Architectural Engineering and Design Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/taem20

Key influences to cost modelling and analysis in off-site construction: research trends and GAP analysis

Joas Serugga, Mike Kagioglou, David Edwards, Saeed Talebi & Nathan Johns

To cite this article: Joas Serugga, Mike Kagioglou, David Edwards, Saeed Talebi & Nathan Johns (14 Nov 2023): Key influences to cost modelling and analysis in off-site construction: research trends and GAP analysis, Architectural Engineering and Design Management, DOI: 10.1080/17452007.2023.2282127

To link to this article: https://doi.org/10.1080/17452007.2023.2282127

Published online: 14 Nov 2023.

ARCHITECTURAL ENGINEERING AND DESIGN MANAGEMENT
https://doi.org/10.1080/17452007.2023.2282127

Key influences to cost modelling and analysis in off-site construction: research trends and GAP analysis

Joas Serugga [a], Mike Kagioglou [b], David Edwards [a], Saeed Talebi [a] and Nathan Johns [a]

[a]Engineering and Built Environment, Birmingham City University, Birmingham, UK; [b]Engineering, Design and Built Environment, De Montfort University, Leicester, UK

ABSTRACT

The last decade has witnessed a proliferation of Off-Site Construction (OSC) operations and systems in the UK in response to persistent performance challenges in the construction industry. However, understanding the real influences of cost modelling for accurate project costing and cost performance remains limited. Consequently, this systematic literature review aims to identify the key parameters associated with effective cost modelling in OSC systems. Using literature in the last 10 years (i.e. 2011–2021) and keyword search terms, the review covers OSC aspects such as cost modelling and models, life cycle costing, cost analysis and taking off. Knowledge gaps are identified within literature and practice in cost modelling despite a backdrop of a proliferation of OSC systems and concomitant literature. Emergent findings uncover thematic clusters in analysed literature with the role of design, 88%, costs, 69% and modelling, 74% dominating the literature reviewed. Moreover, key influences to cost modelling in OSC (e.g. abnormal costs, factory-based preliminaries, and contractor's overheads) do not feature prominently in any published research. This paper provides a cross-sectional snapshot of contemporary developments in the field and highlights the need for new research to support integrated cost modelling to support current OSC practice.

ARTICLE HISTORY
Received 23 February 2023
Accepted 6 November 2023

KEYWORDS
Off-site construction; cost modelling; lifecycle design; lifecycle costing; requirements management; design management; modular construction; volumetric construction

Introduction

According to Sutrisna, Cooper-Cooke, Goulding, and Ezcan (2019) and Sutrisna, Ramnauth, and Zaman (2022), there is a notable dearth of cost data to support cost modelling in Off-Site Construction (OSC) systems. While standards such as the Royal Institute of Chartered Surveyors' (RICS) New Rules of Measurement (NRM) 1 and 2 provide a basis for cost modelling, these are limited when applied to OSC systems (Zaki, Magdy, & Nassar, 2020). Cost data relating to development costs that are heavily front-ended in OSC systems must be captured to reflect the activities and processes specific to these systems (Pan & Sidwell, 2011). Similarly, site establishment and OSC costs will differ from traditional construction because front loading of costing in OSC systems mainly supports manufacturing/production processes for example for modular manufacturing or factory-related preliminaries (Tzourmakliotou, 2021). Such costs are additional to traditional costs relating to design development or contractors' overheads (Tzourmakliotou, 2021). The distribution of manufacturing costs across the various cost centres remains critical to understanding how the broader cost

CONTACT Joas Serugga joas.serugga@bcu.ac.uk Engineering and Built Environment, Birmingham City University, 4 Cardigan Street, Birmingham B4 7BD, UK

modelling influences OSC systems and hence, their optimisation. Sutrisna et al. (2019) proffer that understanding cost influences in OSC requires scrutiny of (i) overall development costs; (ii) variability costs relating to OSC systems uncertainties such as relating to design assemblies, components and product complexities and (iii) cash flow processes. For example, Xue, Zhang, Su, Wu, and Yang (2018) note that ambiguities in current cost data and processes of OSC, among many other challenges such as relating to interface compatibility design, mean that development costs remain high. The authors (Xue et al., 2018) argue that collaborative cost modelling can help in cost optimisation of such systems. Similarly, uncertainties within OSC (Blismas, Pendlebury, Gibb, & Pasquire, 2005), remain a critical barrier to adopting efficient and optimised cost models. To further exacerbate matters, understanding cash flow within OSC systems by critical stakeholders constitutes a significant challenge. There is a significant front-loading of costs in OSC systems, something existing standards for example RIBA based cash flow do not effectively manage. Cumulatively, these aforementioned considerations (e.g. the nature of cost modelling practice, state of industry and understanding of inherent processes) play into any optimisation process to, for example, highlight cost centres where significant costs could be reduced or eliminated.

Another critical element in OSC systems is its inherent latent potential to improve lifecycle performance thus, having implications on the environmental performance of designs, necessitating a life cycle cost modelling (Alshamrani, 2021). Life cycle performance could be impacted by such factors as distribution and location of manufacturing processes relative to the site (Turner, Oyekan, & Stergioulas, 2021). Alongside the overall impact of Off-Site manufacturing, such considerations all contribute to the overall life cycle and cost performance (Li, Shen, & Alshawi, 2014). Life cycle costing (LCC) helps define the economic costs and associated operational costs over its life (Alshamrani, 2021). These costs can ultimately be necessary for any OSC cost modelling process using integrated capabilities to highlight any opportunities for optimisation and inform design decision making. To the authors' knowledge, there is presently no unifying literature currently to bridge the gaps in the separate bodies of knowledge to guide appropriate practice and theory building. The paper therefore contributes to first underscoring the gaps in present understanding and secondly underscoring the need for a unified body of knowledge.

The review crystalises this gap and establishes a basis for a unified body of knowledge in cost modelling in OSC against the key influences for successful cost analysis. Using literature review and synthesis covering 10 years (i.e. 2011–2021), the research reviews OSC cost management research and practice including cost modelling and models, life cycle costing, cost analysis and taking off practices relevant to OSC processes. The review therefore seeks to underscore any knowledge gaps within current bodies of knowledge and practice in cost modelling and management against a backdrop of a proliferation of OSC systems and concomitant literature.

Methodology

The researchers adopted an interpretivist philosophical approach and inductive reasoning to analyse secondary data contained within extant literature and develop new theory on the phenomena under investigation. This review adopts the Xiao and Watson (2019) approach for inclusion, identification, screening defining quality and eligibility thresholds, and any necessary iterations to develop the required level of validity, reliability and repeatability. In proposing this approach, the authors (Xiao & Watson, 2019) argue that a prerequisite level of necessary scientific rigour can be achieved by adopting a systematic way to adequately guide how the review is conducted. Furthermore, literature reviews are an essential element of academic discourse to link present and past research to inform the foundations of new frontiers in a discipline. Literature reviews also broaden the depth of understanding while also being the basis for identifying gaps in theory and practice (Macke & Genari, 2019). Paré, Trudel, Jaana, and Kitsiou (2015) add that reviews can be important in establishing validity and qualifying existing positions in theory and concepts whilst highlighting weaknesses in hypotheses in building new understanding. Therefore, the collation of current theory is essential in building new knowledge that is independent and free from chance effects for qualifying new positions (Reim, Parida, & Örtqvist, 2015).

Against this backdrop, this review sets out to understand current application of cost modelling in OSC and discern the key influences or gaps for successful cost analysis. The main goal is to identify the key themes in cost modelling and how these integrate into OSC. The review adopts keywords that would embody first conventional cost modelling and using this as a starting point to generate specific keywords into Cost Modelling and/or OSC practice and theory. This present review, therefore, poses the following research questions:

RQ1 – What are the main influences in cost modelling in construction projects?

RQ2 – How has the impact of these influences been integrated into OSC cost modelling?

Starting from keyword retrieval of all the potential and relevant search results, the research team uses a combination of keywords. The team then snowballs these to find all meaningful articles in their reference list allowing it to obtain other materials that would be missed in the original search.

The search criteria (C) adopted the following:

C1 – a string of keywords on cost modelling, including 'cost planning' OR 'cost management' OR 'cost analysis' OR 'take-off' OR 'life cycle costing.'

C2 – a string relating to OSC including 'Off-Site construction' OR 'Off-Site Fabrication' OR 'Pre Assembly Construction' OR 'Volumetric Construction' OR 'Off-Site.

Production' OR 'modular construction' OR 'design for manufacture' OR 'modular building' OR 'modular design' OR 'Volumetric Modular Construction' OR 'prefabricated modular construction' OR 'Off-Site construction prefabrication' OR 'modular Off-Site construction.'

C3 – a string relating to barriers and influences including 'Off-Site construction major barriers' OR 'cost barriers offsite construction' OR 'Off-Site construction cost performance' OR 'changeover costs precast construction.' Further combinations are demonstrated in Figure 1.

The steps below detail the search process, also summarised in Figure 2.

(1) Identification: all possible articles to support the study will be identified in this stage. The databases used are Google Scholar, Scopus, Web of Science and EBSCOhost for 2011–2021.
(2) Screening: exclusion criteria are applied to the identified articles to establish their close relevance to the research. Some inclusion considerations included where the article was published between 2011 and 2021, peer-reviewed, was written in English and that each article covered at least one or more of the review concepts.

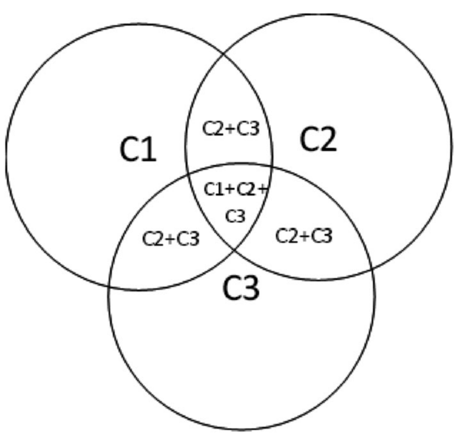

Figure 1. Further combinations of the relevant criteria.

