Current Trends in Construction Site Layout Planning

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ABSTRACT

Site personnel or construction workers will spend most of the construction time within construction sites. If construction workers be able to easily and quickly move within the site, it helps to save time and increase productivity as well as safety. Optimizing the cost, safety, and productivity of a project often relies on the optimal planning of the construction site layout. However, site layout planning, unique for each construction project, depends on many variables such as work areas and facility locations. To optimize work place usage and minimize construction conflicts, participants on a project must consider the constraints that each construction project entails. Currently, the concept of an optimized construction site layout has no clear definition, so practitioners do not have specified guidelines or policies that govern the construction site layout. Therefore, the purpose of this paper is to assess current practices for site layout planning and highlight the need for a rule-based approach to evaluating construction site layouts. The results presented in this paper can provide construction firms with a better understanding of why a rule-based system is important in site layout planning.

Keywords: Site Layout Planning, Optimization, Rule-based checking system.

INTRODUCTION

The placement of materials, facilities, and equipment within a construction project space is referred to as “site layout planning” (Pheng and Hui 1999). A site layout consists of the footprint of a building, parking and storage areas, access roads, and temporary facility locations (Marx and König 2011). An optimized site layout plan ensures the optimum usage of available space, lower project costs, less relocation of materials during construction, better accessibility to and security of a site, and safety of the work environment. To develop an optimum construction site layout, a construction manager takes into account various factors, many of which interfere with the site layout planning. Depending on the variables, each project has its own unique site layout plan (Tam et al. 2002). The first and most important variable of site layout planning, which drives decisions in reference to site logistics, is the actual size and location of the site. A list of the important variables that affect site layout is shown in Fig.1.

Because each project requires a unique set of variables, planning a site layout is a multi-objective task that varies from one construction phase to the next. Thus, site layout planning should be a dynamic activity in a three-dimensional (3D) model of a
site (Ma et al. 2005). In other words, a 3D-based site layout plan can facilitate the planning of a dynamic construction site layout during different phases. To better visualize a site layout space, a site manager can use a building information model (BIM). In addition, BIM can help identify potential safety hazards resulting from the movement of cranes or the placement of temporary facilities (Sulankivi et al. 2009) and simulate existing constraints. To control existing site layout constraints in a BIM-based model and represent a site layout plan, 3D site planning objects such as cranes, material storage, and parking areas should be created. In addition, to check the accuracy of the developed plan, a rule-based checker that evaluates situations such as security, worker circulation, and lighting needs to be generated. The review of the current state of the art shows that limited research has been devoted to rule-based checking systems for site layout designs. Therefore, the purpose of this paper is to provide an overview of current and emerging trends in site layout planning and emphasize the need for a rule-based site layout checking system. First, this paper investigates previously developed approaches for site layout planning and then explores the future trends of site layout planning.

**Figure 1. Construction Site Layout Variables**

**PREVIOUS STUDIES**

A significant amount of research has focused on the path of worker and machinery movement as well as the placement of temporary facilities and material storage areas within a construction site. In the following sections, this paper discusses several efforts toward optimizing the site layout domain.

**4D Simulation Site Layout**

The construction process is dynamic, so day-to-day changes are expected. Thus, anticipating an appropriate and optimal site layout plan from a static model is challenging. For example, if an excavator digs a trench to install a site utility, every location where a trench is dug is a potential location that will interfere with ongoing work on a construction site. Moreover, the trench may cross roads, access points, lay down areas, or even other trenches. To prevent this situation from occurring, a project manager should pay special attention to areas where several utilities intersect with
temporary/permanent roadways, sidewalks, building, entries, material lay down areas, and crane locations; however, with 4D models, project managers can have a clear and dynamic view of a work space. A number of researchers have developed 4D simulation models that provide project managers with a better and more efficient visualization of a dynamic construction site. An effective 4D model contains the following:

- Future buildings
- Roads and infrastructure that will affect the project, either inside or outside of a site’s boundaries
- New access roads, sidewalks, and building entries, which will preclude future excavation
- Temporary infrastructures such as security fencing, crane pads, and access roads
- New and existing underground utilities
- Temporary facility locations

