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A REVIEW OF BIM-BASED APPROACHES FOR SITE LAYOUT PLANNING IN SPACE-CONSTRAINT CONSTRUCTION PROJECTS

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ABSTRACT

The Construction site layout planning is a critical determining factor of project efficiency, safety, cost, especially the projects that are located at complex and confined environment. In space-contained sites, conventional (manual and 2D planning) techniques often fall short in fulfilment of the project demands. This review looks at a critical synthesis of advanced methodologies whereby Building Information Modelling (BIM), particularly 4D BIM, is integrated with computational optimization and generative design (GD). This paper analyzes the shift from static planning to dynamic and data-driven planning, it also discusses the heuristic methods (Genetic Algorithms, Particle Swarm Optimization), and Lean Construction. BIM offers deep, rich data that can be visualized and analyzed. GD can point us toward an effective solution or an optimized solution. However, much of the research in these two fields is done separately, not together. This paper highlights the significant potential of an integrated framework incorporating 4D BIM, generative design, and optimization to be able to automate and optimize CSLP. This paper identifies existing research gaps, such as the need for better data interoperability and real-time dynamic adjustments and outlines a trajectory toward more integrated and intelligent CSLP solutions.

Keywords: 4D BIM, Generative Design, Construction Site Layout, Optimization, Genetic Algorithms, Particle Swarm Optimization, Lean Construction, Automation, Data Interoperability, Confined Sites

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1. Introduction

Construction Site Layout Planning (CSLP) is critically essential, in the architecture engineering construction (AEC) industry, to optimize efficiency, safety and cost (Mei et al., 2025). A proper site layout minimizes the material handling time, and creates smooth workflow, resulting in increased productivity and reduced safety issues (Mei et al., 2025). Conversely, poor layout planning can result in longer material handling times, congestion, lower efficiency and higher costs (Mei et al., 2025) CSLP is an acronym that stands for construction site layout planning. It is the planning of temporary facilities (TFs)- the offices, materials and equipment storage areas, and locations for various equipment- on a construction site to reduce transportation distances and to improve productivity and safety, which eventually benefits workers and contractors (Mei et al., 2025).

CSLP faces distinct challenges in urban construction projects, such construction sites are confined, limited, surrounded by urban infrastructures, residential buildings, and busy streets. Space becomes a luxury (in such environments) and often limited one (Ciribini et al., 2016). In addition, the confined site makes resource allocation, traffic control, and safety very difficult to organize (Ciribini et al., 2016). The traditional method of Construction Site Layout Planning (CSLP) utilizes static and manual plans that may not be effective, due to the constantly changing and complex requirements of construction projects, particularly in limited spaces (Bortolini et al., 2019). In modular construction projects, a unique challenge, unseen in ordinary cast-in-situ construction works, is the handling of spatial requirements for prefabricated elements, lifting equipment, and exact timing between off-site manufacture and on-site assembly (Bortolini et al., 2019).

Building Information Modeling (BIM) has a significant potential for improving CSLP particularly through 4D BIM which is the 3D model integrated with a time dimension (Delci, 2023)(Mazars & Francis, 2020). BIM technology makes construction visualization, simulation, and planning easier, leading to more accurate planning. The use of 4D BIM assists in visualizing the spatial layout of the construction site by determining the locations of each object for a planned period which leads to better utilization of physical space (Delci, 2023)(Mazars & Francis, 2020). Additionally, BIM provides data support for CSLP, overcoming the limitations of traditional manual operations through automated data extraction and modification (Mei et al., 2025)(Jang et al., 2023). For example, BIM can efficiently estimate the input parameters required for CSLP, thereby increasing planning precision (Mei et al., 2025).

In recent years, there is increasing adoption of optimization algorithms, generative design and automation techniques, specifically for the temporary facility placement (Wefki, Salah, et al., 2024). For instance, there are studies that combined BIM and GD to respond to CSLP problems and optimize construction site layouts (Wefki, Elnahla, et al., 2024). Automated generative design, by using graph convolutional neural networks, integrated into BIM proved to enhance construction efficiency in modular construction (Vahdatikhaki et al., 2022). A hybrid framework which combines System Layout Planning (SLP) and Genetic Algorithms (GA) have provided solutions for multi-objective CSLP optimization (N. & Padala, 2024).