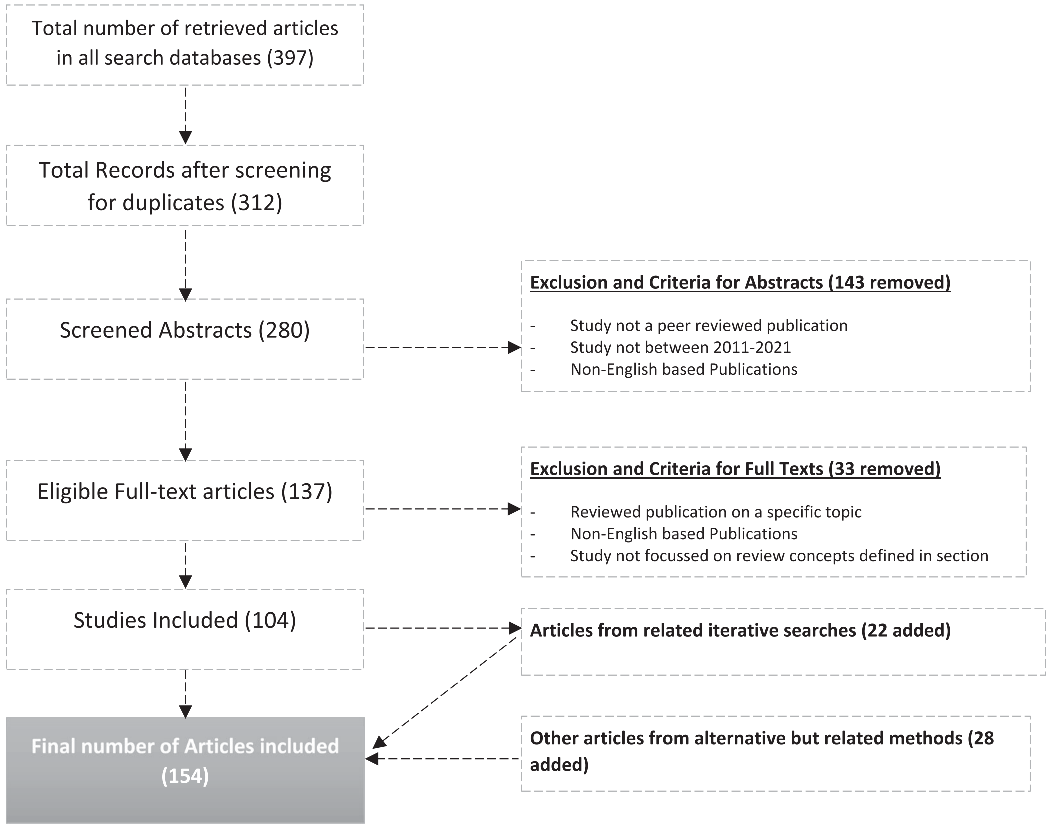

Figure 2. Inclusion and exclusion criteria for the research.

(3) Eligibility – to support the screening stage in ensuring that any articles still under consideration are peer-reviewed, written in English, and relevant to the research's core concepts and that a full-text version is available.

Publications in high-quality peer-reviewed journals and conferences were deemed of sufficient quality. Therefore, this stage looks at quality in the eligibility qualification at the first read-through.

(1) Inclusion – this involved considering articles from reference lists of the most relevant articles that themselves proved relevant to the research. This iterative process explored additional pertinent studies such as those with alternative methods and examples. The quality assessment criteria are illustrated in Figure 2.

To support rigour and validity, the literature review sought to embed best practices in research viz.: (1) adopting a structured research design (see Figure 2); (2) independence in data coding and (3) continuous assessment of quality of articles (see Table 1) as adopted in Inayat, Salim, Marczak, Daneva, and Shamshirband (2015).

The literature search in Scopus for *cost modelling* and *OSC* identified a total of 764 papers. Analysis of keywords within VOSViewer of keywords within document titles, keywords, and abstract sections revealed a gap in knowledge between the two topics. 154 articles are identified specific to the OSC research domain from 18 journals. Figure 3 illustrates an increasing number of published works over the last decade reaching a peak of just over 30 articles in 2020.

Table 1. Summary of key costing in OSC.

Cost	Description	Authors
Capital and Development	Capital or development costs represent the total costs required for a project to become operational (Mao et al., 2016). Capital costs are therefore typically those for outlays of associated works to a project's design and construction. In OSC systems, these can relate to elements associated with both 'On-Site and Off-Site' processes (e.g. associated resource-based costs for materials, plant and machinery). They will therefore represent enabling works for design, manufacturing and prefabrication, distribution, and On-Site installation of prefabricated components and modules. Extensive capital costs are normally needed for OSC systems to develop the end-to-end production system between design and implementation that have to interface between Off-Site and On-Site planning and management including to required processes and systems (Mao et al., 2016).	Mao et al. (2016)
Site Establishment	Site establishment costs are essential for OSC, thus forming a vital part of the contractor's preliminaries. However, they are in the main excluded in the prefabricated buildings and building unit's cost centre within the NRM1 while playing a significant element with OSC systems. The costs generally relate to the main contractor's and common user temporary site accommodation e.g. offices, conference/meeting rooms, canteens, kitchens, drying rooms and washrooms (Obi et al., 2021). The distribution of such costs in OSC systems can depend on the level of 'On-Site and Off-Site' activities and processes. Therefore, their thorough understanding can be critical to successful project cost modelling.	
On-Site Construction	OSC systems can decrease On-Site construction costs (Smith, Hammeran, & Lockwood, 2012; Lee & Kim, 2017). On-Site construction costs in OSC systems can include elements relating to site preparation, demolition and clearance, including any appropriate and necessary excavations (Salama, Salah, & Moselhi, 2017). Excavations can also relate to the substructure's enabling works such as for foundations, pilling and any filling. Costs for On-Site construction will cover elements of any slabs and accompanying drainage. Other costs within this cost centre relate to external and Off-Site works necessary to enable the installation of the modular modules or prefabrication systems. Additionally, costs will cover roads and footpaths, supporting signage and external streetlights, associate landscaping and fencing, and parking for vehicles or cycles, including related waste recycling and storage spaces. Depending on the project's nature, special works for example a pumping station and traffic management may need accounting for.	Smith et al. (2012); Lee and Kim (2017); Salama, Moselhi, and Al-Hussein (2021); Sutrisna et al. (2019)
Modular Manufacturing	In a factory, materials that would otherwise be delivered and processed On-Site feed into the manufacture of modules within factory controlled conditions (Lawrence and Morton, 1993). The modules are then transported to the factory through an appropriate logistics programme (Arashpour, Wakefield, Blismas, & Maqsood, 2015). Palpable benefits of modular construction include opportunities in processes and quality optimisation to augment cost performance (Lawrence and Morton, 1993). The factory process of modular manufacturing ensures simultaneous site preparation and construction processes as well as controlled and optimised module manufacturing (Sutrisna & Goulding, 2019). However, productivity issues have been reported in modular manufacturing processes resulting from specific uncertainties that will ultimately impact cost (Vigneault, Boton, Chong, & Cooper-Cooke, 2020). In modular manufacturing, it is essential that significant costs are separated during cost modelling, for example complete prefabricated building or type of prefabricated room unit (stating the number of units) according to NRM1 based on GIFA. Therefore, the cost will cover complete self-finished prefabricated modular building systems or units included as part of building systems.	Lawrence and Morton (1993); Vigneault et al. (2020); (Arashpour et al., 2015); Sutrisna et al. (2019)

(*Continued*)

Table 1. Continued.

Cost	Description	Authors
Factory Related Preliminaries	Cost modelling in OSC systems has a significant element that is factory based. In the factory, processes can optimise task efficiency while modelling, reducing task complexity that can ultimately reduce resource-related costs (Haas, O'Connor, & Tucker, 2000). This means that unlike conventional construction processes, front-loading of costs significantly weighs towards factory processes (Mao et al., 2016). The front-loading of costs in these processes now requires new techniques for cost optimisation, perhaps on the basis seen in sectors for example in manufacturing. More recently, there has been a proliferation of techniques to optimise factory costs that ultimately reflect in factory preliminaries. There are now many methods to optimise factory processes, including mathematical modelling for supporting factory process planning or facilitating multiple resource environments (Lee & Kim, 2017). Heuristics-based techniques have also been proposed to calculate the parameters of processes requiring minimum costs (Lawrence and Morton, 1993).	Lee and Kim (2017); Haas et al. (2000); Lawrence and Morton (1993); Mao et al. (2016)
Project Team Design Fees	There will be a host of project teams and design fees dependent on the scale and specifics of the project. Such costs relate to legal and regulatory activities, local and national authority charges, planning consultation, planning permission, discharge of planning conditions applications and site investigations. It may suffice such costs are accounted for among many other general costs, for example, the design team. Preconstruction remediations may be required following any investigations for example ecological/habitat and topographical compliance, tree protection noise and dust pollution, asbestos, any legacy contaminations from previous land use, and logistics support for necessary plant and machinery (Edwards et al., 2003). These costs will be on top of the design fees for the wider design team, including architects, structure and civil engineers, M&E engineers, and specialised design teams e.g. for acoustics. Other costs in this cost centre will relate to building control and warranties and energy performance certification that is increasingly integral to new projects considering a move towards improved environmental performance of new builds. Searches may be required for activities, including legacy activities and utility suppliers, to support design and planning decision making. Lastly, in this cost centre, costs for insurance both for latent defects and site operations must be accounted for.	Edwards et al., (2003)
Contractor's Overheads	There is a significant cost for overheads in OSC systems, mainly in the early stages of operational and production setup. The cost distribution will be heavier towards offsite construction activities. Factory setup costs will therefore be a significant cost element in OSC systems. These will cover factors related to factory security, staff and necessary accommodation for example office space and associated and supporting facilities and services (e.g. containers for storage and transportation). Costs will also relate to any temporary supporting works for instance factory-based showcasing together with associated services and supporting works.	
Abnormal Costs	According to the NRM 3, examples of abnormal costs are those relating to issues for example: 'access constraints, legacy data issues, unforeseen events due to the nature of the assessment of works, statutory bodies and listed buildings'. Abnormal costs are therefore considered to be site-specific in OSC and can include legacy issues for instance relating to asbestos clearance on brown field sites. These poor ground conditions impact on foundations or site-specific investigations for contamination and can significantly influence the general cost modelling of a project, translating into unusually higher group elemental and overall costs. While solutions such as site benchmarking are recommended to address abnormal costs (RMB-Council, 2013), being site-specific means that these will be continually influencing.	RMB-Council (2013)

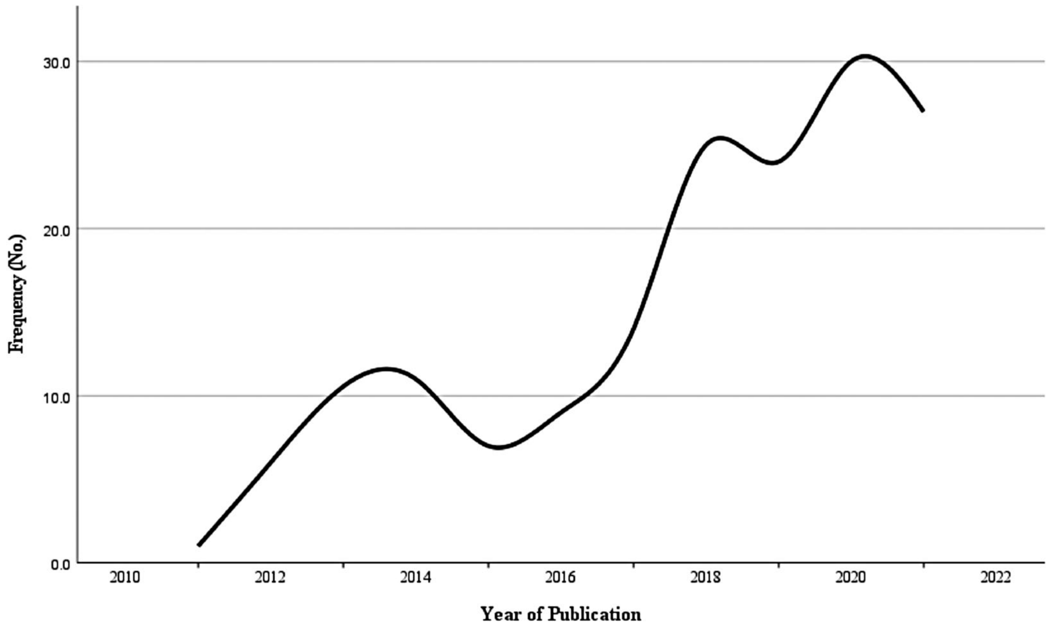

Figure 3. Yearly distribution of articles.

