CONSTRUCTION SITE LAYOUT PLANNING METHODS; AN ANALYTICAL REVIEW

Abstract

Designing an effective construction site layout planning is essential to the successful implementation of construction projects. Construction site layout planning involves the optimal layout of facilities (i.e., fixed, and temporary facilities). Several techniques are used in addressing the construction site layout planning problems. With the advent of the different techniques used in addressing these problems, three major categories have been identified in this study: knowledge-based models, mathematical models, and hybrid models.

Most of the reviewed peer-reviewed articles in this study focused on static construction site layout planning problems, while a significant number also focused on dynamic site layout planning problems. Nearly all the reviewed articles focused on solving the objective function of the optimal layout of facilities. Furthermore, this study made use of a systematic review to extract essential data from the reviewed articles. Analytical data on the research methods, improvement focus, construction site layout planning problems, methods and objective functions were identified and critically analysed to assist practitioners in the industry and future research.

Keywords: *cost, improve focus, optimisation objective functions, productivity, safety, site layout planning techniques.*

INTRODUCTION

Construction site layout planning (CSLP) is a crucial part of the construction planning process. Construction sites usually witness the presence of different facilities at different stages of the construction process. These facilities are usually fixed or temporary. The facilities are required on the construction site to perform construction activities (Abunemeh et al., 2017). The location and distribution of these facilities during construction are influenced by the available space's size on site. Also, at different stages of construction, the types, and dimensions of facilities available onsite can vary. For instance, during construction operations on most projects, many temporary facilities are needed. Such facilities will have to be located within the available space on site, with the locations of the facilities having an impact on critical success factors like productivity, safety, and cost throughout the construction process (Wang et al. 2019; Benjaoran and Peansupap, 2020).

Inadequate facilities layout onsite during construction can increase the cost of construction and project completion time because of the additional resources needed to dismantle and relocate facilities on site (Huang and Wong, 2015). This can further affect safety, construction productivity, and space utilisation (Soltani and Fernando, 2004; Dhanure and Pathak, 2016). Therefore, factors like cost, safety and productivity are critical factors for designing an effective construction site layout plan (Ning and Lam, 2013). Hence, to enhance productivity and safety and reduce cost during construction, facilities' optimal layout is critical (Adrian, Utamima and Wang, 2015).

METHODOLOGY

This study adopts a systematic literature review of the extant literature on construction site layout planning techniques and tools in Scopus's electronic databases, Web of Science and Science Direct. The systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2010). A systematic review is a well-established approach in reviewing and synthesising literature and justifying outcomes from the review process. Systematic reviews have been used to investigate different issues in construction site layout planning (Al Hawarneh, Bendak, and Ghanim, 2020; Xu et al., 2020).

The systematic review has widespread popularity in conducting secondary studies in construction. In a recent systematic review article, Xu et al. (2020) argue that systematic review offers a scientific approach in exploring existing studies, identifying knowledge gaps, and making recommendations for future research opportunities. Likewise, Hasan et al. (2018) identify the advantages of the systematic review method in conducting secondary studies. An advantage is that it avoids unnecessary study duplication. Another advantage of using systematic review is that it allows the reproducibility of the research process.

Scopus's electronic databases, Web of Science and Science Direct, were searched for articles published in peer-reviewed journals in English related to construction site layout planning techniques and tools. A structured,

open, and reproducible protocol based on the PRISMA approach was adopted to select extant literature on construction site layout planning techniques and tools from the search databases. The sourced journal articles were reviewed using the PRISMA protocol of identification, screening, eligibility, and review to carry out a replicable systematic review on construction site layout planning and techniques.

Potential articles to review in the study were collated using an initial screening approach that relied on the titles of the journal articles returned by the search databases based on the study's inputted search criteria. Next, a comprehensive search using the field "Title, abstract, keywords – layout, site planning, techniques, tools, construction" was conducted. A total of 197,138 titles were retrieved from the two search databases and the Google search engine. Consequently, 89 articles were retained after a comprehensive review of the articles using the Title and Abstract elimination process. Additionally, duplicate articles from the search were removed. Afterwards, a total of 71 articles were retained as unduplicated.

