Review of information technology-based tools in construction site layout planning

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Abstract: - Space available on construction sites is one of the crucial resources, on which other construction resources like men, money, machines, material, and time depend. The success of any construction project depends on the effective and efficient management of these resources. It affects the safety, productivity, and operation of construction resources especially in areas where available space is limited. In order to utilize the available site space and to enhance the safety and productivity of construction operations, it is very important to introduce information technology (IT) based advancements in site layout planning. This paper presents a review of the capabilities of various IT-based applications in site layout planning which ensure that construction work progresses efficiently with minimum interruption.

Key-Words: - Construction site layout planning, Information Technology tools

1 Introduction

In the construction industry, the success of a construction project depends on the effective and efficient management of construction resources. Traditionally, five main resources namely: men money, machines, material, and time are considered as important resources. The crucial resource, space on which all five construction resources depend is not considered much in construction projects.

The construction project is executed in the form of a camp. The camp should be so designed that work progresses efficiently with minimum interruption. The arrangements made for the construction camp known as site layout or job layout depends on site space. The arrangement of site space with respect to construction resources so that they are accessible and functional during construction is known as site layout planning [1]. Site layout planning identifies various facilities to support construction operations, determines their sizes, shapes, and places them within the available site space [2].

In congested sites where site space is less, layout needs to be planned carefully. On the other hand, large sites having abundant space availability, the proper positioning of site facilities with respect to each other will largely influence material handling and travel cost. In both the instances space is crucial and will affect the production and safety of resources.

Despite the crucial role played by the space, site layout planning is often neglected, and planner believes that it will be done by the site engineers as the project progresses [3]. The various approaches dealing with the site layout planning are broadly divided into three categories: static layout planning, dynamic layout planning, and space scheduling.

A layout is termed as static when planning efforts results only one site layout for the whole project duration. However, the changing nature of construction projects and its impact on site requirements make site layout outdated only after little progress is made in the project. Site planning is often been treated as a static problem and the layout of the construction site does not change once it is designed, which resultantly causes many accidents, decrease productivity and profits due to the dynamic nature of construction sites.

The needs of construction sites change considerably from time to time throughout the project. As the project grows, more and more area is occupied by permanent facilities leaving less space to position supporting facilities [4]. The types and quantities of material being delivered to the site change considerably throughout the project. Thus, the areas needed for their storage change accordingly. Access roads that are needed during initial stages of construction may not be required during later stages, which generate a need for a

dynamic layout for representations of site requirements.

Early research in the area of site layout planning was limited to static layout problems. Due to the various changes during the project, a static layout appears to be incomplete in meeting the site requirements at a particular time. In most of projects, the demand for on-site support facilities changes as construction progresses. This causes significant changes from time to time in both the required site space to support temporary facilities (TFs) and their relative positions. Creating layouts that change over time as construction progresses is termed dynamic layout planning. The ever-changing site environment makes layout planning as dynamic one. Dynamic layout assigns a set of facilities that occupy the site during a certain time period on a predetermined site area. If during any time period there is no feasible solution, the planner must either alter his schedule or reconsider the area assigned to facilities. Efficient site layout planning is essential for handling materials, helps in minimizing accidents on construction sites and results in higher productivity.

Space is the sixth resource to be accounted for in construction process. Especially when space is less, there is a close interaction between construction resources on sites. Allocating site space required by resources over time as governed by a construction schedule is termed as space scheduling. Activity-level space scheduling involves allocating site space over time to static and dynamic construction resources. It involves identifying individual resource space requirements, determining when and for how long each resource would need space on site, and allocating site space to these resources in different time intervals so that resources are operational and no timing or space conflicts arise [5].

Tommelien and Zouein [5] suggested space scheduling as a bi-directional interaction between scheduling and layout construction. The basic idea behind the research approach was to carry out suitable changes in construction schedule whenever insufficient space is available to accommodate all resources on site for any time period. Later on researchers formulated an improved algorithm for limited space scheduling [6].

