

## Article

# Exploring the Use of Lean, Offsite and Simulation in Housing Delivery: Evidence from the UK

Emmanuel Itodo Daniel <sup>1,\*</sup> , Ashendra Nikeshala Konara <sup>1</sup> and Olalekan Oshodi <sup>2</sup>

<sup>1</sup> School of Architecture and Built Environment, Faculty of Science Engineering, University of Wolverhampton, Wolverhampton WV1 1LY, UK; ashendranik@gmail.com

<sup>2</sup> School of Engineering and the Built Environment, Faculty of Science and Engineering, Anglia Ruskin University, Cambridge CB1 1PT, UK; os.oshodi@gmail.com

\* Correspondence: e.daniel2@wlv.ac.uk

**Abstract:** The subpar performance of housing construction projects has been attributed to their reliance on traditional construction methods. In response to this issue, numerous innovative approaches, including modern methods of construction (MMC), have been employed to facilitate the execution of housing projects. The present study explores the use of MMC, specifically lean, offsite, and simulation (LOS) techniques, in delivering housing construction projects within the United Kingdom. Employing a qualitative research approach, eighteen relevant stakeholders from England, Wales, Scotland, and Northern Ireland were interviewed to fulfil the study's purpose. The findings demonstrate that the integration of LOS techniques is advantageous in the delivery of housing construction projects. Moreover, governmental support, collaboration, leadership, training, stakeholder engagement, and environmental consideration were identified as critical factors facilitating the implementation of LOS in housing project delivery. This study provides valuable insights into the key factors that support the adoption of LOS techniques within the UK context and can serve as a guide for stakeholders in the future use of LOS in the UK housing sector. Furthermore, the empirical and qualitative evidence presented on the application of lean, offsite, and simulation (LOS) in housing delivery in the UK can contribute to efforts to address the country's housing shortage.

**Keywords:** modern method of construction; lean; offsite; simulation; housing delivery



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## 1. Introduction

Over 40 years, the construction industry's productivity has fallen worldwide [1]. The construction of residential homes plays a significant role in the construction sector and impacts the quality of life, health and safety of humans and the economic growth of a country [2]. A shortage of houses in several urban areas creates problems, such as high rental prices and poverty, among others [3]. The housing construction process needs to be critically assessed, as the construction process has a direct impact on the operations of the building, which is identified as one of the most important stages of a construction project [4–6]. Additionally, Olanrewaju et al. (2018) [7] and Ritson (2023) [8] pointed out that the housing construction projects in the UK are encouraged to implement energy efficient and sustainable construction methods to achieve the Net Zero carbon targets by 2050. Furthermore, Daniel et al. (2022) [9] highlighted that supply chain management (SCM), issues related to the skills and operations, land matters, opportunistic behaviour, and demand and supply are the main factors which are influencing housing production in the UK construction industry. The limitations of traditional construction methods have been identified as the reason for widening the demand and supply gap of housing delivery in the UK [10]. Over many years, research has been conducted to find applicable solutions to issues in housing construction [11]. These solutions are targeted at revolutionising the methods used in the construction of houses [12].

Over the years, the construction industry has been adopting transformative approaches for residential homes [13]. Examples of such approaches are offsite construction [10], lean construction [14,15] and simulation [16]. Evidence gleaned from the literature shows that the adoption of these methods improves the time, cost and quality performance of construction projects [17,18]. However, the adoption of these methods is still not prevalent in the construction sector [19]. For instance, Mellado and Lou (2020) [20] acknowledged that the barriers to implementing lean construction are technical issues, the lean construction process, and a lack of knowledge (Goh and Goh (2019) [21]; Heravi and Firoozi (2017) [22]), as well as issues with the government, financial drawbacks, managerial problems, and human attitudes. Improving the adoption rate of these innovative methods across the construction industry is necessary to achieve optimal project outcomes [23].

Previous research has documented the applications of the lean, offsite and simulation (LOS) in the construction sector [21,24,25]. However, some of these studies were based on literature reviews rather than primary research. For example, [24,25] were systematic reviews. Mostafa et al. (2016) [25] examined the integration of lean and agile methodologies in offsite construction using discrete event simulation, but their study was also based on a systematic review. Similarly, Daniel and Oshodi (2022) [24] explored the application of LOS in housing delivery, but their study was also based on a systematic review. This shows that limited studies have empirically examined how LOS are collectively implemented for housing delivery, especially in the UK context. To address this gap, the current study was designed to empirically and qualitatively examine the current applications of LOS approaches in housing delivery in the UK. Previous studies have emphasised the importance of using contextualised evidence to drive the adoption of innovative approaches [26]. Therefore, the findings of this study will support the future empirical application of LOS in housing delivery in the UK. The critical questions answered in this study are:

RQ1: What are the current LOS approaches used in housing delivery in the UK?

RQ2: What factors support the use of LOS in housing delivery in the UK?