The primary contextual references to OSC construction systems from the 154 articles that guided screening, inclusion and exclusion are summarised across the journals and dominant references in journals in Figure 4.

The frequency and proportion of OSC is dominated by prefabrication (60%), modular (27%), and industrialised (13%) construction as the key reference terminologies.

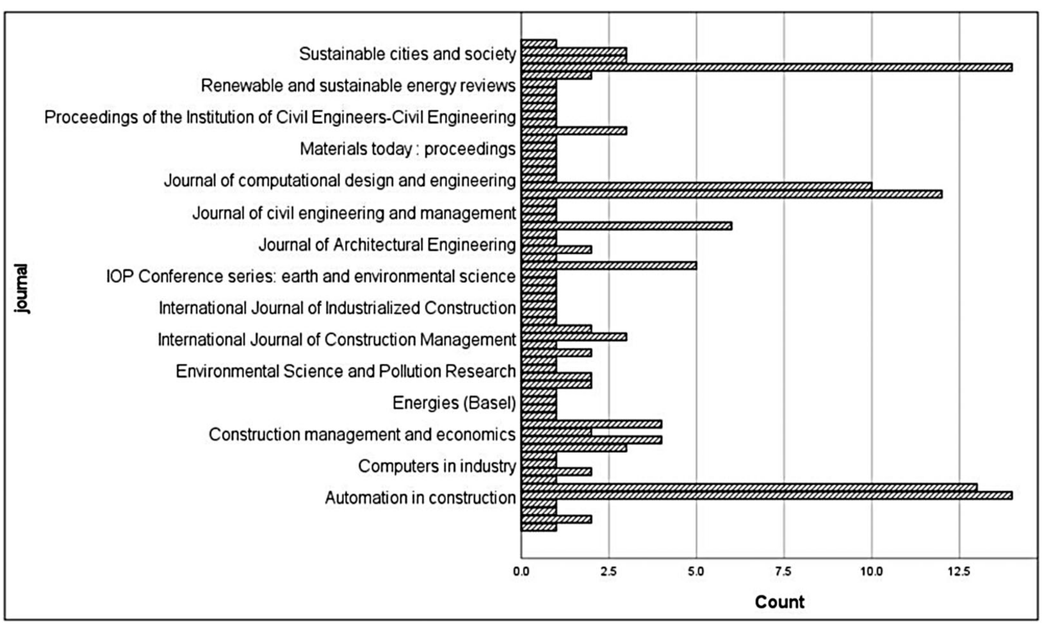

Figure 4. Distribution of articles in journals.

COST modelling and KEY drivers

Cost management is described 'as the process of planning, estimating, coordinating, controlling and reporting a project's costs in ensuring project cost performance within its approved budget' (Ashworth & Ramsay, 2010). The cost management process establishes the 'WHATS, HOWS and WHYS' of any incurred costs in a project (Obi, Arif, & Goulding, 2020). This process usually also considers appropriate actions for planning and controlling costing processes but also information management (Obi, Awuzie, & Islam, 2021). This is an active area of research where many models and approaches are presented to draw an understanding to the basic concepts of project cost management (Alwisy, Bouferguene, & Al-Hussein, 2020; Al-Zwainy & Neran Taher Hadal, 2016; Benjaoran, 2009; Hatamleh, Hiyassat, Sweis, & Sweis, 2018; Kern & Formoso, 2006).

Such strategies for cost management aim to not only represent a set of tools or techniques for cost control (Benjaoran, 2009; Potts & Ankrah, 2008) but also examine costing in a holistic way considering a project's life cycle (Alshamrani, 2021). As such, these models will typically represent appropriate costing elements (e.g. a costing regime's techniques, processes and moderation mechanisms). This approach is instrumental in ensuring stakeholders and technical teams, in particular, can implement and realise cost management outcomes effectively (Alwisy et al., 2020). However, present approaches to costing can take a biased approach to construction processes in an On-Site view. For example, the interfaces between the essential elements of costing processes mean that interdependencies (cf. Ahiaga-Dagbui, Smith, Love, and Ackermann (2015), while representing their various interconnections and dynamics, do so mainly in a traditional construction sense. Nonetheless, such essential representation equally remains crucial costing regimes and as such, be reconfigured to OSC cost management. For example, Kern and Formoso (2006) present one such integrated cost management model based that typically examined: 1) target costing (with a lifecycle costing and value engineering approach); (2) operational estimating (focussing on activity costs that impact on overall running and target project costs) and (3) S-curve from earned value analysis (as a basis for monitoring, forecasting, and controlling processes across key project milestones). Recently, Obi et al. (2020) presented a cost management model for low-cost housing systems highlighting the crucial elements for their costing, including critical influencing roles in their cost management. Other models (cf. (Alwisy et al., 2020) and (Mao et al., 2016)), present a theoretical basis for identifying the critical factors for effective cost estimation. While these studies focus on conventional project processes, the importance of understanding the controlling factors in cost management must not be underestimated. Similarly, Benjaoran (2009) and Görög (2009) separately present new cost control and cash management systems from the perspective of earned value.

Other studies have explored cost management from a lean perspective, for instance in Stephenson (2014), where a Plan Do Check Act (PDCA) approach is integrated into a cost management regime. Omotayo and Kulatunga (2017) similarly explore continuous improvement in cost management systems, ensuring that there is learning along the cost management process. However, such models and techniques do not fully represent OSC processes, for example in integrating the reconfigured processes for successful OSC systems (Hou & Tan, 2019). Mao et al. (2016) present a model for OSC in which a multiple case study sought to analyse expenditure items in the implementation of OSC compared to conventional construction methods. The study (Mao et al., 2016) highlighted specific and essential areas that are important for costing management of OSC processes, including the two crucial elements of – preliminary cost and capital cost/initial costs. Within these, OSC key costing sub-elements include the integrated design for manufacturer and assembly (DfMA) or prefabrication processes, transportation and assembly (Mao et al., 2016). While these critical findings highlight essential processes in OSC costing, the ability to integrate OSC with new digital capabilities such as Building Information Modelling (BIM) or wider Industry 4.0 technologies (cf. Newman et al., 2021) means such studies are insufficient.

Therefore, new models that represent the dynamics in OSC systems cost management are required to better capture their costing requirements in light of these new capabilities. Similarly, while some of the present research exists on planning and control in OSC and other influencing factors for cost management, these must be recast in an OSC systems perspective.

Cost management modelling

Cost modelling is an important and widely utilised aspect of project delivery throughout the construction industry (Borrero & Deffler, 1997; Alwisy et al., 2020). In OSC systems, the starting point in understanding and implementing an effective cost management regime is the component elements of costing (Alwisy et al., 2020). Breaking down the costing process into these elemental units also helps discern an otherwise traditionally accepted cumbersome and complex activity. Similarly, the breakdown into elemental units helps with integration into complementary capabilities for example BIM, where parameters can be optimised from a new understanding of any controlling constraints during design. Alwisy et al. (2020) highlight the dynamics of the project, assemblies and sub-assemblies in proposing a target design model. The authors (Alwisy et al., 2020) argue that understanding the constituent elements and sub-elements is essential to an effective cost modelling process. The design process is arguably the most opportune time to understand these constituent elements and optimise them for broader project performance (Serugga, Kagioglou, & Tzortzopoulos, 2020).

According to Alwisy et al. (2020), the relationship between the assemblies, sub-assemblies and the project is set in the following equation;

$$U = \sum_{i=1}^{n_1} X_i = \sum_{i=1}^{n_1}\sum_{j=1}^{n_2(i)} Y_{i,j} = \sum_{i=1}^{n_1}\sum_{j=1}^{n_2(i)}\sum_{k=1}^{n_3(j)} Z_{i,j,k}$$

where U is the sum of the unit costs of the assemblies in the project, $[X_i]_{i=1,2,\ldots,n_1}$, as the unit assembly elements $[Y_{i,j}]_{j=1,2,\ldots,n_2}$, the sub-assemblies, and $[Z_{i,j,k}]_{k=1,2,\ldots,n_3}$ for the sub assembly components. This equation represents the basic elements in a cost management system. The parameters $n_1(i)$ *and* $n_2(j)$ are dependent on the higher-order attributes of assemblies and subassemblies, respectively.

Parameters at the assembly level can be transformed into modelling parameters relating to technical, regulatory and process, all contributing iteratively to project cost management performance Obi et al. (2020). First, the technical realm embraces the typical techniques in managing project costs across the entire spectrum (Kern & Formoso, 2006; Olawale & Sun, 2013). The various considerations within the technical parameter include approximate and operational estimating, cost budgeting, planning, and reporting, and cash flow analysis according to Obi et al. (2020). Other related considerations include resource planning and monitoring (e.g. for plant, materials and labour) among others; value engineering, target and activity-based costing, and earned value analysis (EVA). Other considerations according to Kern and Formoso (2006) and Olawale and Sun (2013) include interim valuation and cost-value reconciliation that are key influences in cost planning and control techniques. It is therefore essential to understand the basic elements of cost management and the constituent processes that should include: (1) defining the scope (i.e. defining the general target costs in line with the project business case); (2) developing a plan (i.e. where resources are allocated to project cost elements to help establish cost estimates for project tasks and activities); (3) establishing budget(s) (i.e. the elemental estimates are aggregated to inform an overall baseline) and (4) engage with continuous monitoring (i.e. having a responsive monitoring programme for cost performance and managing changes to the baseline costs). In this subsystem, cost management can engage and harness the synergies between the various drivers and cost management techniques iteratively for operational effectiveness and resource optimisation.