Furthermore, a selection of final journal articles to review was selected from the Abstract, Introduction and Conclusion stage, and the full article review was conducted on the final selection of the forty-seven (47) journal articles. Out of the unduplicated 71 articles, 21 articles were excluded because they were not relevant to the study as they focused on other areas of construction and not construction site layout planning. Likewise, one conference paper, PhD thesis and book chapter were excluded from the study as they did not fall within the pre-defined search criterion of articles published in peer-reviewed journals. Finally, necessary data were extracted from the selected 47 journal articles for detailed analysis. See Appendix 1 for the list of articles reviewed in this study and Figure 1 for a detailed graphical illustration of the systematic review process.

The reviewed articles are presented based on their improvement focus, objective functions, construction site layout planning problems and methods in this study. Finally, a significant amount of this study focused on the types of construction site layout planning problems addressed in the selected articles, and the techniques and tools that were used and the variables they considered. This study discusses these themes in the subsequent sections and provides a detailed synthesis and analysis of the reviewed articles.

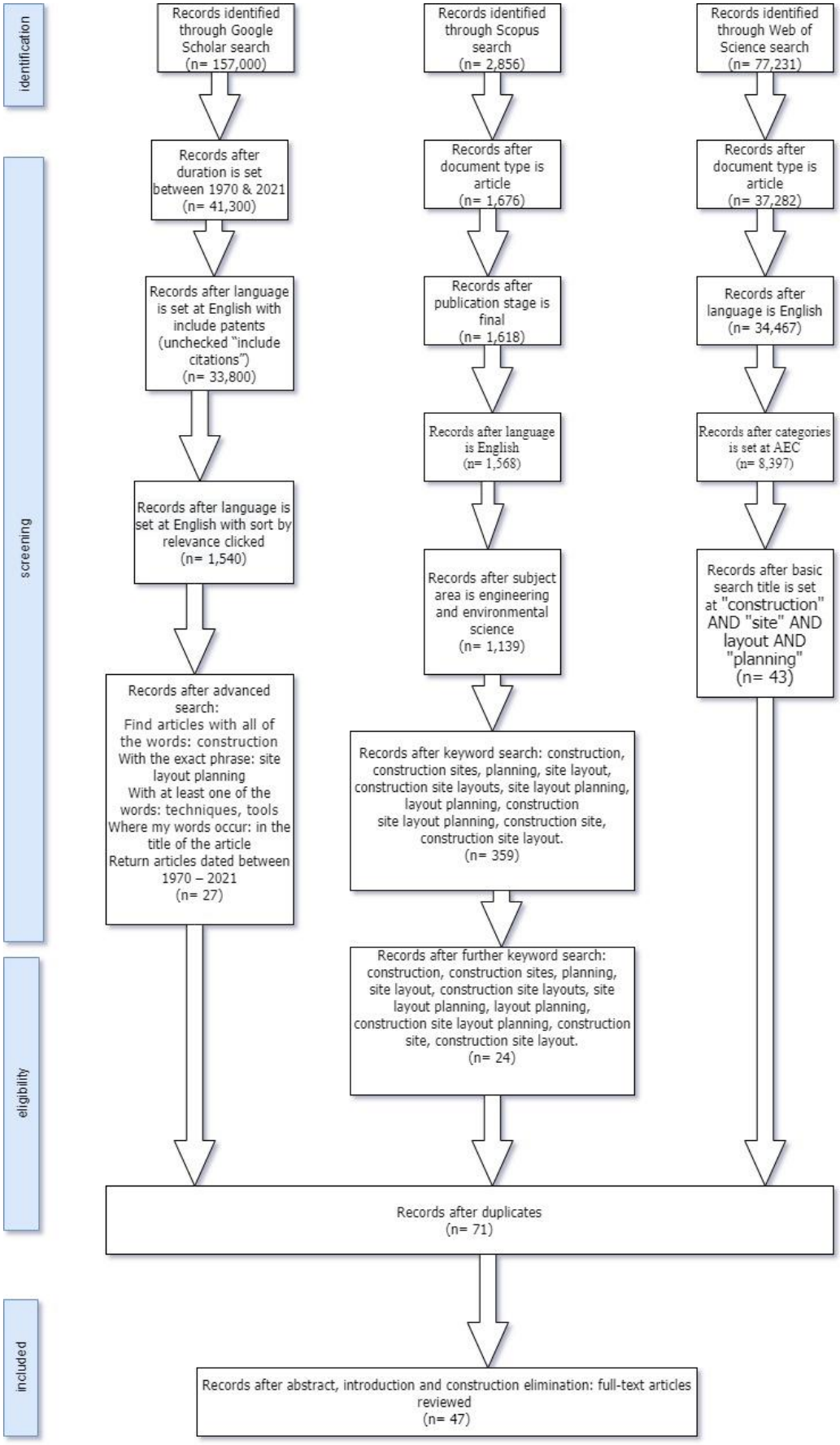

Figure 1: Flow diagram of study selection.

ANALYSIS OF THE REVIEWED ARTICLES