## 2. Literature Review

### 2.1. Review of the Application of Lean, Offsite and Simulation in Housing Delivery Global Perspective on Housing Delivery

The population's needs are driving up technological requirements in all fields, which in turn determines the demand for high-quality housing and requires the development of new approaches and opportunities for the construction industry [27]. Daniel et al. (2022) [19] highlighted that housing construction issues are globally identifiable and not limited to specific countries. Several factors are affecting housing delivery in the global context, such as financial limitations in Australia [28] and Ghana [29], a lack of resources, skills, and government support in South Africa [30], land-related issues in China [31] and Hong Kong [32], and government policy-related issues in the United Kingdom [33] and Malaysia [34].

When considering the UK specifically, the government is committed to building 300,000 new houses annually to alleviate housing scarcity. This goal has not been met for over five years [35]. A notable aspect that sustains the slow development of housing construction and the existing deficit is the construction sector's persistent dependence on conventional building techniques. Therefore, the House of Lords recommended the modern methods of construction (MMC) [36].

### 2.2. Modern Methods of Construction

The modern methods of construction (MMC) are a promising new approach in the construction sector, but traditional construction techniques remain dominant [37]. According to Duncheva and Bradley (2019) [38], MMC refers to various innovative approaches and technologies to optimise the delivery of construction projects. These approaches focus on enhancing productivity and efficiency, improving customer satisfaction, and delivering high-quality products in a reduced time. Daniel and Oshodi (2022) [24] stated that recent

studies have focused on MMC approaches such as LOS, building information modelling, digital twins, virtual reality, and augmented reality. However, their adoption in the sector is not prevalent. Although many MMC approaches exist, this study focuses on applying LOS approaches in housing delivery.

#### Lean Construction

In 1992, Koskela first introduced lean principles to the construction industry [26]. The concept of “lean construction” aims to manage and improve construction processes while minimizing costs and maximizing value, with consideration for customer needs [39]. Lean construction has been successful in reducing waste and optimizing value in construction projects [40,41]. To address areas of waste, the 5S principles (sort, straighten, shine, standardize, and sustain) have been applied [21,42]. Tools such as smart automation, lean project delivery systems, daily huddles, quality management, Building Information Modelling (BIM), and Human Resource Management have also been implemented in lean construction [43,44].

The Last Planner System (LPS) involves all project team members in balancing workloads and increasing workflow reliability [45]. A detailed weekly work plan, based on project goals and benchmarks, is crucial in managing workflow [46]. Daniel, Pasquire, and Dickens (2016) [47] described the LPS as a lean construction technique specifically designed for architectural and engineering projects. The Value Stream Mapping (VSM) approach is used to identify non-value-adding operations and maximise value delivery to the end user [48]. In modular construction, VSM has been successfully implemented to identify waste and improve efficiency [49].

The just-in-time (JIT) delivery of materials, data, drawings, and other project requirements is essential for successful project management and is considered a lean tool [50,51]. Concurrent Engineering (CE) is another lean tool commonly used in the construction industry, integrating design, construction, and related processes to carry out multiple tasks simultaneously [52]. The Kanban system supports efficient record-keeping and inventory management on construction sites [53].

#### Offsite Construction

Offsite construction (OSC) is a revolutionary approach to the construction industry that has been proven to be more successful in addressing the drawbacks of conventional construction [54]. The offsite concept has been implemented in the construction of houses in numerous countries, including the United States, Australia, China, the United Kingdom, Germany, Sweden, the Netherlands, and Japan [55–60].

Adopting OSC has several advantages, such as enhancing quality, productivity, and safety, lowering labour costs and construction duration, and guaranteeing improved sustainable performance [54]. Numerous factors, including the complexity of the buildings, the manufacturing process, the use of technologies, the logistics system, planning, coordination, and control, set the OSC approach apart from traditional construction methods [59]. The most popular forms of MMC utilised in the construction industry as offsite construction methods are modular/volumetric construction, panelised construction, prefabrication, pre-assembly, and offsite manufacturing and production [60].

#### Simulation

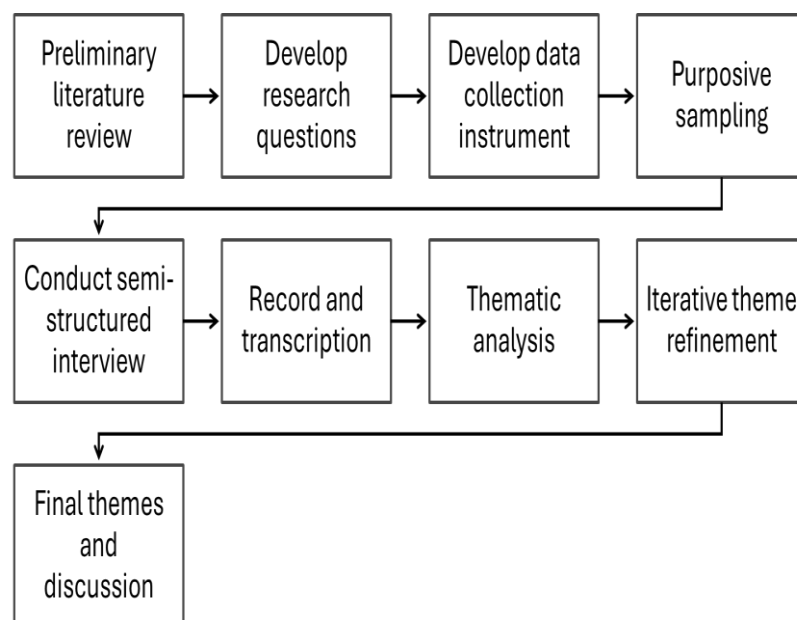
A simulation is a tool used to predict outcomes in terms of cost or completion time before implementation by modelling the behaviour of the actual offsite system [26]. Banks et al. (2014) [61] define simulation as “the imitation of the operation of a real-world process or system over time”. Although simulation techniques have evolved significantly in recent years and are now capable of assisting strategic, tactical, and operational decision-making processes [62], they were primarily developed in the past as a support tool for analysing, designing, and improving companies’ processes [63].