Despite, Building Information Modeling (BIM) utilization has increased, there is still not enough research in 4D BIM with generative design and complex optimization methods for construction site layout planning, specifically for space-constrained, multi-phase construction projects. (Mei et al. 2025)(Wefki ,Elnahla et al 2024)(Essam et al 2023) Currently, researchers use these methodologies mostly separately which makes it a complex and un-unified field and framework. as it cannot keep up with the most complex site layouts in the most dynamic construction environments (Mei et al. 2025)(Wefki, Elnahla et al 2023) (Essam et al., 2023).

Therefore, this review aims to synthesize existing research findings, identify the most effective strategies, and delineate future research directions, with the goal of developing more integrated and intelligent CSLP solutions.

2. Methodology of Literature Selection and Analysis

This study, "*A Review of BIM-Based Approaches for Site Layout Planning in Space-Constraint Construction Projects*" utilizes a semi-systematic literature review strategy that facilitates the identification, analysis, and synthesis of existing studies on 4D BIM, site layout planning, temporary construction facilities, and simulation on confined construction sites.

A peer-reviewed journal article's search was systematically conducted on Scopus, Web of Science, ScienceDirect and the ASCE Library regarding the literature review process. The strong coverage of high-impact journals in construction management and digital engineering was the criterion for selecting the databases. The search concentrated on articles published between 2010 and 2025 due to the wide adoption and maturation of BIM, 4D model, and generative optimization method during this period. The different combinations of keywords are BIM, construction site layout, 4D BIM, temporary facilities, space-constrained site planning, crane position, generative design, construction logistics, and lean construction.

To ensure academic rigor, only articles which are published in journals that are rated within Scopus Q1 or Q2 pertaining to field were included. These journals include those of *Automation in Construction, Advanced Engineering Informatics, Journal of Construction Engineering and Management* and *Engineering, Construction and Architectural Management*. To be considered suitable for analysis, the study had to cover at least one of the following areas: BIM-based site layout planning, temporary facility placement, 4D simulation of crane positioning, lean logistics or generative design, confined construction site or urban construction site. The review did not include any conference papers nor thesis nor technical reports nor non-English publications nor any other study not related to spatial constraints and BIM-enabled site layout planning. Papers that only did structural analysis, estimation of cost or safety training and did not integrate site logistics or temporary facilities were discarded as well.

The chosen papers were read in full to extract relevant details such as research aim, level of BIM application (3D, 4D, clash detection, crane reach analysis, etc), nature of temporary facility layout problem, use of optimization algorithms (genetic algorithm, particle swarm optimization, mixed-integer programming or generative design via Dynamo and Grasshopper, etc) and whether any lean construction principles were used (waste reduction, Just In Time, efficient use space, minimize movement, etc). The synthesis of studies was undertaken and grouped on thematic similarities following which BIM based site layout visualization, site logistics optimization, 4D simulation for construction sequencing, use of crane and material flow analysis and integration of lean and generative design principles to spatial efficiency improvements on constrained sites was observed.

The literature selection procedure was done in two steps to ensure reliability; the first one is done through screening of titles and abstracts, and the second one are full text of those elected papers. Duplicate articles across databases were eliminated. The studies that were selected focused only on challenges regarding temporary facility layout, construction planning in confined site areas, optimization by means of BIM, simulation tools, etc. As a result of this systematic review protocol, it is expected that the review findings will emerge from studies with scientific rigor, thus instilling confidence in their findings which will be based on credible and high-quality studies.

3. Research Gaps and Limitations in Existing Studies

Current research on BIM-enabled construction site layout planning has come a long way but it still has limitations. This is especially true for space-constrained projects. In most of the previous research use of BIM or optimization algorithms, the layouts are usually static, which assumes that enough open space is available for setting up the facilities. These models tend to fail when site boundaries are confined. Additionally, in constraint sites, temporary facilities require reallocation as the phases evolve. This missing capacity to adapt to time is an important gap, particularly in case of high-rise buildings constructed in diverse built environments which require leapfrog sequencing or phased construction.