The second is the process parameter in which cost management establishes influencing processes, activities and tasks. Toor and Ogunlana (2010) highlight some of the importance of evaluating the process parameter including – effectiveness of decision making, costing, baseline costs, cost performance indices and alerts, ease of cost predictability, accuracy of the project and elemental costs and estimates. The process parameter therefore, provides a basis for realistic project costs

(Zimina, Ballard, & Pasquire, 2012), including all the elemental costs that in turn define the nature of the various project activities and tasks (Ashworth & Ramsay, 2010); and ultimately underpin operational cost performance baselines for cost control (Morad & El-Sayegh, 2016).

The third is the regulatory parameter in which cost management can moderate and regulate costing processes for the effective implementation of CMS. Interdependencies among the drivers in the regulatory parameter will often determine the techniques to be employed and therefore, a basis for compliance with requirements (Olawale & Sun, 2013). Regulatory drivers are typically those relating to knowledge and information, people and project context (Obi et al., 2020). These have been identified through research for various contexts, for instance in Trost and Oberlender (2003) works, where process design, competencies and cost information are essential drivers. The authors (Trost and Oberlender, 2003) additionally identify estimating time, nature of the site, procurement, and people as critical drivers. Similar studies identify site management, cost control and collaboration as the key drivers. The understanding of key drivers to a set costing model was explored by Borrero and Deffler (1997) in a military application setting based on work breakdown structure (WBS). Other studies identify key drivers as competence, (cf. Olawale & Sun, 2013; Morad and El-Sayegh (2016); Hatamleh et al. (2018); Olawale and Sun (2013)) detailed design and specification, collaboration and effective project planning (Olawale and Sun (2013)).

The drivers identified in research are important conceptual bases for integrated and optimised OSC cost management processes and modelling. In this case, coupled with complementary capabilities (enabled by digital twins and BIM capabilities), OSC processes can be a basis for developing real-time adaptive and optimised cost management integrating scope constraints within the project plan and budget while ensuring dynamism and responsiveness when needed enabled by technology. However, since the comprehensive study of cost management in OSC by Mao et al. (2016), there has been limited research to develop this understanding further. While emergent research identifies the critical differences in conventional and offsite costing, gaps exist to further help this understanding into exploring the key influences to overall cost modelling something that underpins the present study. Later research by Obi et al. (2020); Obi et al. (2021) explored critical success and risk factors in cost management. One of the key benefits of OSC is improved life cycle performance. Other studies have looked at issues of construction process such as schedule analysis, highlighting its important influence in OSC systems for simultaneous processes and activities (Li, Hong, Fan, Xu, & Shen, 2018; Wang, Hu, & Gong, 2018; Lee & Kim, 2017). This has been argued to contribute to improved project performance regarding lead times. The bulk of studies highlights key project performance influences without relating these to cost performance.

Key costing elements in cost modelling

Understanding the underlying key influences in cost management can be key to any technical process, or regulatory optimisation efforts. It also suffices to note that the distribution of costs in relation to the key drivers can be different in both On-Site and Off-Site systems. The key costing elements are summarised in Table 1.

Hree key implementation factors affecting the cost of OSC

There is an emergent body of knowledge into trends and barriers in OSC systems focussing on various levels of production and processes. Vernikos, Goodier, Nelson, and Goodier (2013) explore the factors impacting on implementation in a contracting case study viz. sustainability, the need for improved quality, the role of BIM and complementary technologies, culture, asset management, and whole life-cycle services and supply chain management. These influencing factors are explored from a contracting perspective, a perspective from which the authors (Vernikos, Goodier, Nelson, and Goodier, 2013) identify a reluctance on contractors to embed long-term OSC strategies among their services provision. The authors also proffer that the lack of strategy has meant many contractors instead choose to outsource their OSC systems operations and strategies. This points to hesitance among the industry's leaders to forge forward with OSC in the manner they do with conventional construction.

Policy

As has been noted by Xue et al. (2018), the industry suffers from a lack of a supportive and enabling policy environment, which would partly explain continuing hesitancy in OSC systems adoption. The authors (Xue et al., 2018) argue that a supportive policy will help address gaps in the supply chain, support emergent and complementary technologies, change the culture around OSC and secure much-needed investment into systems that will enhance quality.

Costs

A supportive environment can also be a key element in addressing the industry's significant influences on entry, for example the significant upfront costs. Similarly, Sutrisna et al. (2019) find that the overall project cost in OSC remains a key influencing factor to entry. The cost variability can also bring uncertainty and cash flow elements in OSC projects that require different payment terms. Mao et al. (2016) conclude that such barriers present increased risks for entry for small-to-medium-sized construction firms into OSC. Despite these influencing factors, OSC still presents future strategic benefits for the industry – whether supporting new economic opportunities through innovation and investment (Yin, Liu, Chen, & Al-Hussein, 2019) or the critical environmental and social benefits it brings to wider societies (Jin, Hong, & Zuo, 2020).

Culture

When Zhai, Reed, and Mills (2014) explored the different influencing factors in OSC adoption, among them, was the socio-cultural factor. While the context of this aforementioned research was undertaken in Asia (Zhai, Reed, & Mills, 2014), the principle of culture influencing attitudes towards OSC remains similar in many contexts (cf. Pan, Gibb, and Dainty (2007). Cultural perspectives can be seen both on the part of developers and users. Perceptions relate to quality fears and the limited understanding of the scope of OSC in delivering for increasing complexity in projects. There is a need for policy to play a part in demystifying many of these cultural biases.

Results and discussion

Using VOSVIEWER and thematic analysis, gaps are analysed from the existing body of knowledge. The analysis is for occurrence and emergence of themes and their shaping on OSC cost modelling and management.

Gaps in key conceptual understanding

An analysis of keywords within VOSViewer of keywords within document titles, keywords, and abstract sections revealed a clear gap in knowledge between *OSC* and *cost modelling*. 117 keywords met the search criteria with a clear lack of synthesis between the two topics other than applications within construction (Figure 5).

While there is a growing conceptual understanding of the link between *OSC* and *cost modelling*, in Figure 5 three distinctive nodes with two polar ends i.e. Cost modelling (red concentrated) on the one hand and OSC (green concentration) on the other linked by emergent concepts between them (mix of colours). A concentrated colour represents a polarised conceptual coverage. Within construction practice, cost management and forecasting are key practices (Al-Zwainy & Neran Taher Hadal, 2016). However, *Figure 5* shows that that there is a limited link between OSC and cost-related nodes with relative narratives in OSC emergent only recently. The gap reinforces the present position that cost modelling has yet to be extensively connected within OSC research. Understanding and modelling the cost performance of OSC systems can be a key benefit to

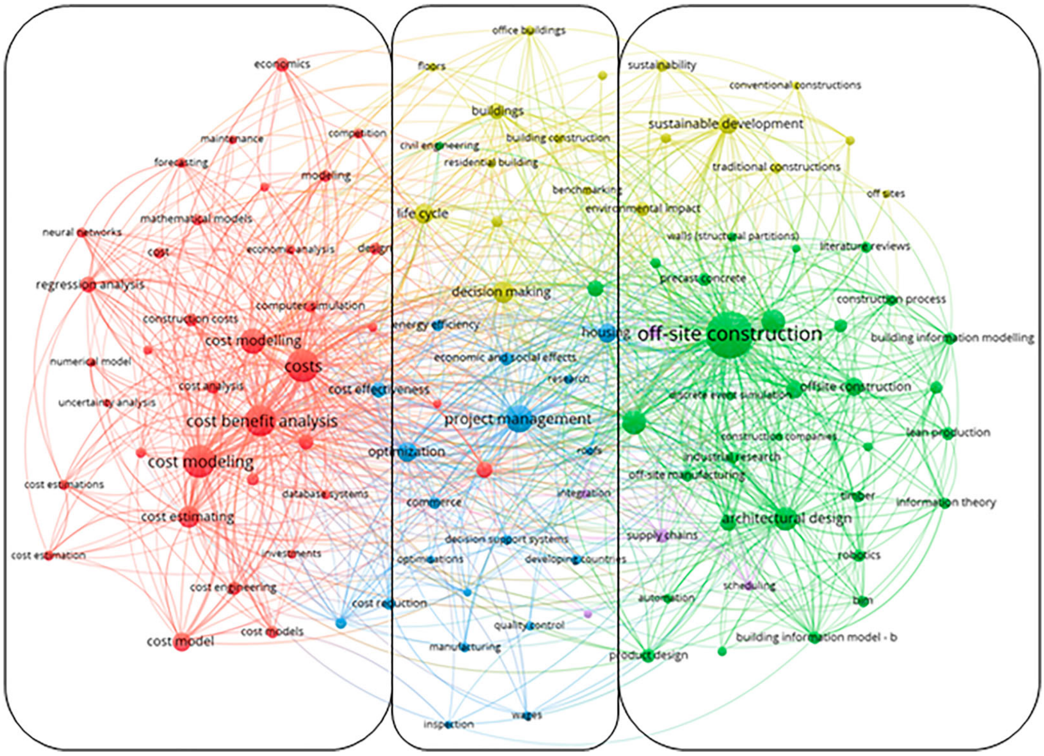

Figure 5. Link between cost modelling and emergent concepts in OSC.

overall project performance among other project benefits (Sutrisna et al., 2019). Gaps in that essential understanding however still exist.

The lack of synergy within literature can also be highlighted by the difference in publication timeframe (see Table 2). OSC is a more recent concept for construction, whereas cost modelling is further into development. This is reinforced by *Figure 5* which together highlight the requirement of further research to bridge cost modelling with OSC to advance the development of OSC through financial viability assessments.

Furthermore, Figure 6 highlights the continuing disconnect among key authors on the key concepts within cost modelling and OSC literature. OSC literature is more recent than cost modelling, the connections between cost modelling are fractured and distant from the main bulk of OSC literature (Figure 6). Cost modelling focuses on various aspects of processes and products. Figure 6 additionally shows that cost modelling is yet to be extensively researched within OSC.

Table 2. Emergent keywords.