### 2.3. Application of LOS in Housing Delivery and the Study Gap

The literature review shows that LOS approaches enhance project delivery and complement each other [21,64]. However, a limited number of empirical studies have explored their combined use in delivering housing projects in the UK. Previous studies on using LOS in construction projects focus on systematic literature reviews [24,25]. To address this knowledge gap, the current research aims to examine the current applications of LOS approaches in housing delivery in the UK through empirical and qualitative research methods.

### 3. Research Method

This study aims to understand how modern construction methods (MMC), including LOS, are used in housing delivery in the United Kingdom. The study uses a qualitative strategy based on interpretative epistemology [65]. This approach was adopted because the study seeks to understand the current application of LOS in housing delivery from the perspective of relevant construction professionals in the UK. Scholars have confirmed that the interpretivism view is appropriate when a study aims to answer the research questions by aggregating the opinions of critical actors associated with the phenomenon investigated [65]. Figure 1 shows the research process adopted in the study.



**Figure 1.** Framework of the research method.

The data collection began with a preliminary literature review to contextualise the ongoing discourse surrounding the adoption of LOS methods in housing delivery. Spanning across the four nations of the United Kingdom, data gathering primarily focused on stakeholders in England, supplemented by representation from Wales, Scotland, and Northern Ireland, which make up the United Kingdom. Using purposive sampling facilitated the selection of participants from diverse backgrounds, including clients, contractors, property developers, and consulting firms, ensuring a comprehensive exploration of perspectives. Purposive sampling was adopted to ensure only those with the relevant knowledge and experience were included [66]. Participants held various roles within their organisations, ranging from Innovation Managers to Site Managers, reflecting a broad spectrum of insights. Table 1 shows the research participant information. While stratified sampling was not utilised, purposive sampling enabled the study to concentrate on the stakeholders directly involved in modern construction methods.

**Table 1.** Background of research participants.

Participant	Position	Years of Experience in the Housing Sector	Company	Nation of Operation in the UK
P01	Technical Director	20	Architectural	England, Wales
P02	Contract Manager	21	Contracting	Scotland
P03	Consultant	10	Consulting	England
P04	Consultant	8	Consulting	Northern Ireland, England
P05	Bid Coordinator and Best Practice Manager	6	Contracting	England
P06	Director (AMC)	28	Developer	England, Wales
P07	Consultant	25	Consulting	England
P08	Managing Director	25	Contracting	Scotland
P09	Delivery Project Manager	19	Client	England
P10	Process Improvement Manager	25	Consulting	Wales
P11	Innovation Programme Manager	10	Client (Council)	England
P12	Project Manager (OSM)	11	Design Consultancy	England, Northern Ireland
P13	Manufacturing Manager	12	Manufacturing and Contracting	England
P14	Productivity and Performance Manager	30	Contracting	England, Wales, Scotland
P15	Site Manager	6	Contracting	Northern Ireland,
P16	Site Manager Housing	8	Contracting	England, Wales, England
P17	Planned Project Officer	8	Client	England
P18	Quantity Surveyor in Housing	7	Contracting	England, Wales, Scotland, Northern Ireland

The in-depth and semi-structured interviews allowed stakeholders to articulate their experiences and viewpoints. Unlike structured surveys, semi-structured interviews afforded flexibility, allowing participants to elaborate on responses and fostering two-way communication between researchers and respondents [67]. The data collection instrument consists of three sections. The first section asks questions about the background information of the research participants. In contrast, the two other sections focus on research question one: What are the current LOS approaches used in housing delivery in the UK? and research question two: What factors support the use of LOS in housing delivery in the UK? All the questions were open-ended, as this allowed the participant to share their experience on the issue investigated in the study [68]. Ethical clearance was obtained from the university's research ethics board, and prospective participants were approached through professional networking platforms. Consent was obtained from all participants, who were aware of their right to withdraw from the study at any stage.

The interviews were recorded to ensure accurate transcription and continued until data saturation was achieved, indicating redundancy in emerging insights [69]. This was observed following the analysis of the seventeenth and eighteenth interviews, and the data collection was ended. The data analysis followed [70] the six-step qualitative analysis process. Transcript familiarisation was followed by identifying initial codes and then systematically searching for themes aligned with the research objectives. The themes were



iteratively refined through collaborative review among the research team, ensuring rigour and coherence in the analysis process.

#### 4. Result and Discussion

In this section, the findings will be elaborated in detail according to the information gathered from the data collection.