The reviewed articles in this study are categorised into three main categories and subcategories, respectively. These categories are based on the focus areas in which they suggested that the improvements they propose will occur. These focus areas are (1) productivity, (2) cost, and (3) safety. The subcategories are (4) cost and productivity, (5) cost and safety, (6) productivity and safety, and (7) cost, productivity, and safety.

Figure 2 depicts the percentage of areas of improvement focused on in the reviewed articles and the number of articles within each improvement focus area. As shown, 11 articles (24%) have a principal focus on productivity, while 11 articles (24%) have a principal focus on cost, and two articles (4%) have a principal focus on safety. Additionally, four articles (8%), 14 articles (30%), two articles (4%), and three articles (6%) have a simultaneous focus on cost and productivity, cost and safety, productivity and safety, and cost, productivity, and safety, respectively.

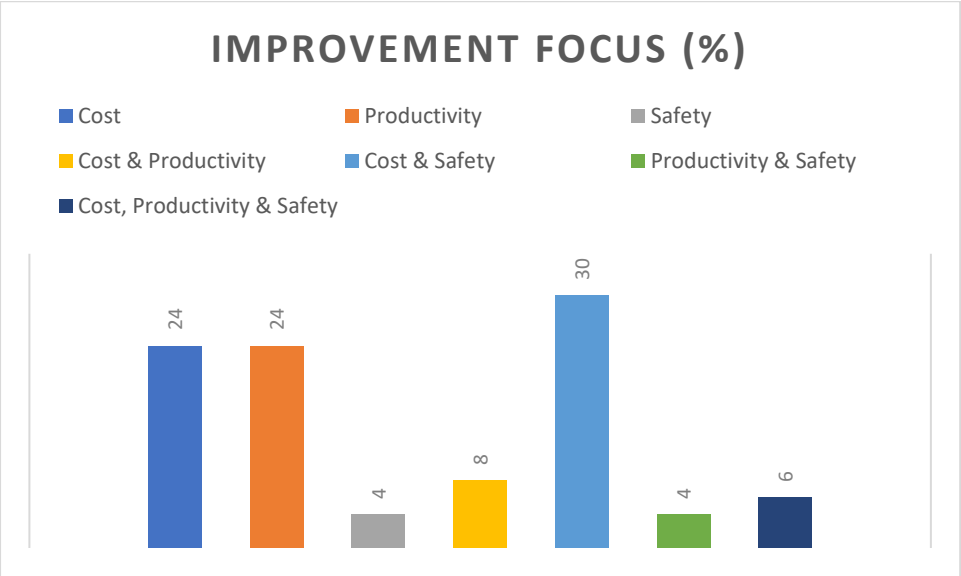

Figure 2: improvement focus areas of the reviewed articles

Cost

Cost is a crucial factor in completing a construction project (Atkinson, 1999). Unfortunately, multiple factors influence construction cost, making estimating the final cost of a construction project extremely difficult. For instance, such cost factors include project type, material cost, design and scope changes, onsite conditions, project duration and size, client type, and tendering method (Ahiaga-Dagbui and Smith, 2012). However, it has been suggested that effective construction site layout planning can significantly impact a construction project's cost (Mawdesley et al., 2002).