Keyword	No. of occurrences	Average pub. year
Prefabrication	37	2018
Cost analysis	22	2017
Economic and social effects	21	2017
OSC/ Modular Construction	272	2017
Costs /Cost Estimation	135	2013
Cost model/ Cost Modelling	43	2016
Life cycle	47	2016
Cost benefit analysis	122	2015
Construction costs	22	2014
Project management	90	2013
Cost modelling	79	2008

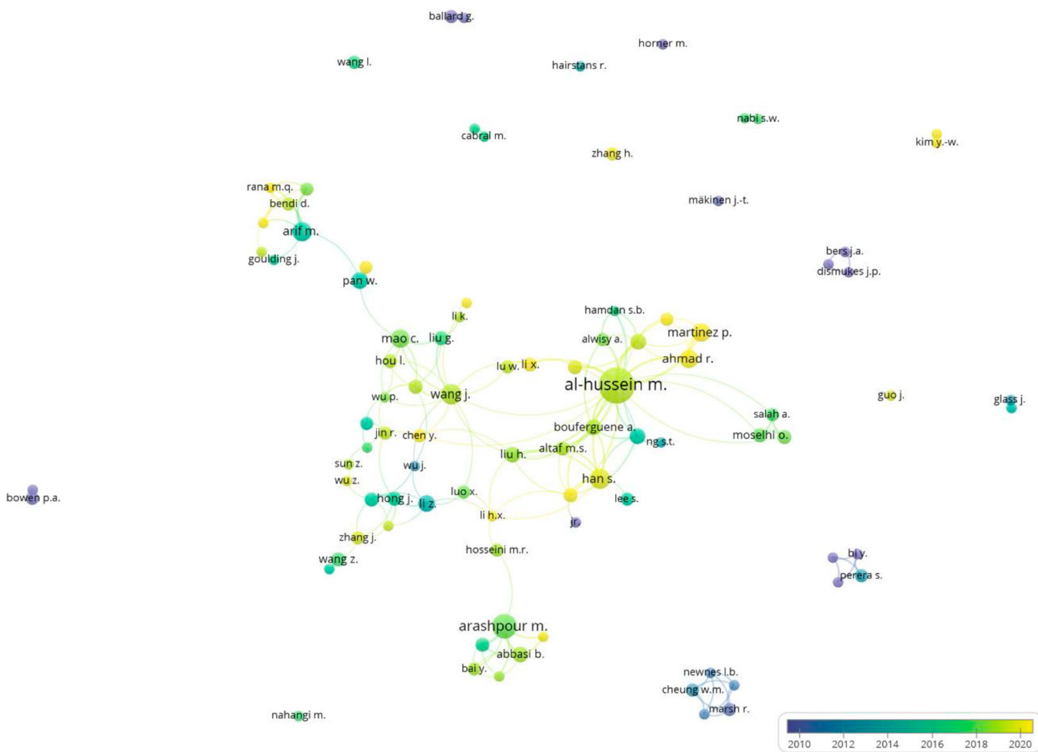

Figure 6. Connection between key authors.

The suggestion is that the essential processes in OSC, including design, Off-Site prefabrication, component production and integration, logistics and inventory and On-Site assembly and construction, are now developed in research. While there is developing research into these potential benefits, findings demonstrate a gap in understanding the key influences on OSC cost modelling. The influencing drivers are compared in Figure 7 and related findings discussed below; where F1 – Costs and Cost Modelling, F2 – Design for Manufacture (DfMA), F3 – Materials Use, F4 – BIM and Technologies, F5 – Modular and Off-Site Construction Systems, F6- Scheduling, F7 – Supply Chain and Logistics, F8 – Design and F9 – Collaboration/Integration. The development of new knowledge into these critical areas for OSC can potentially improve project performance and create opportunities for dynamic and collaborative knowledge exchange in the project lifecycle, that ultimately influences cost management.

Costs and cost modelling

Research more generally covers cost and related influences significantly. Nearly a significant 70% of research analysed mentions the cost influences on OSC project delivery. Increasing complexity in OSC systems, however, means that it is now vital that processes can discern critical dependencies among attributes that have a significant influence on costing, something that is not always evident in practice. Table 3 and Figure 7 are the costing elements author and percentage coverages from the review respectively.

It is vital that essential information on component, product and general design performance feeds into the LCC modelling in any OSC project. However, according to Figure 8 just 13.64% of current research considers influences on Lifecycle Costs (including Lifecycle costs, maintenance and disposal) on the general cost performance of OSC systems.

The majority of research such as by Alshamrani (2021) is limited to just energy performance as the single element within LCC. The other factors including replacement costs for components, products and assemblies are not considered.

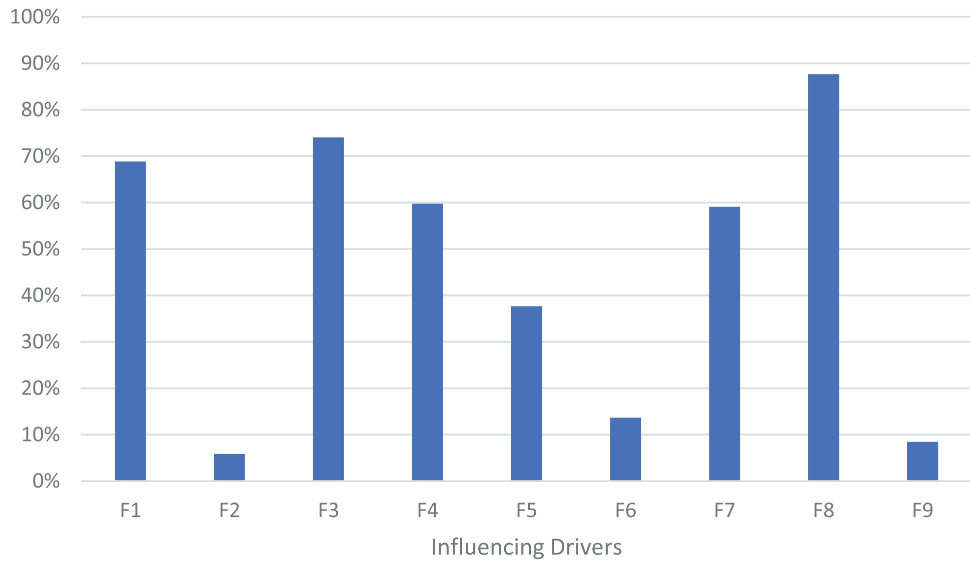

Figure 7. Comparison of cost influences from research.

General cost analysis and costing in OSC are limited generally in research. However, key essential elements seen in Figure 8 in the costing analysis preliminary costs account for 1.95% if literature, capital or development costs 5.84%, prefabrication costs 3.9%, maintenance and operational costs 3.25%, disposal/end of life costs 9.74% and onsite construction costs in relation to OSC, are very limited in current research. It is also observed that available costing research is disjointed and dominated by influences on life cycle costing (35.71% of total cost modelling research), perhaps lending to the environmental benefits heralded for OSC systems. Only 1.3% of research covers costs related to contractor's overheads, while 0.65% of research covers the key costing elements of Site establishment costs, Project team design fees and onsite construction costs each. There is limited research into the costing influences relating to abnormal costs and factory-related preliminaries.

Design for manufacture and assembly (DfMA)

DfMA are design principles that aim to increase the quality, sustainability and cost efficiency associated with design of OSC systems, manufacturing and assembly (Lu et al., 2021). While the benefits of

Table 3. Costing elements covered in research.

Costing element	Author
Life Cycle Costs	Pan and Sidwell (2011), Yunus and Yang (2012), Nahmens and Ikuma (2012), Li et al. (2014), Mao et al. (2016), Kamali and Hewage (2016), Kamali and Hewage (2017), Hong, Shen, Li, Zhang, and Zhang (2018), Dong et al. (2018), Kamali et al. (2019), Daget and Zhang (2019), Hsu et al. (2019), Balasbaneh and Ramli (2020), Heesbeen and Prieto (2020), Akbarieh et al. (2020), Jiang, Huang, and Peng (2020), Gbadamosi et al. (2020), Turner et al. (2021), Kedir and Hall (2021)
Preliminary Costs	Pan and Sidwell (2011), Mao et al. (2016), Hong et al. (2018)
Factory related Preliminaries	–
Capital/Development Costs	Pan and Sidwell (2011), Zhang and Skitmore (2012), Mao et al. (2016), Hong et al. (2018), Jiang et al. (2020), Gusmao Brissi, Debs, and Elwakil (2021), Vaz-Serra, Wasim, and Egglestone (2021)
Prefabrication Costs	Jonsson and Rudberg (2014), Shahtaheri et al. (2017), Wang et al. (2018), Sutrisna et al. (2019), Hsu et al. (2019), Jiang et al. (2020)
Site establishment costs	Mao et al. (2016)
Project team design fees	Mao et al. (2016)
Contractor's Overheads	Pan and Sidwell (2011), Mao et al. (2016)
Onsite Construction Costs	Mao et al. (2016)

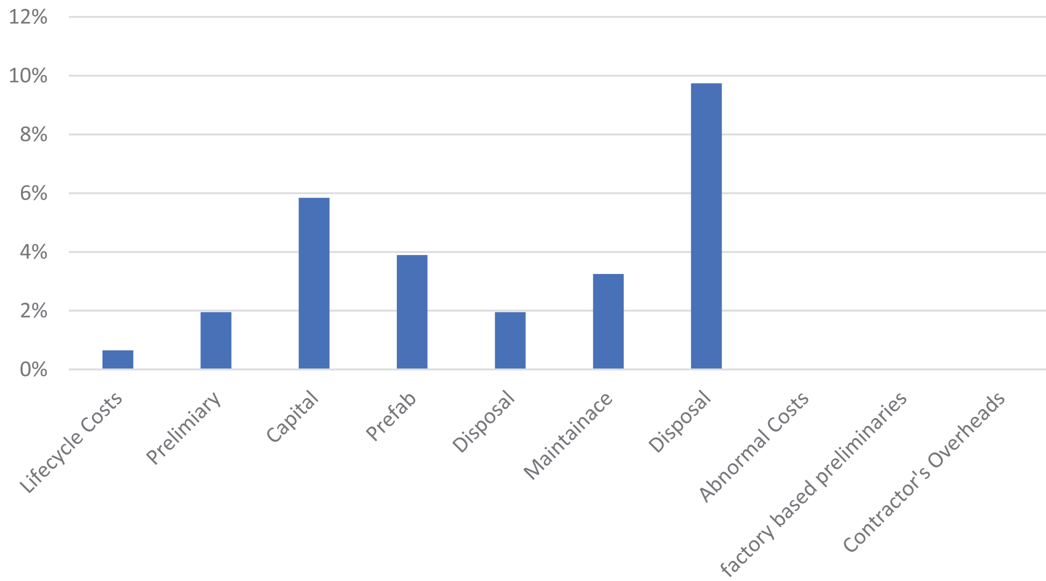

Figure 8. Elemental costs influences.

DfMA can be evident in OSC, only just under 6% of research covers it. DfMA in prefabricated building design can be complemented with parametric design of BIM to support development of concepts and processes for DfMA-oriented parametric design (Yuan, Sun, & Wang, 2018). The principles of DfMA seek to minimise variation in component types through development of changeable interfaces. This way, design can simplify the manufacture and assembly ultimately reducing lead times and project costs; and reduce errors and reworks. This can be achieved in part by developing module, materials, component and product catalogues compatible with an array of interfaces (Yuan et al., 2018). DfMA principles can therefore extend to environmental performance of designs through optimised prefabrication of systems. Despite the benefits of DfMA in prefabrication being a major element in cost modelling in OSC, current research is scant and does not consider the influencing role to cost modelling.