##### 4.1. Current LOS Approaches Used in Housing Delivery in the UK

Several approaches have been identified under the LOS which are currently used in the housing market in the UK. Over the past five years, the use of lean with BIM has increased significantly, with offsite projects being the primary applications of techniques like JIT, Visual management, and the Last Planner System [71]. As specialized knowledge, constant training, and standardisation are essential to apply the combination of LOS in a construction project together, it has been identified as being difficult to execute. It was also highlighted that the demand for the LOS will be decided based on the clients' requirements, design, the budget of the project, location, and many more factors. These approaches will be discussed under each type of application according to the collected data.

##### 4.2. Lean Approaches

When it comes to the lean approach, most of the respondents mentioned the application of lean approaches the most out of all the LOS approaches used in housing construction in the UK. The lean has been identified as a wide subject area, which is a complicated but effective and efficient construction approach currently used, and a trending approach worldwide. Almost all the respondents pointed out various lean approaches, their properties, benefits and drawbacks applicable to the construction industry.

For example, P13 stated that "Without considering the size of the organization, the lean and 5S concepts can be adopted". Further, the respondent explained that the 5S concept is one of the most well-known lean approaches, used not only in the construction sector but also in almost all industries all over the world.

Not only that, but the waste in the construction sites also plays a major role in housing delivery. Some respondents stated: "To manage the deliveries to the site in particular construction projects the JIT is using as a lean technique considering the site condition" [P08]. Elaborating on the application of the lean technique, material usage reduction P05 stated that:

[. . .] from the design stage, as soon as we're involved, we're looking at lean techniques. Whether it's reducing the number of materials that we're going to use in the project to the types of materials that we can use. So, we use technology such as One Click LCA to check new materials on the market.

Another important lean approach identified by the respondents is the just-in-time approach. P06 stated that just-in-time manufacturing is frequently used in the construction industry, especially in housing construction, to speed up construction and minimise wastage in the industry to adapt to lean manufacturing. Some of the respondents stated that:

[. . .] starting to gather the hard data from the completed and ongoing projects which can be used for future construction, project by project, to then feed into our systems, so we can really analyse that data and start working towards some proper JIT (P13).

The study also found that the lean concept needs to be executed in the offsite manufacturing factories, the delivery, the onsite installation, the construction and up until the project handover.

This study's findings pointed out the application of prototyping in housing delivery in the UK. One interviewee stated, "We actually produced two prototypes on our land here at the factory in 2018. The prototypes have been under development since then, and we're

literally, now in the next two weeks, delivering six houses to Sittingbourne, Kent. And we're part of a framework to deliver many more houses within the UK, going forward this year, next and the year beyond." [P13].

Regarding the lean approaches implemented in housing delivery in the UK, one of the interviewees mentioned the first run study, which is used to minimize the delays and defects in the construction industry. The study reveals that this approach will focus more on a construction's design element. By the same token, interviewee [P10] stated "When you give more focus about the design you may do some first run studies and trials and make sure it all fits together, rather than identifying all the problems that typically happen on a normal construction site".

However, lean construction supports the use of weekly and daily work reviews which will help identify the project's status and plan the future works accordingly to minimize any obstacles in the site. Further, this will direct the project team to the success of the project. The interviewee [P02] highlighted that:

"The management team of a contracting company where I worked for several years called all the workers who are involved in the project for the PLOW and the PLOD. Which was Plan Of The Day (PLOD) and, obviously, Plan Of The Week (PLOW). They liked to look ahead, to find out if there were any sort of problems".

Other than PLOW and PLOD, the interviewee highlighted that they can be categorized under collaborative planning. For instance, collaborative planning is identified as a lean approach which helps to find out how teams will work around each other, and even as a decision-making tool before signing contracts and planning meetings.

#### 4.3. Offsite

MMC overshadowed the traditional methods such as onsite constructions, with positive impacts from the inception to the usage of a building in the construction industry. These traditional methods, when adopted, would limit several factors such as the time, the cost, and the quality of the construction projects in the housing delivery. However, this does not mean that the traditional methods of construction do not contribute to the construction industry in the UK. This shows the need to go with the innovative MMC to compete with the day-to-day changing technologies to refine housing delivery in the UK.

Offsite construction is the process of producing parts or modules under controlled conditions in advance and then delivering and installing them at the construction site [72]. The study also pointed out that the offsite is where, as much as possible, the raw materials are processed into some sort of finished product. Most constructors use these offsite products due to the ease of delivery and installation. The offsite construction allows for less time wastage at the site, fewer issues with health and safety, and fewer people on the site, and, especially when it comes to a pandemic situation like COVID-19, this method is helpful for reducing the complications in the construction projects. Interviewee [P8] shared an experience where the materials had high specification requirements. In some instances, offsite construction relieves the constructors by providing a high standard of quality and achieving regulations, such as CDM regulations and Part M regulations.

Furthermore, one of the respondents stated that although there are a few complications with the offsite constructions, 90–99% of offsite orders are in quite good condition [P17]. Additionally, by considering the risk aligned with the construction projects interviewee [P10] suggested:

[. . .] if there's only one supply chain building this using offsite, there's a big risk of something going wrong, so you need multiple people producing similar things so that there's a bit of buffer in the supply chain. There needs to be a buffer somewhere.