Moreover, there is another gap in the linking of BIM, optimization and 4D simulation. Many studies use optimization techniques like genetic algorithms, particle swarm optimization or mixed-integer programming to find the best locations for a crane or facility. However, these outcomes seldom align with 4D construction schedules. This means the optimization is not tested through simulated time-dependent conditions and remains theoretical. Very few studies have included 4D BIM to verify whether optimized layouts are still valid during actual construction schedules. Not many studies deal with the relocation of the site offices, cabins, or storage facility during the progress of construction, in-spite of being a critical need at sites with space constraints. In addition, the current BIM methods do not use lean principles for waste minimization, reduction of movement of materials and efficient space utilization. These methods focus on the reduction in the cost or travel distance of materials, without considering the space waste caused due to large footprints of facilities.

There isn't much research on the integration of BIM with generative tools like Dynamo or Grasshopper which can automatically generate and evaluate multiple layout alternatives under strict spatial constraints. According to the few studies that exist that use generative approaches, these are focused more on design than logistics on-site.

4. Site Layout Planning in Construction

Site Layout Planning for Construction (CSLP) can help in ensuring successful implementation, enhancing productivity, ensuring safety and cost control of the project. It involves the identification, sizing, and strategic positioning of temporary facilities, such as offices, warehouses, material laydown areas, and equipment zones, within a construction site. Effective site layout profoundly influences on-site transportation, construction logistics, and overall safety (Tsegay et al., 2023).

CSLP aims to make the construction work more efficient, by optimizing the layout of temporary facilities, which eventually results in lower construction costs. A well-organized site layout benefits work environment, productivity and consequently the project success (Xu et al., 2020). CSLP presents a complex, multi-objective optimization problem that substantially increases in scale with the number of facilities and constraints (Xu et al., 2020). Proper planning has a direct link to construction efficiency, while inadequate planning leads to excessive material handling times, bottlenecks and less productivity and leading to more costs (Xu et al., 2020)

A construction site layout consists of different temporary facilities and areas such as:

1. Cranes: Cranes have an immense impact on the execution of construction as well as its preparation costs. Their strategic positioning with lifting points is crucial for smooth construction processes and low costs (Xu et al., 2020). 2. Storage Area: Generally, most of the material that moves at a site relates to storage areas. The hoisting and storage of prefabricated components are essential and critical consideration for modular construction, underscoring the importance of well-organized CSLP which will help improve productivity and safety (Liu et al. 2024). 3. Site Offices, and relevant zones: The Strategic arrangement of these temporary facilities and zones such as Site Offices, Warehouses, Equipment Areas, Waste Management Areas, Safety Zones, and Access Routes can assist in optimizing the project. The placement of these temporary facilities can have a substantial impact on the material handling and operational cost, which is a major source of indirect cost in a construction project (Xu et al., 2020).

In traditional CSLP approaches project managers' experience and expertise are the predominant drivers (Xu et al. 2020). Many planners still use manual methods for construction method selection and site layout planning (Xu et al, 2020). Traditional methods have many limitations; data entry takes long time due to the manual aspect of the work. In case of design and construction plans alteration, it requires manual effort to enter the altered data (Hmidah et al., 2022). Conventional two-dimensional (2D) layout methods are unable to guarantee the safety of large-scale hoisting operations (Rodrigues et al., 2022). The dynamic nature, complexity, and inherent uncertainties of construction projects diminish the accuracy of input parameters (Xu et al., 2020). Researchers have introduced various computational techniques to tackle the limitations of traditional methodologies; Genetic Algorithm (GA) is a widely used algorithm to optimize CSLPs and it is capable of multi-objective optimization (Xu et al., 2020). For instance, SLP-GA integrates System Layout Planning with GA to optimize CSLP (Xu et al., 2020). The Particle Swarm Optimization (PSO) method is also utilized in the CSLP to minimize the travelling distance between facilities and alleviate the risks of safety (Xu et al., 2020) (Khalili-Fard et al., 2024). Ant Colony Optimization (ACO), An improved Pareto ACO algorithm can address multi-objective, dynamic, and unequal-area CSLP problems (Xu et al., 2020)(Lin & Hsieh, 2022). Fuzzy-based Bee Colony Optimization (BCO) models can be employed to consider multiple objectives such as cost, safety risks, and noise pollution (Xu et al., 2020)

Simulation-based decision support tools can assist in enhancing site layout planning, especially when construction projects involve inherent uncertainties and complex relationships between influencing factors and decision variables (Ding et al., 2024).

