage of offsite production and onsite work, should be well thought out before execution.

5.3.3 Early Design Freeze

A design freeze is a deadline for making all the major design decisions for a construction project. This allows the design team to set and work within set dates and procurement milestones. Understanding early design freeze, especially for the client team, is necessary to avoid design changes later in the process (Choi et al., 2016). When such a freeze is not considered, design changes are imminent. This will require extensive reworking of drawings to fit a manufacturer's module sizes or, in some cases, multiple module sizes produced, which impacts cost-effectiveness.

5.3.4 Effective Supply Chain ~~And~~and Risk Management~~.~~

The OSC project's supply chain includes a variety of sectors, such as design, engineering, and manufacturing, that have interdependent relationships (Jung et al., 2021) and hence require effective management. Such management will involve identifying potential problematic areas and implementing strategies to prevent or minimise their occurrences within the chain and on the project. Tools that support effective coordination between these various sectors must be put in place (Masood et al., 2023). This allows cross-teams to create and utilise information on various project activities, improving construction productivity, enhancing competitive advantage, and satisfying the client requirements at the lowest possible cost (Li et al., (2017). This would proactively help in risk identification and prevention throughout the OSC process.

5.3.5 Continuous Learning ~~And~~and Improvement

Project performance should be continuously improved through performance analysis and appropriate benchmarking practices. Promoting a learning culture at organisation and project levels through workshops and seminars can also support staff and team knowledge on OSC processes. The study agrees that continuous learning and improvement are critical for improving OSC implementation practices, and this has been advocated for through research and industry practice. However, the ISM reveals that achieving this factor requires several other factors discussed first to be put in place.

6 ~~6~~ Conclusion

OSC is increasingly becoming a preferred method over the traditional construction approach for many projects in the UK. Improving OSC implementation practices at the project level is critical to realising the objectives and expectations of key stakeholders. This research investigated the interrelations and logical dependencies of CSFs for OSC implementation on projects in the UK. An interpretive structural model of eighteen CSFs influencing OSC implementation is developed. The model defined seven levels of importance for the eighteen CSFs and showed their directional and bilateral relationships. A CSF classification framework has also been developed to benefit clients and project teams involved in OSC implementation on building projects in the UK. The MICMAC analysis categorised CSFs according to driving and dependence power into three clusters, and all ~~the~~ five driving CSFs mostly consistent with previous studies.

The study contributes to the establishment of relationships among the CSFs, especially for OSC implementation, which has not been previously investigated, particularly within the UK context. It also developed a classification framework for CSFs in OSC implementation: Leadership, Technology-enhanced collaborative working and operational management. It validated previous research findings that argued CSFs have logical dependencies and interrelationships contributing to existing knowledge in OSC success factor literature. OSC client and project teams can also leverage the CSFs identified in this research as a valuable reference for further contextual investigations in their country contexts. The model and the classification framework can assist client and project teams in developing bespoke strategies to mitigate poor OSC implementation performances and promote better leadership and collaborative practices. However, clients, designers, contractors, and manufacturers need to understand the nature and impact of their input in decision-making and actions within the OSC process. Their commitment to achieving success should start with refocusing priorities from CSFs at the top of the model that are often outcomes of other influencing factors to those at the base. Investment of resources in establishing systems that can facilitate timely engagement of the right set of OSC workers/professionals, leadership style, and business models appropriate to deliver client needs must take priority to drive successful OSC implementation.

There are a few limitations associated with this research. The finding reflects only the UK local context as the evaluated CSFs for OSC implementation were developed based on UK OSC experts' views. Hence, the priority list in the study may differ for other countries which require further investigations. The ISM model has not been validated on real-life OSC projects. Therefore, future studies can test the model in real-life settings to evaluate its performance against success criteria for OSC project success. In addition, the model was premised on qualitative interpretations and was not statistically validated. It is then recommended that future studies examine the contextual relations of each individual CSFs with respect to the OSC stages and use quantitative approaches such as Structural equation modelling (SEM) and regression analysis.