The process of space allocation for construction activities is time consuming and costly. Time-space conflicts create a variety of problems such as constructability issues or delays in the construction process. To specify the required space for construction activities and manage time-space conflicts, Akinci et al. (2000) represented a 4D WorkPlanner, which first detects clashes within specified working areas and then aggregates detected time-space conflicts. In the next step, it classifies conflicts into various categories such as design and safety conflicts and then categorizes them based on their severity. Such a system enables project managers to anticipate potential spatial conflicts at construction sites and provides a solution before the start of a construction project. Furthermore, to simplify the process of locating the place of a work request, Taneja et al. (2010) modeled a WLAN-based localization framework via fingerprinting algorithms. Their proposed framework resulted in a more precise value for localizing and predicting user locations. To develop a real-time management of the workspace of a construction activity, Chavada et al. (2012) established a 4D/5D model by integrating the project schedule with the BIM data of construction models. Likewise, Ma et al. (2005) integrated schedules, 3D models, resources, and site spaces with 4D computer-aided drawings (CAD) to develop a 4D graphical visualization for dynamic site layout planning. Compared to 2D drawings, such a system allows users to better visualize site layout plans, but lack of functionality of data exchange standards does not allow users to share data with other 4D systems (Ma et al. 2005).

Chau et al. (2005) found that a huge number of current 4D approaches lack some aspects of constraints such as resource management and data exchange. Hence, to provide a more comprehensive system for construction planning, they integrated the work breakdown structure, the 3D model, scheduling, resources, and decision support tools. Marx and König (2011) identified essential constraints such as construction methods, building and building site layout, and material movements, which are required to provide construction simulation. The construction simulation facilitates the effective management of the current schedule or the creation of a new one; however, it has some limitations such as the capability of applying changes in the planned layout while simulating it (Marx and König 2011; Zhang and Li 2010).
In the past few decades, many researchers have focused on the potential use of information technology in the 4D simulation of site layout planning. Digital technologies such as artificial intelligence (AI) (Elbeltagi et al. 2001), virtual reality (VR) (Heesom et al. 2003), and building information modeling (BIM) (Chau et al. 2005; Chavada et al. 2012; Ma et al. 2005) can be widely applied to optimize construction site layout planning. For example, by combining artificial intelligence tools, Elbeltagi et al. (2001) modeled a system that depended on the schedule for site space allocation. Such a system offers optimized site layout alternatives for different construction phases. Table 1 summarizes some of the current and emerging research on the 4D simulation of site layout planning.

Table 1. Sample of the Application of 4D Simulation on Site Layout Plans

<table>
<thead>
<tr>
<th>Year</th>
<th>Tools/Techniques</th>
<th>Features</th>
<th>Citation</th>
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<tbody>
<tr>
<td>2012</td>
<td>Critical Path Method, 3D model and BIM</td>
<td>Application of 4D/5D model for real-time management of activity execution workspace</td>
<td>(Chavada et al. 2012)</td>
</tr>
<tr>
<td>2011</td>
<td>SiteSim Editor (an interactive 4D tool for construction simulation)</td>
<td>Investigation potential constraints for construction simulation</td>
<td>(Marx and König 2011)</td>
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<tr>
<td>2005</td>
<td>3D model, schedule, work breakdown structure, resources and site spaces</td>
<td>Development a 4D simulation system for site layout and facilities placement</td>
<td>(Ma et al. 2005)</td>
</tr>
<tr>
<td>2005</td>
<td>3D model, schedule, resource stencil (including material, labor, site, and equipment), work breakdown structure</td>
<td>Implementation of a 4D site management model for site space utilization</td>
<td>(Chau et al. 2005)</td>
</tr>
<tr>
<td>2004</td>
<td>AutoCAD (3D model) and schedule</td>
<td>Developing an approach for layout of site facilities by integrating 3D model with scheduling data and resources</td>
<td>(Chau et al. 2004)</td>
</tr>
<tr>
<td>2003</td>
<td>AutoCAD (3D model), Unified Classification for the Construction Industry (UNICLASS), schedule</td>
<td>Formalizing a system to visualize construction space usage in a 4D environment</td>
<td>(Heesom et al. 2003)</td>
</tr>
<tr>
<td>2002</td>
<td>3D model, schedule, project spaces</td>
<td>Presenting a time-space conflict analysis formalism in a 4D environment in order to identify any time-space conflicts in the model prior to construction</td>
<td>(Akinci et al. 2002)</td>
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Temporary Facilities Layout