CSLP faces unique application challenges in urban construction environment, some of these challenges are as follows:

1.Limited space: Urban sites are often surrounded by existing buildings, and busy streets. (Tsegay et al., 2023). 2. Complex dynamic constraint: crane constraint, site constraints, and construction schedule are all dynamic and evolve over time (Xu et al., 2020). 3.Material handling and safety: Managing prefabricated components and lifting equipment within limited spaces and coordinating off-site manufacturing and on-site assembly at the right point in time, presents challenges (Chen et al., 2021). 5. Risk Assessment: It is necessary to evaluate and address potential hazards, such as fire and explosion waves, to minimize risks (D. Kim et al., 2024) (Yan et al., 2024).

Inadequate site layout planning can have multiple negative impacts such as reduced productivity, project delays, and elevated costs (Xu et al., 2020).

As technology advances, the CSLP is being led away from 2D planning techniques. The methodology known as Building Information Modeling (BIM) has gained popularity for use in the Architecture, Engineering, Construction and Facility Management (AEC/FM) industry (Waqar et al., 2023)(Lee et al., 2016). According to the findings, BIM tools are responsible for site layout 3D visualization and optimization (Hmidah et al. 2022). BIM facilitates data for CSLP, and based on the design data, site managers and planners can better understand the site layout (Z. Wang & Liu, 2020)(A. Li et al., 2024).

Semantic technologies, enhance the accuracy, effectiveness, and creativity of spatial layout design by separating knowledge of objects, spatial relationships, and constraints from the generative process (Hmidah et al., 2022). Data-driven approaches such as Crane-centric

CSLP decision-making methods, when combined with BIM, can automate data extraction and optimize hoisting operations (Xu et al., 2020). Unmanned Aerial Vehicles (UAVs) can be utilized for 3D reconstruction in dynamic site layout planning for large construction projects, particularly for mapping hoisting areas in petrochemical plant construction (Chen et al., 2021). BIM-GIS integrated frameworks can dynamically optimize construction site layouts to minimize multiple objectives (Chong et al., 2016).

These advanced methods aim to address the complexities of traditional CSLP, improve planning efficiency, and better adapt to the dynamic changes and multi-objective optimization requirements in construction projects (J. Li et al., 2024)(F. Li et al., 2023).

5. Lean and Generative Design Concepts

The integration of lean construction and generative design inside building information modeling derives a new approach to optimize site layout planning in space-constrained construction projects. Lean Construction focuses on eliminating waste and enhancing efficiency in movement of workers, materials, and data. It aims at delivering 'just-in-time' materials and creating a fit-for-purpose product (Moradi & Sormunen, 2023) (Aziz et al., 2024). Waste in construction includes unnecessary movements, waiting time, overproduction, defects, and unused workers' capacity. The lean methodologies aim to reduce or eliminate these wastes (Moradi & Sormunen, 2023). Lai

According to lean philosophy, in the context of site layout planning, it requires an efficient arrangement of temporary facilities to reduce travel distance, material handling time and cost, enhance safety and productivity (R. Li et al., 2025)(Kumar & Cheng, 2015)((Abdelalim et al., 2024)(Farmakis & Chassiakos, 2017)(Papadaki & Chassiakos, 2016). Poorly planned layouts can lead to increased material handling times, bottlenecks, reduced productivity, and ultimately higher costs, directly contradicting lean objectives (Borges et al., 2024). For instance, the placement of materials and equipment based on just-in-time principles can help reduce waiting time and unnecessary transportation which are critical waste elements in lean thinking (Cheng and Chang,2018). Additionally, lean strategies support flexible site layout planning, in which the location of temporary facilities is modified over various phases of the construction process to meet changing requirements, ultimately ensuring efficiency and waste minimization of operations over the project life cycle (Ismail et al., 2025)(Tao et al., 2022)(Sing et al., 2021)(Andayesh & Sadeghpour, 2014).