According to Huang and Wong (2015) and Khalafallah and El-Rayes (2020), recent studies show that efficient layout of construction site reduces material handling costs and minimises the travel times of workers, materials, and equipment onsite, among others. For instance, Hammad, Akbarnezhad, and Rey (2016) suggest that the optimum layout of facilities on construction sites reduces transportation costs. Likewise, the optimal layout of facilities during construction can minimise travel distance between them and reduce transportation flow and costs (Lam, Tang and Lee, 2005; Lam, Ning & Lam, 2009; Ning, Lam & Lam, 2010). Different models have been used in the optimal layout of facilities, and these include knowledge-based, mathematical and hybrid models in construction site layout planning.

In this study, 24% of the reviewed articles focused on using construction site layout planning to reduce cost. However, 30% and 8% of the reviewed articles focused on improving cost along with safety and productivity, respectively. In contrast, 9% of the reviewed articles focused on improving cost and productivity and safety at the same time.

Productivity

Productivity is crucial to the growth of the construction industry. The significance of productivity in optimising profits and reducing construction costs is essential to the construction industry. Several studies have been conducted on construction productivity (Hasan et al., 2018). Various factors impact productivity in construction, and there is a need to understand and identify what those factors are to understand project performance in construction (Atkinson, 1999; Choy and Ruwanpura, 2005; Ghoddousi and Hosseini, 2012). Many factors that influence productivity in construction have been proposed (Hasan et al., 2018); one of such factors is optimal facilities layout in construction site layout planning.

According to Elbeltagi and Hegazy (2001), the activities between two facilities significantly impact onsite productivity on construction sites. These activities include the location of equipment, materials handling, personnel movements, and information exchange between the two facilities. For instance, an optimal facilities layout on a construction site will minimise the travel routes between the facilities and lead to improved productivity (Soltani and Fernando, 2004). Also, a construction site's layout affects the overall construction operation productivity (Wang et al., 2019). Thus, Construction site layout planning is crucial to the productivity and safety of construction operations throughout the different construction project stages (Hammad, 2020).

An effectively planned construction site layout will increase construction productivity and maximise space utilisation during construction (Dhanure and Pathak, 2016; Adrian, Utamima and Wang, 2015; Ning, Lam & Lam, 2010). In this study, a significant percentage (24%) of articles reviewed focused on using construction site layout planning to improve construction productivity. However, only 8% of the reviewed articles focused on improving productivity and cost simultaneously. At the same time, 6% of the reviewed articles focused on simultaneously improving productivity along with safety and cost.

Safety

Safety in construction is a critical objective function in construction site layout planning (Anumba and Bishop, 1997). Safety planning is a crucial consideration in the construction industry as the industry suffers the highest number of job-related fatalities globally. According to International Labour Organisation (ILO) (2021), the global construction industry contributes a disproportionately high recorded accidents rate compared to other sectors. Also, a Health and Safety Executive (HSE) (2020) Report states that in Britain between 2017 and 2020, 3.5% of construction workers suffered work-related ill-health against 3.4% of workers across all industries.