Materials use

An important element in project cost modelling is the bills of materials and is covered in 74.68% of research. In OSC, raw materials form part of the 'On-Site and Off-Site' production processes, need transporting and define the nature and scope of components and products integrated into a design. It also determines life cycle performance through energy performance and materials processing. Materials, however are mainly considered for their contribution to sustainability and energy performance or designs. Akbarieh, Jayasinghe, Waldmann, and Teferle (2020) examined materials repurposing at the project end of life, while Dong, Wang, Li, Jiang, and Al-Hussein (2018) and Xu, Wang, and Wang (2019) explored the use of materials for energy performance in OSC systems. Materials' influencing role in cost modelling is barely covered in current bodies of research. Any specification or fabrication of material or indeed any waste ultimately is a cost on the project.

BIM and emergent technologies

BIM and emergent technologies account for 59.74% of analysed literature dominated in part by developing research into BIM (64.13% of research into BIM and technologies); and its applications to OSC systems. BIM's application to construction has seen a rise in recent years in part because of the opportunities for integrated project processes and collaborative environments it can foster from design to end-of-life project design. Akbarieh et al. (2020) is one such study that examined BIM's integration with end-of-life assessments for reduced waste both in implementation and demolition. In other research, Lee and Kim (2017) utilised BIM as part of task and scheduling processes in modular construction using a relational matrix for sustainable construction. BIM's capabilities therefore, extend from object-oriented attributes of a design (2D-BIM and 3D-BIM) through to production-oriented characteristics (4D BIM to nD-BIM) that focus on whole-life project performance (Li, Shen, Wu, & Yue, 2019). For example, BIM's capabilities are explored in applications for example scheduling for 4D-BIM in improving productivity through linking design and construction processes (Qi, Razkenari, Costin, Kibert, & Fu, 2021). BIM's complementary capabilities have seen the development of solutions for instance for integration with DfMA for improved efficiencies between design and construction processes (Alfieri, Seghezzi, Sauchelli, Di Giuda, & Masera, 2020; Tan, Mills, Papadonikolaki, Li, & Huang, 2023). Among the other nascent technologies include industry 4.0 that promises to bring synergies between the virtual world and the physical environment through data-based and information technologies for instance digital twins, Big data, internet of things (IoT), cloud and cognitive computing, among others (Li et al., 2019). The current application of such capabilities and technologies are, however mainly for conventional construction. However, BIM and other digital technologies can empower OSC cost modelling, something that is very limited in research. 5D BIM, for example can link design and costing through real-time materials take-offs and bills of materials generation.

Modular and off-site construction

This element is discussed in 37.7% of literature. While important overall for the wider industry cost modelling practices, its specific influence OSC is integral to all the other eight elements and therefore covered variously within these.

Scheduling

Scheduling is an essential element of construction project delivery. OSC processes can often be fragmented, bringing risks that can adversely affect scheduling performance. Any delays resulting from scheduling often cause delays in deliveries and ultimately poor cost performance. OSC-specific processes require contextualising the unique scheduling risks that face projects. There can be various risks from logistics to assembly and commissioning, with real implications on cost modelling for projects based on real-world production environments (Wang et al., 2018). While there is increasing research into capabilities and opportunities for improved scheduling in OSC through integrated simulation models (cf. Li et al. (2018) Wang et al. (2018)), these remain limited in research with only 13.64% coverage. The importance of scheduling is integral to project performance. It is interdependent with other parameters such as supply chain and logistics, design and planning as well as project implementation. This interdependence makes scheduling an essential consideration alongside supply chain management, planning and control of project processes and costs during cost modelling. The planning, monitoring and controlling of critical production variables can be key to successful scheduling integration with other project processes, which can arise due to variability, ensuring cost performance and opportunities for cost optimisation during cost modelling.

Supply chain and logistics

In OSC, modules, components and products must be transported between site and factories and this activity constitutes a significant costing influence. The role of logistics and supply chain is well covered in 59% of research. It is covered from its importance in On-Site through to factory processes. Just-in-Time and Lean solutions can be integrated into the supply chain for efficient distribution processes (Hussein & Zayed, 2021), while integration with BIM is also explored in research (Whitlock, Abanda, Manjia, Pettang, & Nkeng, 2018; Papadonikolaki, Vrijhoef, & Wamelink, 2016). Literature reveals that often in OSC, large module and component-sized elements must be transported to urban sites (Hsu, Aurisicchio, & Angeloudis, 2019). This requires an efficient and proactive storage and logistics process. Site location and its physical characteristics (e.g. topology and ground conditions) therefore, influence the cost performance resulting from the supply chain through impacting on operational capacity, associated plant and machinery costs, delivery and assembly schedules. In this case, the role of supply chains is seen in linking the Off-Site production, transportation, On-Site assembly and, when optimised, can minimise the chain-wide costs while allowing project lead time performance (Zhai, Zhong, Li, & Huang, 2017).

Design

The role of design in influencing costing is increasingly significant across OSC research and practice, with over 87% coverage. This highlights the increasing understanding of the key influencing role of design in OSC processes in improving overall project performance. Uncoordinated design can risk design changes in prefabrication, according to Du, Jing, Castro-Lacouture, and Sugumaran (2019). In addition, OSC systems need flexible interfaces, which can be achieved through the increasing complementary computational and technological capabilities such as BIM that focus on the front end for integrated OSC systems design (Adnan, Einur Azrin Baharuddin, Arzlee Hassan, Mahat, & Kaharuddin, 2019). Another key benefit for OSC is the opportunity for concurrent processes between 'On-Site and Off-Site' activities for shorter lead times and improved cost performance (Hyun, Kim, Lee, & Park, 2020). Therefore, it can be essential to understand critical dependencies in the processes and activities to reduce errors, for example, reverse information flow and reverse logistics (Hosseini, Rameezdeen, Chileshe, & Lehmann, 2015). However, Hyun et al. (2020) suggest that understanding these interdependencies among attributes with increasing complexity may not always be possible. Therefore, the significance of design (in this case), is to help develop mechanisms for managing design change factors and events and ultimately manage any risks in OSC systems.

Another important element for design research and practice is its predominance towards conventional systems. DfMA, while essential in OSC systems, is covered in only 5.84% of research undertaken. This is even much less when considered with complementary capabilities for example BIM to optimise assemblies and components in OSC. Therefore, the role of design is covered for its general influencing role on project performance. Design's influencing role on cost during project cost modelling that is key for optimisation and performance is less so; despite for example, design contributing up to 80% of operational costs (Bogenstätter, 2000). The broader design implications on cost are even lesser considered, including to architects, mechanical, electrical and structural designers and other building consultants (e.g. building services). However, these all can be significant and need to be understood in the context of project cost analysis and optimisation.

Integrated and collaborative processes

Integration of processes is widely identified as a critical opportunity in OSC construction systems (Arashpour, Wakefield, Abbasi, & Hosseini, 2018). However, 8.44% of research covers integration that is key to the vital information flows and knowledge exchanges. Integrated processes are essential in facilitating collaboration among project stakeholders, particularly in design, production, transportation, implementation processes (Sebastian, 2010). Integrated processes can also help with coping with changing user requirements. Therefore, they can form a platform to help manage component and product selection to help cope with varying design requirements (Said, Chalasani, & Logan, 2017). This lack of integration within processes can influence project performance, for example, uncertainty in the design process, leading to errors and inefficient information flows, which ultimately can affect project cost performance (Hyun et al., 2020).

Contribution to theory and practice

This paper's first major contribution is its analysis of the outlook on and identification of gaps theory and practice of cost modelling in OSC research. The research secondly identifies nine key cost modelling influences to set a basis for new theory building in OSC cost modelling. The data following the analysis of 154 articles over the decade 2011–2021 identifying the nine key cost influencing factors is summarised in two findings:

(1) Current cost modelling research is limited, reflecting biases in present understanding and application of OSC systems research and practice (Mao et al., 2016; Obi et al., 2020; Obi et al., 2021). There appears to be limited to no relevant research to underpin understanding of cost modelling influences in OSC systems. While the role of design, components and materials in influencing cost is fairly explored in recent research, that of related attributes that influence the key costing elements for optimised cost modelling of OSC systems is not (Obi et al., 2021; Pan & Sidwell, 2011). Without knowing these influencing factors, project optimisation both for designs and costing can be fraught, more so with the increasing complexity in OSC projects.
(2) The interrelationships between the costing influences suggest that research needs to bring new balance to more broadly reflect the key intricacies in OSC processes. However, there are notable biases in the reflection of these influences to OSC costing, reflecting contextual influences on current research.

The research accepts potential occurrences of bias in its interpretivist analysis which may require future supporting case-based investigations to support any generalised positions in regard to the key findings. The gaps identified however add to the need for this new research not only to fill them, but also to support further triangulation. New investigations can explore new lines of inquiry relating to new understanding of costing influences on overall cost performance of OSC systems, integrated lifecycle modelling of OSC systems, exploration of interoperable capabilities and technologies between cost modelling in OSC and the design process, and criteria to evaluate cost performance in OSC systems.

Conclusions

As the first review of OSC cost modelling, this paper provides a basis for new research into the themes highlighted above to better understand cost management. Research on cost modelling and lifecycle costing in OSC is limited, only barely achieving 10% of analysed studies despite nearly 70% of research discussing it in some form. Additionally, it is now understood that integrated costing and design capabilities are needed to improve OSC performance. Many of the studies focus on the many attributes of OSC without drawing to the costing implications. The paper highlights, for example that less than 10% of research (for the decade 2011–2021) is focused on lifecycle cost performance and end-of-life/demolition costs yet, it is one of the key benefits cited for OSC. New research into the key benefits and how they fit into the wider project performance is needed to understand cost implications onto which many other project attributes will depend. This paper's focus on cost modelling and its influences sets it apart from previous reviews both in scope and findings and finds its place in research on cost performance in construction in offsite systems.

This paper highlights significant gaps in the present research and accepts limitations in its findings.

This research presents some noteworthy findings particularly important for project implementation as the industry continues to embrace emergent OSC technologies and systems. Industry practitioners and researchers will need to come together and work collaboratively to redefine any nascent themes, standards and inform policy regarding emergent needs of OSC practice. Approaches and strategies to cost modelling in OSC will need renewal, enriched from this emergent body of knowledge. These could perhaps lend to theory and practice from complementary sectors such as from lean manufacturing Gaps in bodies of knowledge demonstrate a need for new knowledge. The inherent dynamics in OSC systems cost management and modelling require for example that new systems integrate modelling parameters relating to technical, regulatory regimes and processes as well as relevant drivers in OSC. This paper first identifies underlying gaps and secondly underscores the need for a unified body of knowledge in supporting this.

The paper accepts there may be an alternative outlook on the main influencing themes that have formed the basis for the research conclusions. Second, there are various understandings and references of OSC in various contexts that may not have been reflected in this research owing to its exclusion and inclusion criteria, which may be relevant to the findings.