Generative Design (GD) and algorithm-driven optimization are potent methodologies to achieve these lean objectives in construction site planning. GD makes use of some computer algorithms to automatically generate several design alternatives by using a set of rules, aims, and restrictions (Semjén and Szép 2025). This paradigm moves the focus from designing manually to automated exploration of design spaces, thereby opening pathways for identifying optimal designs that may be missed using manual design (K. Li et al., 2024). In the construction site layout planning, GD can make use of various computational tools like Dynamo, Grasshopper, and evolutionary algorithms to study complex and combined problems (Mohammed Fathy et al., 2022) (Xu et al., 2020). An instance of these tools is using genetic algorithms (GAs) to optimize multi-objective functions, such as travel distance minimization and safety maximization to evolve optimal layouts through natural selection (Borges et al., 2024)(Abdelalim et al., 2024)(RazaviAlavi & AbouRizk, 2021)(Papadaki Chassiakos, 2016). Similarly, Ant colony optimization (ACO), which is inspired by ants foraging behaviors and it is used to find optimum paths and layouts addressing challenges like unequal area allocation and dynamic conditions (Ning et al., 2011)(Y. Li, 2018)(Calis & Yuksel, 2010).

BIM and GD combination make it easier to assess data regarding on-site planning. Building Information Modelling (BIM) is a rich central repository of project data. GD algorithms can access precise information regarding site topography, building geometry, material requirements, construction scheduling (R. Li et al., 2025)((K. Li et al., 2024)(Kumar & Cheng, 2015)(Zavari et al., 2022)(Le et al., 2019). This interoperability allows for dynamic updating and evaluation of layout alternatives against lean performance indicators. For example, a BIM-integrated framework can automatically extract data on temporary facility types, dimensions, and quantities, which are crucial inputs for GD algorithms to generate and optimize layouts (M. Kim et al., 2021).BIM can visualize the layouts it generates and check them against the site constraints and operational requirement (Schwabe et al., 2019).

Generative design supports lean principles directly by eliminating waste, by optimizing the layout of temporary facilities and specifying the paths through which materials flow, GD reduces the movements which is considered a major contributor to waste in construction (Abdelalim et al., 2024)(Wefki, Elnahla, et al., 2024). GD evaluates different layouts promptly and presents a design that can optimize and minimizes waiting time for equipment, workers and materials supply, which leads to improved workflow (Farmakis & Chassiakos, 2017)(Mohammed Fathy et al., 2022). The ability of GD to consider various constraints and objectives simultaneously, such as safety distances, access routes, and storage areas, also contributes to reducing rework and preventing accidents (Abdelalim et al., 2024)(Wefki, Elnahla, et al., 2024). Advanced generative models, such as those based on Generative Adversarial Networks (GANs), have generated more realistic and context-aware designs for urban sites or building elements; further potential for wastage reduction (Chai et al., 2024).

Although the integration of BIM, Lean, and Generative Design shows promise for temporary site layout planning, several research challenges and limitations persist. One key challenge is the development of comprehensive datasets for advanced generative model training, specifically for unique or complex construction scenarios (Yang et al., 2024). The inherent complex nature, construction site layout planning entails an array of dynamic changes, conflicting objectives, and space and time constraints require sophisticated algorithms able of handling high-dimensional problem spaces (Farmakis & Chassiakos, 2017)(Ning et al., 2011)(Xu et al., 2020). Due to these complexities, traditional optimization methods do not often help, and deep learning must be used (Soliman et al, 2025).

In addition, the limitation of data interoperability of BIM-based GD still requires manual methods to extract data and update models (Kumar & Cheng, 2015). Despite BIM environment is data rich, however the integration of these data with generative design tools and downstream analysis for lean metrics remains an active area of research. The effective translation of qualitative lean principles into measurable requirements and constraints for GD algorithms also remains a challenge and requires a robust framework which can balance both the qualitative and quantitative factors in optimization (Le et al., 2019). The adoption of such advanced technology, used in construction industry, is hindered by organizational and cultural barriers and adoption processes are complex within AEC organizations (Chowdhury et al. 2024).

The transition from manual, experience-based planning to automated, AI-driven solutions require overcoming resistance to change and ensuring that practitioners are adequately trained in these new methodologies (Borges et al., 2024)(K. R.* et al., 2020). The long-term implications of design changes, which are often unpredictable, also highlight the need for intelligent systems that can predict the impact of such changes on cost and schedule, further integrating machine learning into the BIM workflow (Abdulfattah et al., 2023).