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Table 1: **Salient critical success factors for OSC practices.**

Salient factors identified from literature		Reference
1	Policy incentives and penalties	Jiang et al,2018, Razkenari et al., 2019; Correia et al., (2020) Wuni and Shen (2019a), Wuni and Shen (2019b) Wuni and Shen (2020a), Wuni et al. (2020b) Zhang et al, 2020; Jung et al (2021), Al-Aidrous et al (2022)
2	Extensive planning and scheduling	Hou et al., (2020), Wuni and Shen (2019a), Wuni and Shen (2019b) Wuni and Shen (2020a), Wuni et al. (2020b) Zhang et al, (2020) Jung et al (2021) Rahimian et al., (2017). Razkenari et al., (2019), Ojoko et al (2018) Al-Aidrous et al (2022), O'Connor et al. (2014), Choi and O'Connor (2016), Azhar et al (2013)
3	Standardisation and repeatability	Wuni and Shen (2019a), Wuni and Shen (2019b) Wuni and Shen (2020a), Wuni et al. (2020b) Zhang et al, (2020), Jung et al (2021), O'Connor et al. (2014), Jiang et al,2018 Rahimian et al., (2017). Razkenari et al., 2019 Correia et al., (2020) Al-Aidrous et al (2022) Choi and O'Connor (2016), Pan et al. (2012); Azhar et al (2013)
4	Effective risk management	Choi et al. (2016); Wuni and Shen (2019a), Wuni and Shen (2019b) Wuni and Shen (2020a), Wuni et al. (2020b) O'Connor et al. (2014), Choi and O'Connor (2016),
5	Collaborative procurement delivery methods	Razkenari et al., 2019; Correia et al., (2020) Zhang et al, 2020 Al-Aidrous et al (2022)
6	Supply chain integration and management	Li et al., (2017) Wuni and Shen (2019a), Wuni and Shen (2019b) Wuni and Shen (2020a), Wuni et al. (2020b) Correia et al., (2020) Al-Aidrous et al (2022 O'Connor et al. (2014), Choi and O'Connor (2016),
7	Effective use of data driven technologies	Hou et al., (2020), Wuni et al., (2020b) Razkenari et al., 2019; Jiang et al,2018; Correia et al., (2020); Li et al. (2018); Jung et al (2021), Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022) O'Connor et al. (2014),
8	Adequate knowledge and experience of client team in OSC	Jiang et al,2018; Li et al. (2018); Wuni and Shen (2019), Wuni et al (2020b), Wuni et al. (2020b) Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016),
9	Adequate knowledge and experience of design team in OSC	Jiang et al,2018; Li et al. (2018); Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016),
10	Adequate knowledge and experience of contractor team in OSC	Jiang et al,2018; Li et al. (2018); Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016),
11	Adequate knowledge and experience of supply and manufacturing team in OSC	Jiang et al,2018; Li et al. (2018); Wuni and Shen (2019a), Wuni et al (2020a), Wuni et al. (2020b) Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022)
12	Continuous improvement and learning	Wuni et al., (2020) Jiang et al,2018 Razkenari et al., 2019; Choi et al (2016) Wuni and Shen (2019a) Karmar et al (2014) Al-Aidrous et al (2022)
13	Effective collaboration	Choi et al. (2016); Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Jung et al (2021), Choi et al. (2016) Karmar et al (2014) Ismail et al (2012) Hwang et al. (2018); Zhang et al, 2020 Al-Aidrous et al (2022) Azhar et al (2013)

14	Effective communication and information sharing	Hou et al., (2020) Choi et al. (2016); Wuni and Shen (2019), Wuni et al (2020a), Wuni et al. (2020b) Jung et al (2021), Choi et al. (2016) Karmar et al (2014) Ismail et al (2012) Ojoko et al (2018) Al-Aidrous et al (2022)
15	Early involvement of manufacturers and suppliers	Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Zhang et al, 2020Jung et al (2021), Pan et al. (2012); Karmar et al (2014) Ismail et al (2012) Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016),
16	Early contractor involvement	Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Zhang et al, 2020 Jung et al (2021), Choi and O'Connor. (2016); Pan et al. (2012); Karmar et al (2014) Ismail et al (2012) Ojoko et al (2018) Al-Aidrous et al (2022 Azhar et al (2013))
17	Early design freeze	Choi et al. (2016); Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Jung et al (2021), Zhang et al, 2020 Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016), Azhar et al (2013)
18	Availability of OSC skilled workforce	Hwang et al. (2018) Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Jung et al (2021), Al-Aidrous et al (2022)
19	Availability of adequate local transport infrastructure	Hwang et al. (2018b); Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Jung et al (2021), Ojoko et al (2018) Hwang et al. (2018); O'Connor et al. (2014), Choi and O'Connor (2016), Azhar et al (2013)
20	Robust drawing specification	Wuni and Shen (2019a), Wuni and Shen (2020a), Wuni et al. (2020b) Jung et al (2021), Al-Aidrous et al (2022) O'Connor et al. (2014), Choi and O'Connor (2016), Pan et al. (2012); Azhar et al (2013)
21	Top management support	Choi et al. (2016); Wuni and Shen (2019a); Hwang et al. (2018); Ojoko et al (2018), Azhar et al (2013)
22	Effective coordination of on-site and off-site trades	Wuni and Shen (2020) Wuni and Shen (2019a) Choi and O'Connor. (2016) Karmar et al (2014)
23	Logistics management	Karmar et al (2014) Ismail et al (2012) O'Connor et al. (2014), Choi and O'Connor (2016),
24	Client understanding and willingness	Zhang et al, (2020), Hwang et al. (2018); Choi et al. (2016); O'Connor et al. (2014 Azhar et al (2013)