The need for new research from the gaps identified will be vital to support further process optimisation, support development and integration with complementary technologies to further improve performance in OSC project delivery. The delivery of optimised cost management processes is key to the emergent need for better project performance in light of increasing demand from wider industry and communities to improve on resource utilisation. Coupled with complementary capabilities like those afforded by BIM and Digital Twins, cost management and modelling in OSC it is possible that emergent solutions will be important in the wider environmental agenda now driving many discussions and forums across many political and geographical spectrums.

The paper's findings therefore are a call for novel understanding of OSC cost performance based on new knowledge of costing influences and modelling complementary to emergent and complementary technologies for instance Digital Twins, BIM, DfMA and lean construction.

Disclosure statement

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

ORCID

Joas Serugga http://orcid.org/0000-0002-5814-1522

References

Adnan, H., Einur Azrin Baharuddin, H., Arzlee Hassan, A., Mahat, N. A. A., & Kaharuddin, S. K. (2019). *Success factors among industrialised building system (IBS) contractors in Malaysia*. IOP Conference Series. Earth and environmental science 233.

Ahiaga-Dagbui, D., Smith, S. D., Love, P. E., & Ackermann, F. (2015). Spotlight on construction cost overrun research: Superficial, replicative and stagnated.

Akbarieh, A., Jayasinghe, L. B., Waldmann, D., & Teferle, F. N. (2020). BIM-based end-of-lifecycle decision making and digital deconstruction: Literature review. *Sustainability*, *12*, 2670. doi:10.3390/su12072670

Alfieri, E., Seghezzi, E., Sauchelli, M., Di Giuda, G. M., & Masera, G. (2020). A BIM-based approach for DfMA in building construction: Framework and first results on an Italian case study. *Architectural Engineering and Design Management*, *16*, 247–269. doi:10.1080/17452007.2020.1726725

Alshamrani, O. S. (2021). Integrated LCA-LCC assessment model of offsite, onsite, and conventional construction systems. *Journal of Asian Architecture and Building Engineering*, *21*(5), 2058–2080.

Alwisy, A., Bouferguene, A., & Al-Hussein, M. (2020). Framework for target cost modelling in construction projects. *International Journal of Construction Management*, *20*, 89–104. doi:10.1080/15623599.2018.1462446

Al-Zwainy, F. M. S., & Neran Taher Hadal, T,N. (2016). Application artificial forecasting techniques in cost management. *Journal of Engineering*, *22*, 1–15. doi:10.31026/j.eng.2016.08.01

Arashpour, M., Wakefield, R., Abbasi, B., & Hosseini, R. (2018). Optimal process integration architectures in off-site construction: Theorizing the use of multi-skilled resources. *Architectural Engineering and Design Management*, *14*, 46–59. doi:10.1080/17452007.2017.1302406

Arashpour, M., Wakefield, R., Blismas, N., & Maqsood, T. (2015). Autonomous production tracking for augmenting output in off-site construction. *Automation in Construction*, *53*, 13–21. doi:10.1016/j.autcon.2015.03.013

Ashworth, S., & Ramsay, K. W. (2010). *Should audiences cost? Optimal domestic constraints in international crises. Manuscript*. Princeton, New Jersey: Princeton University.

Balasbaneh, A. T., & Ramli, M. Z. (2020). A comparative life cycle assessment (LCA) of concrete and steel-prefabricated prefinished volumetric construction structures in Malaysia. *Environmental Science and Pollution Research*, *27*(34), 43186–43201.

Benjaoran, V. (2009). A cost control system development: A collaborative approach for small and medium-sized contractors. *International Journal of Project Management*, *27*, 270–277. doi:10.1016/j.ijproman.2008.02.004

Blismas, N. G., Pendlebury, M., Gibb, A., & Pasquire, C. (2005). Constraints to the use of off-site production on construction projects. *Architectural Engineering and Design Management*, *1*, 153–162. doi:10.1080/17452007.2005.9684590

Bogenstätter, U. (2000). Prediction and optimization of life-cycle costs in early design. *Building Research & Information*, *28*, 376–386. doi:10.1080/096132100418528

Borrero, M., & Deffler, J. (1997). *Development of a Standard Test Program Set Cost Model. 1997 IEEE Autotestcon Proceedings AUTOTESTCON'97*. IEEE Systems Readiness Technology Conference. Systems Readiness Supporting Global Needs and Awareness in the 21st Century. IEEE, 278–284.

Daget, Y. T., & Zhang, H. (2019). Decision-making model for the evaluation of industrialized housing systems in Ethiopia. *Engineering, Construction and Architectural Management*, *27*(1), 296–320.

Dong, L., Wang, Y., Li, H. X., Jiang, B., & Al-Hussein, M. (2018). Carbon reduction measures-based LCA of prefabricated temporary housing with renewable energy systems. *Sustainability*, *10*, 718. doi:10.3390/su10030718

Du, J., Jing, H., Castro-Lacouture, D., & Sugumaran, V. (2019). Multi-agent simulation for managing design changes in prefabricated construction projects. *Engineering, Construction, and Architectural Management*, *27*, 270–295. doi:10.1108/ECAM-11-2018-0524

Edwards, D. J., Harris, F. C., & McCaffer, R. (2003). *Management of off-highway plant and equipment*. CRC Press.

Gbadamosi, A. Q., Oyedele, L., Mahamadu, A. M., Kusimo, H., Bilal, M., Delgado, J. M. D., & Muhammed-Yakubu, N. (2020). Big data for Design Options Repository: Towards a DFMA approach for offsite construction. *Automation in Construction*, *120*, 103388.

Görög, M. (2009). A comprehensive model for planning and controlling contractor cash-flow. *International Journal of Project Management*, *27*, 481–492. doi:10.1016/j.ijproman.2008.08.001

Gusmao Brissi, S., Debs, L., & Elwakil, E. (2021). A review on the factors affecting the use of offsite construction in multi-family housing in the United States. *Buildings*, *11*, 5. doi:10.3390/buildings11010005

Haas, C. T., O'Connor, J. T., & Tucker, R. L. (2000). Prefabrication and preassembly trends and effects on the construction workforce. *Center for Construction Industry Studies*, *14*.

Hatamleh, M. T., Hiyassat, M., Sweis, G. J., & Sweis, R. J. (2018). Factors affecting the accuracy of cost estimate: Case of Jordan. *Engineering, Construction and Architectural Management*, *25*(1), 113–131.

Heesbeen, C., & Prieto, A. (2020). Archetypical CBMs in construction and a translation to industrialized manufacture. *Sustainability*, *12*(4), 1572.

Hong, J., Shen, G. Q., Li, Z., Zhang, B., & Zhang, W. (2018). Barriers to promoting prefabricated construction in China: A cost–benefit analysis. *Journal of Cleaner Production*, *172*, 649–660. doi:10.1016/j.jclepro.2017.10.171

Hosseini, M. R., Rameezdeen, R., Chileshe, N., & Lehmann, S. (2015). Reverse logistics in the construction industry. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *33*, 499–514. doi:10.1177/0734242X15584842

Hou, L., & Tan, Y. (2019). Challenges of off-site construction: A critical review. In K. Papadikis, C. Chin, I. Galobardes, G. Gong, & F. Guo (Eds.), *Sustainable buildings and structures: Building a sustainable tomorrow* (pp. 307–312). CRC Press eBooks.

Hsu, P.-Y., Aurisicchio, M., & Angeloudis, P. (2019). Risk-averse supply chain for modular construction projects. *Automation in Construction*, *106*, 102898. doi:10.1016/j.autcon.2019.102898

Hussein, M., & Zayed, T. (2021). Critical factors for successful implementation of just-in-time concept in modular integrated construction: A systematic review and meta-analysis. *Journal of Cleaner Production*, *284*, 124716. doi:10.1016/j.jclepro.2020.124716

Hyun, H., Kim, H., Lee, H.-S., & Park, M. (2020). Integrated design process for modular construction projects to reduce rework. *Sustainability*, *12*, 530. doi:10.3390/su12020530

Inayat, I., Salim, S. S., Marczak, S., Daneva, M., & Shamshirband, S. (2015). A systematic literature review on agile requirements engineering practices and challenges. *Computers in Human Behavior*, *51*, 915–929. doi:10.1016/j.chb.2014.10.046

Jiang, W., Huang, Z., & Peng, Y. (2020). Factors affecting prefabricated construction promotion in China: A structural equation modeling approach. *PloS one*, *15*, e0227787.

Jin, R., Hong, J., & Zuo, J. (2020). Environmental performance of off-site constructed facilities: A critical review. *Energy and Buildings*, *207*, 109567. doi:10.1016/j.enbuild.2019.109567

Jonsson, H., & Rudberg, M. (2014). Classification of production systems for industrialized building: A production strategy perspective. *Construction Management and Economics*, *32*(1-2), 53–69.

Kamali, M., & Hewage, K. (2016). Life cycle performance of modular buildings: A critical review. *Renewable and Sustainable Energy Reviews*, *62*, 1171–1183.

Kamali, M., & Hewage, K. (2017). Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. *Journal of Cleaner Production*, *142*, 3592–3606.

Kamali, M., Hewage, K., & Sadiq, R. (2019). Conventional versus modular construction methods: A comparative cradle-to-gate LCA for residential buildings. *Energy and Buildings*, *204*, 109479.

Kedir, F., & Hall, D. M. (2021). Resource efficiency in industrialized housing construction–A systematic review of current performance and future opportunities. *Journal of Cleaner Production*, *286*, 125443.

Kern, A. P., & Formoso, C. T. (2006). A model for integrating cost management and production planning and control in construction. *Journal of Financial Management of Property and Construction*, *11*(2), 75–90.

Lawrence, SR., & Morton, T. E. (1993). Resource-constrained multi-project scheduling with tardy costs: Comparing myopic, bottleneck, and resource pricing heuristics. *European Journal of Operational Research*, *64*, 168–187. doi:10.1016/0377-2217(93)90175-M

Lee, J., & Kim, J. (2017). BIM-based 4D simulation to improve module manufacturing productivity for sustainable building projects. *Sustainability*, *9*, 426. doi:10.3390/su9030426

Li, C. Z., Hong, J., Fan, C., Xu, X., & Shen, G. Q. (2018). Schedule delay analysis of prefabricated housing production: A hybrid dynamic approach. *Journal of Cleaner Production*, *195*, 1533–1545. doi:10.1016/j.jclepro.2017.09.066

Li, X., Shen, G. Q., Wu, P., & Yue, T. (2019). Integrating building information modeling and prefabrication housing production. *Automation in Construction*, *100*, 46–60. doi:10.1016/j.autcon.2018.12.024

Li, Z., Shen, G. Q., & Alshawi, M. (2014). Measuring the impact of prefabrication on construction waste reduction: An empirical study in China. *Resources, Conservation and Recycling*, *91*, 27–39. doi:10.1016/j.resconrec.2014.07.013

Lu, W., Tan, T., Xu, J., Wang, J., Chen, K., Gao, S., & Xue, F. (2021). Design for manufacture and assembly (DfMA) in construction: The old and the new. *Architectural Engineering and Design Management*, *17*, 77–91. doi:10.1080/17452007.2020.1768505

Macke, J., & Genari, D. (2019). Systematic literature review on sustainable human resource management. *Journal of Cleaner Production*, *208*, 806–815. doi:10.1016/j.jclepro.2018.10.091

Mao, C., Xie, F., Hou, L., Wu, P., Wang, J., & Wang, X. (2016). Cost analysis for sustainable off-site construction based on a multiple-case study in China. *Habitat International*, *57*, 215–222. doi:10.1016/j.habitatint.2016.08.002

Morad, M., & El-Sayegh, S. M. (2016). *Use of earned value management in the UAE construction industry*. 2016 International Conference on Industrial Engineering, Management Science and Application (ICIMSA). IEEE, 1–5.