6. BIM-Based Optimization and 4D Integration

Building information modelling (BIM) has basically transformed the construction site layout planning (CSLP) and temporary facilities arrangement, particularly in projects with limited and confined space (R. Li et al., 2025)(Schwabe et al., 2019). BIM offers a digital foundation and backbone to the architecture, engineering and construction (AEC) industry, enabling project's data handling and visualization throughout a project's lifecycle (Khattra et al., 2021)(Muñoz-La Rivera et al., 2020)(Pan & Zhang, 2022). Its implementation in CSLP involves optimizing the placement of temporary facilities, cranes, storage zones, access routes, and cabins which have a major impact on enhancing and minimizing materials transport inefficiencies. (R. Li et al., 2025)(Schwabe et al., 2019)(Nguyen, 2020) The traditional methods of CSLP often require lengthy data extraction processes and advanced mathematical modeling, which are often fragmented and incompatible with specialized software (R. Li et al., 2025). BIM integrates geometric, physical, functional, and economic data that allow for more efficient planning and management of site resources and facilities (Cui et al., 2024). As BIM models are comprehensive, which make it easier to simulate and analyze several construction scenarios, allowing for better and more informed decisions regarding the placement and sizing of the temporary facilities (Borges et al., 2024)(Zavari et al., 2022).

The inclusion of temporal dimension alongside the three spatial dimensions into BIM, termed as 4D BIM, further enhances its utility in CSLP by linking construction elements with a schedule to simulate the progress, logistics and space usage over a period of time (Cheng & Chang, 2018)(Rehman et al., 2025). Through this dynamic visualization, of construction activity over time and its impact on the site layout, stakeholders would be able to manage constraints and congestion of urban projects (Boton et al., 2022). 4D BIM simulations assist in spotting and identification of potential clashes and inefficiencies such as temporary facilities overlap and delivery clashes. (Rehman et al. 2025). For instance, it can model the dynamic allocation of construction materials, as well as the adjustment of layouts based on project phases, thereby mitigating reduced-efficiency, inflated costs and unnecessary loss of time (Cheng & Chang, 2018). Studies indicate rapid expansion of the 4D BIM in construction industry- due to its prospective in enhancing visualizing planning and managing resources (Rehman et al., 2025).

In constrained urban sites BIM is widely used for modeling and simulating the movement of essential equipment and resources. This simulation includes the detailed modelling of the cranes, cabins, storage zones and access routes for better optimization and placement (Li et al. 2025) (J. Wang et al. 2015). For example, a data-driven lifting-centered CSLP approach with BIM can integrate tower crane characteristics, which are often inadequately considered in traditional planning (Li et al., 2025)(Wang et al., 2015). This will help to evaluate the crane reach, load trajectories, and interference with other objects on-site (Liong et al., 2023). Visuals of these operations in 3D environment with schedule or time sequencing provide clarity to plan for complex lifting operations while complying with essential safety regulations (Liong et al. 2023)(Rashidi et al. 2022). Similarly, BIM-based frameworks have been created that can automate site layout planning in congested areas while minimizing travelling distance for on-site workers and machines (Kumar & Cheng, 2015).

The use of different optimization techniques in CSLP significantly enhances the efficacy of 4D BIM. These techniques include population-based algorithms such as Genetic algorithms (GA) and particle swarm optimization (PSO) which are utilized for optimal or near-optimal solutions for complex CSLP problems (Nili et al., 2021)(Borges et al., 2024). Multi-objective optimization models are useful for CSLP since they facilitate the assessment of contradicting objectives like minimizing costs, maximizing safety and lowering environmental impact (Zavari et al. 2022)(Nguyen 2020). A hybrid framework for multi-objective CSLP, in which Systematic Layout Planning (SLP) is combined with GA to optimize site temporary facilities placement (Borges et al. 2024). The optimization techniques may either be integrated within the BIM systems or from external computational tools such as Dynamo, Grasshopper, MATLAB and Python (Seghier et al., 2025). The data from BIM model, including geometric data, attribute data, provides essential input which enables data-driven decision making (Cui et al. 2024).