For the proper management of the supply chain, sub-assembly parts of the building are then delivered to the site based on the just-in-time approach using offsite construction. Some respondents stated: "When considering construction of one house vs. fifty houses, the construction process is getting complex. Concrete, bricks, mortar, lintels, roof trusses and

other materials need to get delivered to the site when it comes to the traditional building construction". Additionally, P06 pointed out that with the help of the offsite construction, the wastage can be minimised, and resources can be optimized for their utilisation in a housing construction project. As per the information discussed previously regarding just-in-time, it needs to be adapted to the housing construction, while offsite manufacturing is a part of the construction process. The study also found that the concept, design and construction of a house building as a whole model extends the time duration taken to complete the construction due to the lack of prefabrication offsite.

#### 4.4. Simulation

Interviewee [P05] observed, "Basically, there are different techniques in simulation, like discrete-event simulation and steel-system learning, but usually, most of the organisations do not use those because they are really complicated. They need a lot of resources. Simulation is a useful tool for stakeholders to assess the precision and effectiveness of a suggested assembly line design or modification [73]. Other than that, P05 echoed that the simulation needs a dedicated engineering team, which is an additional cost, and no one wants to go for that. So, BIM is also a type of simulation used for clash-detection".

#### 4.5. Lean, Offsite and Simulation (LOS)

Integration of LOS (either partial or full) would be beneficial to the project. This integration provides the project team with information on adapting strategies to mitigate project risks. Interviewee [P10] stated that "Off-site alone is not the answer because you can pre-manufacture something, and it can be wrong on site. So off-site, in coordination with BIM, in coordination with the last plan assistant, for example, getting your teams to talk to each other very early when you're designing and building this, figuring out how you can, maybe, work structuring, so handing different pieces of work to different trades". For instance, LOS can be used to identify the best area to locate a crane for unloading precast components being delivered to a confined site in an urban area.

#### 4.6. Factors Supporting the Use of LOS in Housing Delivery in the UK

Daniel et al. (2022) [9] highlighted that integration of LOS would add value to the process of housing delivery. Additionally, the study identified several factors which will support the use of LOS in housing delivery, as shown in Figure 2.

Some of the respondents stated that:

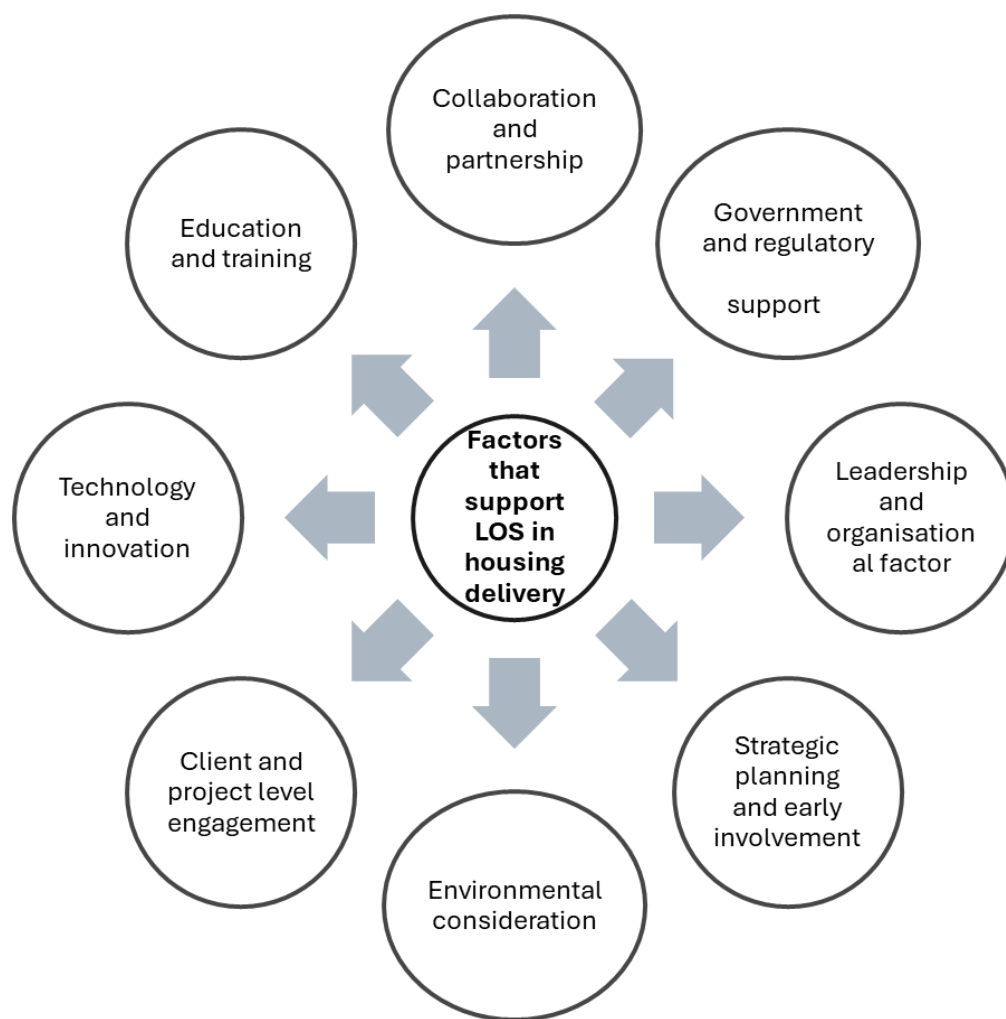
In the construction industry, these three construction techniques play a significant role. If you get something wrong with one component during the construction process, that is then going to be replicated across all the components. If it is the standardised components, you would need to really test that using the lean and BIM models. So, the two of them work very well together. They should be used in tandem otherwise you are not going to get the efficiencies that you are looking for [P5].