Nahmens, I., & Ikuma, L. H. (2012). Effects of lean construction on sustainability of modular homebuilding. *Journal of Architectural Engineering*, *18*(2), 155–163.

Newman, C., Edwards, D., Martek, I., Lai, J., Thwala, W. D., & Rillie, I. (2021). Industry 4.0 deployment in the construction industry: A bibliometric literature review and UK-based case study. *Smart and Sustainable Built Environment*, *10*(4), 557–580. doi:10.1108/SASBE-02-2020-0016

Obi, L., Arif, M., & Goulding, J. (2020). Low-cost housing: A cost management model for process integration and evaluation. *Architectural Engineering and Design Management*, *16*, 411–425. doi:10.1080/17452007.2020.1738993

Obi, L. I., Arif, M., Awuzie, B., Islam, R., Gupta, A. D., & Walton, R. (2021). Critical success factors for cost management in public-housing projects. *Construction Innovation*, *21*(4), 625–647.

Olawale, Y., & Sun, M. (2013). PCIM: Project control and inhibiting-factors management model. *Journal of Management in Engineering*, *29*, 60–70. doi:10.1061/(ASCE)ME.1943-5479.0000125

Omotayo, T., & Kulatunga, U. (2017). The research methodology for the development of a kaizen costing framework suitable for indigenous construction firms in. Lagos, Nigeria.

Pan, W., Gibb, A. G., & Dainty, A. R. (2007). Perspectives of UK housebuilders on the use of offsite modern methods of construction. *Construction Management and Economics*, *25*, 183–194. doi:10.1080/01446190600827058

Pan, W., & Sidwell, R. (2011). Demystifying the cost barriers to offsite construction in the UK. *Construction Management and Economics*, *29*, 1081–1099. doi:10.1080/01446193.2011.637938

Papadonikolaki, E., Vrijhoef, R., & Wamelink, H. (2016). The interdependences of BIM and supply chain partnering: Empirical explorations. *Architectural Engineering and Design Management*, *12*, 476–494. doi:10.1080/17452007.2016.1212693

Paré, G., Trudel, M.-C., Jaana, M., & Kitsiou, S. (2015). Synthesizing information systems knowledge: A typology of literature reviews. *Information & Management*, *52*, 183–199. doi:10.1016/j.im.2014.08.008

Potts, K., & Ankrah, N. (2008). *Construction cost management: Learning from case studies*. Abingdon, Oxon: Routledge.

Qi, B., Razkenari, M., Costin, A., Kibert, C., & Fu, M. (2021). A systematic review of emerging technologies in industrialized construction. *Journal of Building Engineering*, *39*, 102265. doi:10.1016/j.jobe.2021.102265.

Reim, W., Parida, V., & Örtqvist, D. (2015). Product–service systems (PSS) business models and tactics – a systematic literature review. *Journal of Cleaner Production*, *97*, 61–75. doi:10.1016/j.jclepro.2014.07.003

RMB-Council. (2013). *Whole plan viability assessment*. Rotherham: Rotherham Metropolitan Borough Council.

Said, H. M., Chalasani, T., & Logan, S. (2017). Exterior prefabricated panelized walls platform optimization. *Automation in Construction*, *76*, 1–13. doi:10.1016/j.autcon.2017.01.002

Salama, T., Moselhi, O., & Al-Hussein, M. (2021). Overview of the characteristics of the modular industry and barriers to its increased market share. *International Journal of Industrialized Construction*, *2*, 30–53. doi:10.29173/ijic249

Salama, T., Salah, A., & Moselhi, O. (2017). *Integration of offsite and onsite schedules in modular construction. ISARC*. Proceedings of the International Symposium on Automation and Robotics in Construction. IAARC Publications.

Sebastian, R. (2010). Integrated design and engineering using building information modelling: A pilot project of small-scale housing development in The Netherlands. *Architectural Engineering and Design Management*, *6*, 103–110. doi:10.3763/aedm.2010.0116

Serugga, J., Kagioglou, M., & Tzortzopoulos, P. (2020). Value generation in front-end design of social housing with qfd and multiattribute utility theory. *Journal of Construction Engineering and Management*, *146*, 04020019. doi:10.1061/(ASCE)CO.1943-7862.0001787

Shahtaheri, Y., Rausch, C., West, J., Haas, C., & Nahangi, M. (2017). Managing risk in modular construction using dimensional and geometric tolerance strategies. *Automation in Construction*, *83*, 303–315.

Smith, C. T., Hammeran, J. H., & Lockwood, C. (2012). *Module fabrication strategy for today's nuclear industry*. International Conference on Nuclear Engineering. American Society of Mechanical Engineers, 125–137.

Stephenson, T. (2014). *Understanding construction drawings for housing and small buildings*.

Sutrisna, M., Cooper-Cooke, B., Goulding, J., & Ezcan, V. (2019). Investigating the cost of offsite construction housing in Western Australia. *International Journal of Housing Markets and Analysis*, *12*(1), 5–24.

Sutrisna, M., & Goulding, J. (2019). Managing information flow and design processes to reduce design risks in offsite construction projects.

Sutrisna, M., Ramnauth, V., & Zaman, A. (2022). Towards adopting off-site construction in housing sectors as a potential source of competitive advantage for builders. *Architectural Engineering and Design Management*, *18*, 165–183. doi:10.1080/17452007.2020.1807306

Tan, T., Mills, G., Papadonikolaki, E., Li, B., & Huang, J. (2023). Digital-enabled design for manufacture and assembly (DfMA) in offsite construction: A modularity perspective for the product and process integration. *Architectural Engineering and Design Management*, *19*, 267–282. doi:10.1080/17452007.2022.2104208

Toor, S.-u.-R., & Ogunlana, S. O. (2010). Beyond the 'iron triangle': Stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects. *International Journal of Project Management*, *28*, 228–236. doi:10.1016/j.ijproman.2009.05.005

Trost, S. M., & Oberlender, G. D. (2003). Predicting accuracy of early cost estimates using factor analysis and multivariate regression. *Journal of Construction Engineering and Management*, *129*, 198–204. doi:10.1061/(ASCE)0733-9364(2003)129:2(198)

Turner, C., Oyekan, J., & Stergioulas, L. K. (2021). Distributed manufacturing: A new digital framework for sustainable modular construction. *Sustainability*, *13*, 1515. doi:10.3390/su13031515

Tzourmakliotou, D. (2021). Modular disruption in construction industry – The environmental benefits. *Journal of Civil Engineering and Architecture*, *15*, 1934–7359.

Vaz-Serra, P., Wasim, M., & Egglestone, S. (2021). Design for manufacture and assembly: A case study for a prefabricated bathroom wet wall panel. *Journal of Building Engineering*, *102849*.

Vernikos, V., Goodier, C., Nelson, R., & Goodier, C. I. (2013). Implementing an offsite construction strategy: A UK contracting organisation case study.

Vigneault, M.-A., Boton, C., Chong, H.-Y., & Cooper-Cooke, B. (2020). An innovative framework of 5D BIM solutions for construction cost management: A systematic review. *Archives of Computational Methods in Engineering*, *27*, 1013–1030. doi:10.1007/s11831-019-09341-z

Wang, Z., Hu, H., & Gong, J. (2018). Framework for modeling operational uncertainty to optimize offsite production scheduling of precast components. *Automation in Construction*, *86*, 69–80. doi:10.1016/j.autcon.2017.10.026

Whitlock, K., Abanda, F., Manjia, M., Pettang, C., & Nkeng, G. E. (2018). BIM for construction site logistics management. *Journal of Engineering, Project, and Production Management*, *8*, 47. doi:10.32738/JEPPM.201801.0006

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research*, *39*, 93–112. doi:10.1177/0739456X17723971

Xu, Z., Wang, S., & Wang, E. (2019). Integration of BIM and energy consumption modelling for manufacturing prefabricated components: A case study in China. *Advances in Civil Engineering*, *2019*, 1–18.

Xue, H., Zhang, S., Su, Y., Wu, Z., & Yang, R. J. (2018). Effect of stakeholder collaborative management on off-site construction cost performance. *Journal of Cleaner Production*, *184*, 490–502. doi:10.1016/j.jclepro.2018.02.258

Yin, X., Liu, H., Chen, Y., & Al-Hussein, M. (2019). Building information modelling for off-site construction: Review and future directions. *Automation in Construction*, *101*, 72–91. doi:10.1016/j.autcon.2019.01.010

Yuan, Z., Sun, C., & Wang, Y. (2018). Design for manufacture and assembly-oriented parametric design of prefabricated buildings. *Automation in Construction*, *88*, 13–22. doi:10.1016/j.autcon.2017.12.021

Yunus, R., & Yang, J. (2012). Critical sustainability factors in industrialised building systems. *Construction Innovation*, *12*(4), 447–463.

Zaki, T., Magdy, A., & Nassar, K. (2020). BIM-based bill of quantities generator following POMI and NRM2 methods of measurement. *EG-ICE'20-27th International Workshop on Computing in Engineering*.

Zhai, X., Reed, R., & Mills, A. (2014). Factors impeding the offsite production of housing construction in China: An investigation of current practice. *Construction Management and Economics*, *32*, 40–52. doi:10.1080/01446193.2013.787491

Zhai, Y., Zhong, R. Y., Li, Z., & Huang, G. (2017). Production lead-time hedging and coordination in prefabricated construction supply chain management. *International Journal of Production Research*, *55*, 3984–4002. doi:10.1080/00207543.2016.1231432

Zhang, X., & Skitmore, M. (2012). Industrialized housing in China: A coin with two sides. *International Journal of Strategic Property Management*, *16*, 143–157. doi:10.3846/1648715X.2011.638945

Zimina, D., Ballard, G., & Pasquire, C. (2012). Target value design: Using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics*, *30*, 383–398. doi:10.1080/01446193.2012.676658