The operational planning aspect of 4D BIM is further improved by advanced features such as clash detection, crane reach analysis and cabin relocation simulation. It allows for the identification of spatial and temporal conflicts between temporary facilities and permanent structures or construction activities (Rehman et al., 2025). The ability to track progress is essential to mitigate risk and delay during construction, which is increasingly being applied in phased construction sequences (e.g. leapfrogging and zone-based sequencing) in large or complex projects (Rehman et al., 2025). The capability to visualize a construction project throughout the entire construction process can enhance clash detection compared to a static 3D model. For example, machine learning can be integrated with BIM to assess the effects of design changes and assist in clash detection and resolution (Abdulfattah et al. in 2023).

Lean construction principles can effectively utilize BIM for sophisticated data management to reduce waste and optimize values (Rivera et al. 2020) (Waqar et al. 2023). Generative design provides multiple design options based on predefined rules and objectives, leverages BIM's parametric modeling capabilities to automatically generate and evaluate numerous site layout configurations (Salah et al. 2023). For instance, the automation of 4D BIM development by resource specification and optimization algorithms to estimate the time of construction components on building projects (Fazeli et al., 2022). Such integration allows for a more efficient exploration of design spaces and the identification of highly optimized solutions for complex site logistics (Salah et al., 2023).

Despite all the significant improvements, BIM-based optimization workflows face many limitations and research challenges. A common problem is the rigid nature of prescriptive schedules, which usually fail to adapt to fluctuating and dynamic nature of construction site; as a result, the actual work proceeds differently than the optimized plan (Nili et al., 2021)(Fazeli et al., 2022). The manual transfer of optimization results back into BIM environments remains a bottleneck, time-consuming and prone to errors (Li et al., 2025)(Kumar & Cheng, 2015). Additionally, there is a lack of automation capability for dynamically adjusting temporary facilities in response to rapid project iterations or unforeseen situations and conditions (Li et al., 2025). This necessitates continuous human intervention, limiting the real-time responsiveness of the system. Future research needs to focus on enhancing real-time data integration, developing more adaptive scheduling algorithms, and improving the automation of temporary facility relocation and adjustment within BIM environments to fully control its potential in space-constrained construction projects (Li et al., 2025)(Hiltunen et al., 2023).

7. Future Direction

Future research must go beyond layout modelling and explore the development of adaptive, time-dependent site planning systems which automatically update the layout as construction moves vertically or horizontally across zones. There's a need for connecting generative design tools (e.g. Dynamo/ Grasshopper) with BIM and construction scheduling software to create self-updating and rule-based layouts that can move around facilities as space becomes available. The incorporation of construction phasing systems such as scaling and/or zone-based construction using 4D BIM and optimization processes permit a much more realistic simulation of the site logistics and space constraints. In future work, layout optimization could incorporate lean construction principles aimed at minimizing waste due to transportation and material handling as well as improving the spatial efficiency of the construction site. Research should also include realistic constraints like crane reach limits, emergency routes, material delivery paths and dynamic safety clearances, which are seldom discussed in academic studies. Validation in the real-world through case studies, sensor data or digital twins should be undertaken to increase reliability and industry relevance. With the help of BIM (building information modelling), generative algorithms, artificial intelligence and automated decision-making; the future of site layout planning in space-constrained construction may be improved significantly.

8. Conclusion

The study of BIM-based methods for the planning of confined construction projects indicates that, though digital means importantly improved visualization, planning and communication on construction sites, their application in the highly space-restricted urban environment remains incomplete. Current research shows that in conjunction with scheduling tools and optimization techniques, BIM can be used effectively for crane positioning, material logistics and site facility planning. However, most of these approaches are static, site-specific and do not adapt to the changing spatial availability through construction life cycle. Previous studies lack integration of generative design, lean construction principles and 4D BIM simulation, as well as dynamic relocation of temporary facilities such as site cabins, stores and equipment zones. This review shows how important it is to have a framework that is more comprehensive and versatile. Many studies either study cost or travel distance as the main objectives but other vital components such as space and layout adaptability which are important in dense urban construction are ignored. The results support the need for a generative BIM and 4D simulation integrated approach, as proposed in the main research, to determine the placements of temporary facilities using objective criteria such as minimal spatial footprint, safety clearances and logical construction sequence.

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