Furthermore, P3 highlighted that with the implementation of offsite and BIM, the construction of buildings may achieve the expected outcomes while highlighting the benefits. One of the interviewees stated that:

[...] these approaches, LOS definitely should be used in tandem otherwise you are not going to get the efficiencies that you are looking for [P5].

The factors that support using LOS approaches in housing delivery are discussed below.





**Figure 2.** Factors supporting LOS approaches in housing delivery.

#### 4.6.1. Government and Regulatory Support

The study found that the government is trying to provide the necessary support to ease the process of the delivery of housing projects. P02 also elaborated that, through legislation, the government could force clients to mandate modern methods. Pasquire et al. (2006) [74] pointed out that even though innovative construction methods are introduced to building construction, stakeholders are reluctant to implement those modern construction methods for several reasons. Some of the respondents stated that:

From an external factors perspective, I think most importantly is for significant encouragement to come from the government. If there is significant encouragement from the government then organisations can key into these better. If the government encourages housing, government encourages off-site, government encourages simulation, adoption of lean on projects [P03].

[...] the last element is about that external factor that you mentioned which I think maybe you can now bring in government support here to drive the innovation and consultation with suppliers and external entities as well [P04].

Apart from that, the government needs to pay attention to the education and training of construction professionals, as this should be the requisite to the adoption of modern construction approaches such as LOS [P04]. Similarly, some respondents stated that:

Homes England do own masses of land all over the country and if they're supplying their land for private developers as well, they'll insist on the same legislation that, 'If we are supporting, then you must go down this route of MMC.' So, yes, whether it will become

legislation or, you know, that is just the way they expect you to do business with them is you've got to go down this route [P06].

However, some of the respondents pointed out the requirement of government incentives for construction projects with offsite construction.

It's the Government, Homes England, stepping in and not insisting, well, they are insisting that any projects they support from a monetary perspective have to be delivered using 25% minimum of MMC [P06].

Other than the encouragement of the government and the regulatory bodies, the study identified the importance of government funding in the housing construction delivered using MMC. Some of the respondents stated that:

I feel like we can add the underlying factors like, for instance, a lack of appropriate, you know, government funding to invest in social housing to begin with, it can be identified as a stringent or as a foreign factor or, you know, high cost of renting and income or home ownership, if you like, it's also contributing to that fact [P04].

#### 4.6.2. Collaboration and Partnership

Regarding collaboration and partnership in supporting the LOS application in housing delivery, one of the interviewees said, "Well, it definitely needs to be created in, sort of, collaboration with the key players in the industry out there, so for example, constructing Excellence and the Supply Chain School" [P05]. Furthermore, it highlights the requirement of developing a proper framework with the industry players. Jin et al. (2017) [75] explained that stakeholders with the power to either advance or impede a construction project's progress, including design teams, clients, contractors, and project managers, can be considered as industry players. These identified stakeholders can be considered as the industry players in housing delivery. Some respondents made statements regarding the application of supply chain capacity to deliver and collaborate with the LOS application in housing delivery.

So, I think some of it is capacity in the supply chain. And I think it's more of a case of just working with them to see, you know, not rejecting it outright but actually working with the supply chain to find out what's going wrong and what can be done to change what their process is, their quality process is, to make things better [P05].

As an example, one of the respondents highlighted the importance of having partnerships during the construction process with the experience gained during the housing delivery.

[...] from a housing project, the one in Shrewsbury was quite groundbreaking in a number of ways because we worked with, and at the time I worked with an SME, as a director at another SME design manufacturer of façade systems and we were moving into the housing market during the year when Grenfell happened and, you know, the atrocities that took place there [P06].

#### 4.6.3. Leadership and Organisational Factors

Saving the project cost can be identified as one of the major benefits of implementing LOS in the construction sector [76]. Similarly, Interviewee [P10] stated that practicing of LOS can be used for the construction cost management of the project, but in the initial stage of introducing such an MMC it will be expensive, as the startup stage is not always easy. Furthermore, P10 explained the concept of introducing champions in a project, particularly for LOS. For example, when it comes to LOS in a construction project, the project team may appoint a lean champion, offsite champion and/or BIM champion who has excellent knowledge and experience in the relevant field to monitor the progress of the project or the supply chain. The study found that these specified champions will not be working in a particular office or a permanent workplace; they will focus on the specialized field of work only, and overall supervision could not be expected from them.