Table 2: Participants profile

	Profession	Role	Work experience	OSC Experience
1	Architect	OSC designer	15 years	8 years
2	BIM manager	OSC designer	12 years	5 years
3	Construction manager	Contractor	20 years	10 years
4	Project manager	Contractor	18 years	5 years
5	Design Engineer	Client advisor	10 years	10 years
6	Design Engineer	OSC designer	13 years	7 years
7	Construction manager	Academic	8 years	3 years
8	Procurement Manager	Contractor	18 years	12 years
9	Business manager	OSC manufacturer/supplier	19 years	9 years
10	Operations manager	OSC manufacturer/supplier	17 years	6 years
11	Quantity surveyor	Academic	15years	12 years
12	Facility manager	Client advisor	11 years	5 years

Table 3: **Experts views on critical success factors for OSC implementation**

S/N	Salient factors identified from literature	Experts' actions	Experts' comments
1	Policy incentives and penalties	Remove	There are policies exisiting and this is high up at sector level.
2	Extensive project planning and scheduling	Retain	Retain as termed.
3	Standardisation and repeatability	Rename	Process and Product standardisation
4	Effective risk management	Retain	Retain as termed.
5	Collaborative procurement delivery methods	Retain	Retain as termed.
6	Supply chain integration and management	Rename	Effective supply chain management
7	Effective use of data driven technologies	Retain	Retain as termed.
8	Adequate knowledge and experience of client team in OSC	Merge	Adequate OSC knowledge and experience by project teams Knowledge and experience of the contractors, designers, and manufacturers and their workforce/teams as covered in one factor
9	Adequate knowledge and experience of design team in OSC		
10	Adequate knowledge and experience of contractor team in OSC		
11	Adequate knowledge and experience of supply and manufacturing team in OSC		
12	Continuous improvement and learning	Retain	Retain as termed.
13	Effective collaboration	Merge	Effective Collaboration and communication Effective communication and collaboration work hand in hand and enables information exchange at various stages of the process from all parties leading to better performance on the project.
14	Effective communication and information sharing		
15	Early involvement of manufacturers and suppliers	Merge	Early team involvement All key members of the client and project team- design, supply, manufacturing and contractor teams should be involved as early as possible.
16	Early contractor involvement		
17	Early design freeze	Retain	Retain as termed.
18	Availability of OSC skilled workforce	Remove	"Availability is secondary now in the UK OSC sector for now. We currently have a few workers that are knowledgeable or experienced in the process. So, we need to have a pool of skilled workers including professionals and then we can look at the problem of those available or willing to engage in the respective roles.
19	Availability of adequate local transport infrastructure	Remove	existing transport infrastructure may not be changed as would cost a lot, but moulds/components can be designed to fit into existing transport infrastructure.
20	Robust drawing specification	Rename	Robust and accessible project information
21	Top management support	Retain	Retain as termed.
22	Effective coordination of on-site and off-site trades	Merge	It is a part of planning and scheduling
23	Logistics management	Merge	Logistics management is a part of supply chain management.

24	Client understanding and willingness	Rename	Client commitment to OSC
25	Robust and accessible OSC database	Added	*A database to access OSC information (either from projects and/or companies) would inform a consistent approach for managing and evaluating OSC project performance"*
26	Equitable trust and buy-in	Added	*"client assuring trust in the design and the delivery approach, and that the operations team have trust that the client will not change direction without probable cause; this enables all stakeholders to have project buy-in".*
27	Flexible leadership approach	Added	*"flexible leadership style such as temporary leadership could be assigned to lead certain stages of the OSC process within the boundaries and oversight of the project manager".*
28	Flexible business model	Added	*"OSC contractors need to be open to flexible business models. With a thorough understanding of the client requirements, flexibility to implement combination OSC methods appropriate to deliver the project successfully is critical and not just one size fits all".*