El-Rayes & Khalafallah (2005) argue that the construction industry's high fatalities rates call for the need to develop advanced and expanded construction site layout planning techniques optimised for safety planning during construction. Likewise, effective construction site layout planning is crucial for efficient safety planning during construction (Ning et al. 2010; Ning et al. 2018; Hammad, 2020). For instance, Xu & Li (2012) suggest that using construction site layout planning to maximise the distance between high-risk and high-protection facilities will enhance safety on construction sites. However, in this study, only 4% of articles reviewed focused on using construction site layout planning to improve safety during construction. However, 30% and 4% of the reviewed articles focused on improving safety along with cost and productivity, respectively. In comparison, 6% of the reviewed articles focused on improving safety and productivity and cost simultaneously.

DISCUSSIONS

Findings from the reviewed articles show that different construction site layout planning techniques impact construction cost, safety, and productivity. For instance, Knowledge-based methods provide a comprehensive approach to site layout which makes it very efficient. However, it still relies heavily on the construction site layout planning designer's expertise, and solutions cannot be duplicated in other projects easily since no two sites are similar (Elbeltagi & Hegazy, 2001). In their study, Osman et al. (2003) integrate CAD with GA to address the optimisation problem of onsite transportation cost between facilities to minimise cost. However, the study only addressed a mono-objective and could not address secondary objectives due to its design limitations. Likewise, the CAD system presents the solution in a 2-dimensional manner against 3-dimensional visualisation presentations that will present near realities of a real construction site. In a similar study, Lam, Ning, and Ng (2007) made assumptions that are very unlike a typical situation on a construction site and focused on a static construction site layout planning problem even though construction sites are usually dynamic.

The study by Soltani and Fernando (2004) considered a static construction site layout planning problem even though it recognised the dynamic nature of the construction site and identified that the optimisation analysis tool is limited in its capacity only to be used effectively for small and medium-sized projects. However, the study simultaneously investigates issues around transport cost, safety risks, and visibility on site. This is a rare combination of factors to consider in a single study, and this suggests that many studies can be investigated considering similar factors. Similarly, in the study by El-Rayes & Khalafallah (2005), the construction site layout planning model positively impacted cost but experienced a trade-off in safety. Likewise, this study's various optimisation algorithms can be extended to address multi-objective optimisation problems in construction site layout planning, focusing on the different critical factors to successful site layout planning and simultaneously solving both static and dynamic site layout planning problems.

Furthermore, in their study, Lu et al. (2007) focused on activities and workflows during construction by integrating them with the site layout. However, it did not focus on only site layout planning. The study took a step further to consider what it would look like to integrate the actual workflow onsite into an existing site layout planning while considering a few construction site layout planning variables. This study can provide further research opportunities for onsite layout planning optimisation but can be improved upon by considering a dynamic construction site layout planning problem and not a static one. Similarly, in their study, Ning et al. (2010) explored an area that most studies have not by evaluating different site layout planning using multiple objectives and determining the best use case. However, the study still relied heavily on the use of 2D drawings.

CONCLUSIONS

Future efforts should consider applying construction site layout planning models in simultaneously solving static and dynamic problems onsite using different techniques. This approach will allow researchers to compare the different methods and their impact on construction site layout planning. For instance, such comparative analysis could involve applying knowledge-based models and mathematical models to develop hybrid models to address static and dynamic construction site layout planning problems within the same study. Additionally, the models can be integrated with other emerging technologies like costing and scheduling software, visualisation, and cloud-based technologies to improve critical success factors like addressing pre-planning problems in the design, track cost and safety levels during construction, enhance communication and collaboration among onsite workers and construction teams in construction. Future research should consider onsite factors and constraints like space utilisation, unequal space availability, regular and irregular shaped geometry of facilities, and vertical facility layout in construction site layout planning.

In conclusion, there is a consensus from all the reviewed articles that optimising the layout of facilities throughout the construction process should be used for construction site layout planning. For example, Kumar & Cheng (2015) suggest that construction site layout planning techniques that optimise facilities layout should be favoured above the conventional techniques. These non-conventional techniques complement the conventional methods but are more flexible and efficient in planning dynamic site layouts (Soltani and Fernando, 2004) and help site planners design optimal site layouts (Lam et al., 2009).

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