#### 4.6.4. Educational and Training Initiatives

The study found out the importance of educational and training initiatives as a highlighting factor supporting in implementing the LOS approaches in the housing delivery. Some of the respondents stated that:

And with regard to project level, I think clients' education on the long-term benefit of the off-site production and its process and procedure and so on will be quite key because lack of knowledge or understanding from also the client is a key [P04].

This can be identified as an education of the client on the benefits at the project level of housing construction. This means not only the clients, but all the stakeholders involved in a housing project need to have the proper knowledge throughout the project construction, from the inception to the completion, for a successful housing project delivery. Furthermore, one of the respondents described that delivering knowledge and understanding to the professionals involved in a housing project can be carried out through different identified ways, such as constructing excellence, supply chain school, own channels, etc. [P05].

So kind of networking with a lot of different organisations to make sure that that message goes out to wider industry that it can be done and it can be done well [P05].

Mesároš and Mandičák (2015) [28] elaborated on the importance of having proper knowledge of the positive impacts of combining MMC with housing delivery, recent advanced technologies used for housing construction, and the economic viability of implementing innovative construction methods, etc, for successful project completion. As an example, some respondents stated that:

So, we have been working with the Supply Chain Sustainability School to develop some learning pathways to help them. There are different events that they can attend, and they also provide one on one support to different companies so we kind of invest in that and make sure that our supply chain partners are bought with us on that journey [P05].

The above statement shows the importance of proper education and connecting with the construction industry and how it might benefit housing delivery. For the past few decades, the UK housing market has seen a shortage of houses and a sharp increase in demand [77]. Aneesa et al. (2015) [78] pointed out that supply chains play a vital role in housing delivery as they are interconnected with the client, suppliers, and customers for the successful flow of materials, information, and other required resources. Some of the respondents mentioned Supply Chain School, which is an organization and one of the main contractors, who support the up-skilling of the supply chain on topics such as sustainability, offsite, and digital builds in the construction industry. In addition to the study, the Supply Chain School has tons of learning materials on all the related topics to the construction industry, not only about MMCs such as LOS, but also other construction techniques such as Digital Twin, etc.

MMC has been applied more frequently in the housing industry in recent years in an effort to address the current housing scarcity and enhance building quality considering the identified benefits to the housing delivery [79]. The study also reveals the requirement of basic knowledge about the benefits of implementing the MMC in housing delivery. One of the respondents stated that:

Because if they're taught about the benefits of using that approach, then if they do go into construction or architecture, that is going to be at the forefront of their minds. So absolutely, I think education is really key to make sure that people are learning the best practice that is going on in the industry, and not just from their particularly, sort of, traditional managers perhaps [P05].

#### 4.6.5. Technology and Innovation

Another critical factor influencing the LOS approach usage in housing delivery is technology and innovation. The study reveals the importance of applying modern technologies and innovation to the construction industry, especially for housing construction in the UK. Kuklina et al. (2021) [80] explained that the construction industry cannot expand without cutting-edge technologies. As a result, modern measuring tools, automated control systems,

BIM technology, computerised and automated systems, etc., are used in the building sector to implement technological procedures [80]. Furthermore, the study reveals that digital methods can be utilised to check the quality of the prefabricated elements produced using the offsite construction approach. One of the interviewees stated that:

And also, the digital side of things, all the factories are using the same digital tools to check the quality. So, we've got-, you can check the quality right from the factory, right through to when it's installed, and then in operation and in use. It's all of those three things I guess, kind of, that is made it a really good project [P05].

#### 4.6.6. Client and Project Level Engagement

The participants in this interview pointed out that the client is the main focus in a construction project as we are doing the construction based on clients' requirements. Similarly, AlBarami et al. (2020) [81] explained that the construction operations determine whether a project is successful, or if the client significantly impacts failure. However, a construction project consists of multiple stages from inception to completion, where the client is involved in almost all the stages. Despite this, several stakeholders are also involved in a housing project throughout the construction process, which can be categorised under design, construction, and operation [82].

This does not only apply to the construction project stages, as it is also essential to work through different scenarios with the client at a really early stage; as Interviewee [P05] described,

[. . .] early engagement is key to be able to consider all of those things, sort of, simultaneously, and make sure that you've got the right supply chain to deliver an efficient proper housing project with use of LOS [P05].

The study also shows different types of clients in housing construction. Some may have adequate knowledge and experience about the building construction processes, while on the other hand, some clients may have zero knowledge regarding the same processes, considering that P05 highlighted the need for MMC workshops to increase level awareness of MMC among clients. Understanding the construction process would increase support for implementing these techniques, such as LOS.

[. . .] we personally do MMC workshops with clients at a really early stage, so even if they're just thinking about doing a scheme, and we kind of take them through the different things that they have to think about at each stage. So, whether it's during the design, whether it's logistics they have to think about, what can and cannot be done from an off-site perspective [P05].