Site layout planning, unique for each project and depending on a large number of variables (Tam et al. 2002), resembles multi-objective problems. The biggest challenge to optimizing site layout planning is to account for various constraints such as the location of the project and facilities and the shape of the construction site. To provide a decision-aiding model for designing a site layout for such multi-criteria problems, Yeh (1995) proposed an annealed neural network; through two case studies, he found that site planning still requires human experience and that some required variables that are not easily predetermined. To optimize facilities placement on the site grid, Hegazy et al. (1999) formalized a site layout model by incorporating a genetic algorithm procedure. Their proposed model was comprised of horizontal, vertical, and rectangular locations as a reference for placing facilities. Although their model worked efficiently, an evaluation of the model identified several limitations. For example, if large and small facilities were not placed in a specific order, their proposed solution would be time consuming, or if small facilities were placed within a construction site, placing large facilities would be more challenging. Another major factor impacting site layout planning is the close relationship among facilities, which controls travel distances. The key components that interfere with the close relationship among facilities are work flow, information flow, safety, work spaces, and personal preferences (Lam et al. 2005). Also important is ensuring that the number of preplanned facility is less than the number of free existing locations (Lam et al. 2009). Lam et al. (2009) formalized a model through a combination of both the max-min ant system-genetic and genetic algorithms to optimize the ratio of predetermined facilities to free existing locations for construction site layout planning. Table 2 illustrates a summary of the previous research on facility layout optimization.

Table 2. Sample of the Previous Research on Facility Layout Optimization

<table>
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<th>Year</th>
<th>Tools/Techniques</th>
<th>Features</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>VBA in AutoCAD, Microsoft Access</td>
<td>Presenting a CAD-based site layout model helping users to utilize their knowledge in designing site layouts</td>
<td>(Sadeghpour et al. 2006)</td>
</tr>
<tr>
<td>2009</td>
<td>Approximate dynamic programming</td>
<td>Formalizing a system to consider future effects of layout decisions made in early stages</td>
<td>(El-Rayes and Said 2009)</td>
</tr>
<tr>
<td>2011</td>
<td>Genetic algorithm system</td>
<td>Developing a system to optimize material procurements and storages within a project</td>
<td>(Said and El-Rayes 2010)</td>
</tr>
<tr>
<td>2012</td>
<td>-----</td>
<td>Proposing a floor-level construction material layout planning model to optimize the travel path with a site</td>
<td>(Park et al. 2011)</td>
</tr>
<tr>
<td>2012</td>
<td>Electimize algorithm</td>
<td>Modeling a framework to optimize travel path between material storages and facilities</td>
<td>(Abdel-Raheem and Khalafallah 2012)</td>
</tr>
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</table>
NEED FOR A RULE-BASED SITE LAYOUT CHECKING SYSTEM

After a general review of previous construction site layout planning research, this study highlights some construction site layout planning problems. One of the issues is the movement of resources and the close relationship among the facilities within a construction site (Hegazy and Elbeltagi 1999; Ning et al. 2010). The next issue is that site planners typically view site facilities as rectangular blocks for easier positioning in any location on construction sites (Sadeghpour et al. 2006). Such a view creates a challenge for unequal-area construction site layout planning (Ning et al. 2011). In addition, because materials are often wrongly placed in construction sites, their positioning (e.g., if materials are placed too far from the work area) is actually based on what planners guess to be a suitable location, so materials will probably be relocated several times. Thus, superintendents and site managers currently adhere to a first-come-first-serve system for placing their materials and facilities, which results in disorganized sites with safety issues (Sadeghpour et al. 2006; Tam and Tong 2003). Well-planned site layout planning minimizes travel time and effort spent on material handling and increases productivity and safety (Sadeghpour et al. 2006).

The planning and design phases provide a substantial opportunity for site planners to re-organize the layout and relocate facilities, material storage, parking areas, and offices within a project site. Current site layout planning approaches utilized for decision making in construction site layout planning are ineffective because they primarily focus on just one or a few site layout variables. Therefore, applying an automated real-time rule-based checker to design a construction site layout in a 3D-BIM enables managers to check a site layout plan against some pre-defined rules and to ensure minimal conflicts with the design prior to construction. However, because such rules and regulations for site layout planning have not been formulated, all parties involved in a construction project must make decisions based on their experience. Unfortunately, their decisions are usually incomplete, and given the complexity of the construction site, poor decisions will lead to an inefficient, conflict-ridden and unsafe site layout.

Before making a decision, a site planner should consider various constrains in designing a site layout, such as site boundary constraints, physical overlap constraints between facilities placement, max/min distance constraints between facilities, and zone constraints for facilities placement and construction activities zone (El-Rayes and Said 2009). To develop a site layout rule-based checking system, the site layout constraints will be investigated. To implement constraints in designs, a computer-based model checker helps with automatically code compliance checking and enable designers to check the precision and correctness of their designs. A rule-based checking system refers to software assessing a design based on the configuration of objects, not modifying a design (Eastman et al. 2009). The rule-based systems assist users to apply rules and constraints to their models with “pass” and “fail” results (Eastman et al. 2009). To check a site layout design against pre-defined site layout rules, a rule-based checking system will apply the rules within a BIM model and provide solutions based on the pre-defined site layout rules. The process of rule checking consists of four major stages (Eastman et al. 2009):
1. Rule interpretation phase: building design rules are in human language formats and they need to be interpreted into a machine processable format.