Appendix 1

CSF	Factors	CSF 1	CSF 2	CSF 3	CSF 4	CSF 5	CSF 6	CSF 7	CSF 8	CSF 9	CSF 10	CSF 11	CSF 12	CSF 13	CSF 14	CSF 15	CSF 16	CSF 17	CSF 18	**Driving power**
1	Effective planning and scheduling	1	1*	1	0	0	1	1*	1*	0	0	0	0	0	0	0	0	0	1	**7**
2	Robust and accessible OSC database	1	1	1*	0	0	1	1*	1*	0	0	0	0	0	0	0	0	0	1	**7**
3	Process and product standardization	1	1*	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	**7**
4	Use of data driven technologies	1	1*	1	1	1	1*	1*	1*	0	0	0	1	0	0	1	0	0	1	**11**
5	Robust and accessible project information	1	1*	1*	1	1	1	1	1	0	0	0	1	0	0	1	0	0	1*	**11**
6	Early design freeze	0	0	0	0	0	1	1*	1	0	0	0	0	0	0	0	0	0	1	**4**
7	Effective supply chain management	1*	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	**6**
8	Effective risk management	1*	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1*	**6**
9	Collaborative procurement methods	1	0	1*	1*	1	1	1	1	1	0	0	1	0	0	1	0	1	1	**12**
10	Client commitment	1	1	1	1*	1	1*	1	1	1	1	1	1*	1*	1	1	1	1	1*	**18**
11	Top management support	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**
12	Equitable trust and buy-in	1	1*	1*	1	1*	1	1	1	0	0	0	1	0	0	1	0	1	1	**12**
13	Flexible leadership approach	1	1	1	1*	1	1*	1	1	1	0	0	1	1	0	1	0	1	1	**14**
14	Flexible OSC business models	1*	0	1*	1*	1*	1	1	1	1	0	0	1	0	1	1	0	1	1	**13**
15	Effective Collaboration and communication	1	1*	1	1	1	1	1	1	0	0	0	1	0	0	1	0	0	1	**11**
16	Adequate OSC knowledge and experience	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**18**
17	Early team involvement	1	0	1*	1*	1	1	1	1	1	0	0	1	0	0	1	0	1	1	**12**
18	Continuous learning and development	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
	Dependence	**16**	**11**	**16**	**11**	**11**	**17**	**17**	**17**	**7**	**3**	**3**	**11**	**4**	**4**	**11**	**3**	**8**	**18**	**188**

Appendix 2: Iteration Levels

CSF	Factors	REACHABILITY SET	ANTECEDENT SET	INTERSECTION	LEVEL
1	Effective planning and scheduling	1,2,3,6, 7,8, 18	1,2,3,4,5,7,8,9,10,11,12,13,15,16,17,	1,2,3, 7,8,	III
2	Robust and accessible OSC database	1,2,3,6, 7,8 18	1,2,3, 4,5,10,11, 1213,15,16	1,2,3	III
3	Process and product standardisation	1,2,3,6,7,8,18	1,2,3,4,5,7,8,9,10,11,12, 13, 14,15,16,17,	1,2,3,7, 8,	III
4	Use of data driven technologies	*1,2,3,4,5,6,7,8,12,15,18*	*4,5,9,10,11,12,13,14,15,16-17*	*4,5,12,15*	IV
5	Robust and accessible project information	1,2,3,4,5,6,7,8,12, 15,18	2,4,5, 9,10,11,12,13,14,15,16,17	2,4,5,12, 15	IV
6	Early design freeze	6,7,8, 18	1,2,3,4,5,6,7,8,9,10,11,12, 13, 14,15,16,17	6,7,8	II
7	Effective supply chain management	1,3,6,7,8,18	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,	1,3,6,7,8,	II
8	Effective risk management	1,3,6,7,8,18	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,	1,3,6,7,8,	II
9	Collaborative procurement methods	1,3,4,5,6,7,8,9,12,15,17,18	9,10,11,13,14,16,17	9,17	V
10	Client commitment	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	10, 11,16	10, 11,16	VII
11	Top management support	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18	10,11, 16	10,11,16	VII
12	Equitable trust and buy-in	1,2 3 4 5 6 7,8,12,15,17, 18	4 5,9,10,11,12,13,14, 15, 17,16	4 5, 12, 15, 17	IV
13	Flexible leadership approach	1,2,3,4,5,6,7,8,9,12,13,15, 17 18	10,11,13,16	,13,	VI
14	Flexible OSC business models	1,3,4,6 7,8,9,12,14,15,17,18	10,11,14,16	14	VI
15	Effective Collaboration and communication	1,2,3,4,5,6,7,8,12,15,18	4,5,9,10,11,12,13,14, 15,16,17	4,5,12, 15	IV
16	Adequate OSC knowledge and experience	1,2, 3, 4,5,6,7,8,9, 10,11, 12,13, 14,15,16,17,18	10,11,16	10,11,16	VII
17	Early team involvement	1,3,4,5,6,7,8,9,12,15,17 18	9,10,11,12,14,16,17	9, 12,17	V
18	Continuous learning and development	18	12,3,4, 5,7,9,10,11,12,13,15,16,18	18	I