#### 4.6.7. Environmental Considerations

Buildings are one of the top seven sources of resource consumption and emissions into the atmosphere [83]. Chau et al. (2007) [84] explained that in comparison to other life-cycle stages, building construction has typically resulted in emissions and impacts that are roughly equivalent, due to significant material utilisation and significant emission contributions [85]. Some of the respondents stated that:

[. . .] we consider, like, where it's not in London we'll consider, sort of, near-site manufacturing facilities as well to bring it closer to site, so obviously you're not using as much carbon with the deliveries back and forth, so that is something that we'll consider as well. Factory location to reduce carbon footprint [P05].

#### 4.6.8. Strategic Planning and Early Involvement

Involvement in the early stages is essential for successful project completion, especially regarding housing construction. However, the Royal Institute of British Architects (RIBA) has also elaborated seven categories of MMC through the RIBA work plan of 2020. Under that, it clearly mentioned the importance of the involvement of the project teams in different stages for particularly identified tasks. Additionally, one of the respondents stated that "so you need to think about it as first thing. So, it is no good waiting until RIBA stage four-

you know, it is too late, so you need to, like the architect and the client need to think in the first instance or get a contractor on board early so that you can think of using these systems and tools and processes right from the outset because they do need to be planned and they do need to be thought about" [P05]. This shows that early involvement at RIBA stage one may lead to better inputs and the effective application of LOS construction techniques for housing delivery in the UK. Similarly, Wondimu et al. (2016) [86] pointed out that early contractor involvement is usually considered to impact the outcome of the construction project positively. Furthermore, by incorporating contractors' early involvement in the process, the MMCs that are evolving are intended to eliminate such common challenges.

On the other hand, strategic planning also has a considerable impact on LOS application in housing delivery in the UK. As discussed earlier, the Supply Chain Schools are playing a vital role in housing delivery as they have significant learning materials on all these three construction techniques in detail. Strategic planning is required to maintain the construction sector's growth [87]. Additionally, the study reveals that a predetermined framework would be able to guide the implementation of LOS for proper housing delivery. For example, some respondents pointed out that "the framework needs to be created in, sort of, collaboration with the key players in the industry out there, for example, Constructing Excellence and the Supply Chain School" [P05]. One of the interviewees described that:

Through strategic planning a framework can be developed to apply those three approaches, LOS, which would definitely be helpful for the people who are involved in the project [P05].

In addition to that, a developed digitalisation was identified by the interviewees, and due to that, the construction industry is moving towards the prefabrication and BIM approaches. The study also reveals that when the sector facilitates MMC it will act as a new model, combining the LOS as one unit for housing projects. Some of the respondents stated that:

It will encourage the integration of this newer models that will also harness the supply chain management or, if you like, the downstream players with these upstream players together and then once they are integrated or enhanced then I think you are looking at better productivity and so on [P04].

Regarding the factors that support the LOS approaches in housing delivery, one of the interviewees pointed out the accreditation of offsite manufacturing as an important fact. When it comes to housing construction, quality cannot be overshadowed. Because of that, the quality control needs to be monitored adequately from the inception up to the demolition stage of the building. Considering that one of the respondents stated "The fact that potentially if you were going to use off site there's only a certain number of suppliers. It's getting those qualities accredited as well" [P05]. Furthermore, interviewee P05 explained that:

[. . .] I know BOPAS has done quite a lot of work towards that now in making sure that off-site manufactured buildings can be accredited, but I know that was a problem in the past, and still continues to be fairly significant now. I guess those are probably the main reasons.

## 5. Conclusions

This study explores the use of LOS in delivering housing construction projects in the UK. Although LOS has been adopted as a stand-alone, it is not prevalent in the construction sector. The study found that government support, collaboration, leadership, training, stakeholder engagement, environmental considerations, and early stakeholder involvement support the implementation of LOS. The results of this investigation show that using LOS improves the outcomes of housing construction projects.

The evidence from this study suggests that LOS can be adopted as a practice to improve the outcome of housing construction projects. Such improvements would address the shortfall in housing supply, especially in urban areas. However, using LOS is not a noticeable practice in the construction industry. The government and its procurement



agencies can make ‘willing to implement LOS’ one of the selection criteria for public-funded housing projects. These projects would provide evidence to justify the implementation of LOS in the delivery of housing projects. The present study lays the groundwork for future research into identifying the ‘best’ way to implement LOS to achieve optimal outcomes for housing projects.

Being limited to interviews, the findings cannot be generalised to a larger population. Despite its exploratory nature, this study offers some insights into the benefits of using LOS to deliver housing projects. Considerably more work [based on an action research approach] will need to be done to showcase the benefits of LOS to housing projects. Unless the construction industry adopts innovative methods, the shortfall in housing supply will keep increasing.

Furthermore, based on the review, it is evident that the studies focused on using LOS in housing delivery and were limited to the UK context. Even though the construction industry is practising several MMCs, with the information from the literature review and the collected data, the research was focused on the current LOS approaches used in the construction industry limited to housing construction projects. Most notably, the lack of the availability of construction projects practising LOS approaches together was a significant limitation in the housing projects.

Recommendations for future research projects

This study suggests the necessity for the following areas to be considered in further research:

- Impact of LOS approaches in housing delivery: UK context
- Challenges to implementing LOS approaches in the UK construction industry.
- Strategies to overcome the challenges of implementing LOS approaches in the UK construction industry.

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