2. Building model preparation phase: the type of rule checking for a building model must be defined to effectively provide the essential rule checking information.

3. Rule execution phase: designers implement their target model with applied rule checking simultaneously.

4. Results reporting phase: reports of the rule checking shows whether the design conditions are satisfactory or failed.

These four steps of the rule checking approach are major keys to develop a site plan rule-based checker on BIM programs. To date, the existing BIM design tools do not provide model checking functions for site layouts, thus developing an application or plug-in on BIM platforms could be beneficial. Such a system would enable construction managers or site planners to assess their models against the defined site layout rules in real time; however, exchanging data between various BIM platforms is challenging. The industry foundation classes (IFC) is the only neutral model for describing a building model for rule checking, which helps to solve the issue of exchanging data (Liebich et al. 2006). The IFC is an object-oriented database management system (Faraj et al. 2000) and an independent design tool and a neutral data model representation accepting most BIM design models (Eastman et al. 2009).

A rule-based checking system reviews site layout designs in BIM-3D designs and interactively or automatically suggests solutions to comply with site layout principles. Such a system enables designers or site planners in their decision making process to design construction site layouts. They will be able to check and concentrate on the requirements of a site layout design and use the provided report by rule-based checking system to improve their developed site layout designs. The rule checking process of a site layout checker entails the following rules:

1. Rule interpretation phase: first, a comprehensive site layout rules is needed to be developed and then since the rules are not computer-understandable statements, they should be translated from human language to machine processable format.

2. Building model preparation phase: Users define a set of construction objects and locating constraints. Users should prepare designs to ensure if objects type and properties are correctly assigned. In addition, to implement a correct translation and testing, the site layout rules must be correctly encoded in IFC by the software developers; however, the current IFC documents has a limited set of site layout entities.

3. Rule execution phase: Prior to applying rule checking, users should make sure that required data for rule checking is available from BIM models (Eastman et al. 2009). To check the accuracy and correctness of BIM models, the rule-based checking system implements the machine-readable code against site layout models.

4. Results reporting phase: the rule checking system generates reports including solutions to improve the site layout design. The report can be displayed in graphical or text format. The rule checker system results pass, if design conditions are satisfactory; otherwise, the result is fail.

Such a system results in a more effective decision making process and enables project teams to easily find the issues of site layout designs earlier in the process. It
also decreases the number of relocations of facilities and materials as well as the distance for handling materials.

To better understand the application of a rule-based checking system within a construction project, a process modeling notation is developed using business process modeling notation (BPMN). The BPMN standardizes a business process model and consists of activity nodes, control nodes, and gateways as basic flow elements (Dijkman et al. 2008; OMG 2008). The BMPN enables various parties to convey specialized information and allows to link any new concept of artifacts to the current process through associations, so new artifacts do not affect the basic sequence (OMG 2008).

Figure 2 illustrates the integration of a site layout rule-based checking system within a construction project. The BPMN diagram illustrates the integration of a rule-based checking system in construction process and the interaction and information exchanges among various parties. First, in the construction preparation phase (31-40 20 00), a site manager investigates a project site’s conditions and constraints and sends a status report to a site designer. Then the site designer prepares the model for the rule-based checking system and integrates designs provided by project designers with the project schedule to ensure a timely site layout design. In the next step, the site designer checks the correctness of the developed site layout model by the site layout rule-based checking system. The site designer should repeat this process until the site layout model satisfies the pre-defined rules. In the next step, in the construction phase (31-40 40 00), the site designer sends the 4D site layout models to the site manager for implementation. The site manager always should control and monitor the project status and report any changes, which impacts the 4D site layout models, to the site designer. The site designer will modify the designs and check whether new design conditions are satisfactory in terms of the site layout rules or not. Afterwards, the site designer will send the modified designs to the site manager for execution.

Figure 2. A process model for application of the site layout rule-based checker
CONCLUSION

This research highlighted the importance of a rule-based checking system for site layout designs. As discussed in this paper, the accuracy and correctness of a site layout model can be automatically checked to ensure designing an optimized site layout. Such a model checker assists site planners in designing an optimized site layout by enabling them to easily check their designs against site layout rules and considering the future implications of site layout decisions made in the early stages of a project.

To develop a site layout rule-based checking system, first, several issues should be addressed. For example, since the current IFC documents have a limited set of site layout entities, it’s not easy to encode the site layout rules in IFC and this lack makes it more challenging to develop such a comprehensive site layout rule-based checking system. The next phase of this study is to investigate the essential rules and constraints for designing an optimum construction site layout.

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