Dynamic layout planning and space scheduling both are limited resource allocation problems involving the inherently two dimensional variable space. A critical problem in dynamic environments and especially on construction sites is coordinating the use of limited space to accommodate resources and their changing demand for space over time. In reality, construction practice changes as per site and project conditions. Therefore, an efficient and dynamic layout is important to encourage safe and efficient operations, minimize travel time, decrease materials handling and avoid obstructing materials and equipment movements [7].

2 Need of Site Layout Planning

The construction site layout problem is that a set of facilities needs to be located on the site, while optimizing layout objectives and satisfying a set of layout constraints. The allocation of space to TFs is a complex construction management task. There are many factors that need to be taken into account. Planners and managers rely on trial and error and the use of partial layouts from previous job sites for constructing layouts that meet a project and its site's requirements [8]. Because so many changes take place over time, updating layout to keep track of all facilities is a prerequisite for a safe construction site. Site layout drawings are a superimposition of several site layouts, each pertaining to a different period. Any person who is to interpret such drawings needs good spatial and temporal conceptualization skills [8]. Dynamic visual aids and more standard layout methods can facilitate visualization, interpretation and identify beforehand any health and safety problems that may occur during the construction period. Dynamic visual aids make it easy for planners to visualize components of the site layout problem [9].

Elbeltagi and Hegazy [10] suggested that to evolve a safe site and to increase productivity, three aspects must be considered during site planning: defining the necessary TFs needed for safety reason on construction sites; defining proper safety zones around the construction space; and considering safety in the process of determining the optimum placement of facilities within the site.

Sadeghpour et al [11] identified that three entities namely, objects, site properties, and constraints affect site layout planning. Moreover, the components and different entities of the planning system affect its capacity and versatility to generate practical layouts. The three entities attribute support the functional requirements required for site layout. These factors affect the way site planners approach the site layout problem. Objects refer to items like equipment, material, temporary support facilities, buildings, lay down areas, working areas, and generally anything that exists on site and occupies space. Site properties are existing items on site like trees and buildings that affect the final layout of that site. The areas like

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ponds, steep slopes are known as constraints on the site and are hazardous and unsafe for locating facilities, constraints are rules defined to fulfill layout objectives.

3 Site Layout Planning Techniques

Exhaustive literature is available on the application of IT-based advancements in layout planning, which has been categorized into the various parts and is discussed in subsequent subsections for the benefits of the construction industry:

3.1 Heuristic Technique

Heuristic technique refers to solutions that are based on heuristic rules, experience, and simplified approaches. It is a knowledge-based approach to solve larger size site layout problems. It depends on expert's knowledge and experience of site planning expressed in a systematic form [12]. Early approaches were based on heuristics or guidelines which are more of manual rather than automated [7]. Hamiani [13] and Tommelein [14] used a rule-based system to place TFs on site, one at a time through a constraint-satisfaction search. Heuristic approach attempts to satisfy spatial relationships among facilities and provide good but not optimal solutions. Heuristic approaches place the facilities on a construction site in a loosely packed manner. A loosely packed arrangement of facilities, as opposed to a tightly packed one, refers to the situation when spaces are permitted between facilities [3].

3.2 CAD-Based Techniques

CAD-based techniques support visualization and facilitate user-system interaction for defining the required site objects and constraints in a project and improve current practice by providing site planners with a centralized computer environment which facilitates the creation of new objects and reuse of domain knowledge, with gradual increase in model's knowledge base. It introduces a geometric reasoning approach to analyze site space forfinding an optimum or near-optimum location for facilities which facilitates easy visualization of the site planning process [15]. A CAD-based site layout model aid site planners in developing layouts in an interactive manner. The interactive graphical capabilities of CAD-based model facilitate the site planning process and make it more comprehensive to site planners.

3.3 Genetic Algorithms-Based Technique

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics [16]. Li and Love [17] presented a genetic algorithm (GA) based approach for facility allocation. The users simply specify locations of facilities and the algorithm assign facilities in their best locations so as to minimize the total travel distance between facilities. The algorithm only addresses the static layout problem. The solutions generated are completely independent of the site layout geometry and individual facility size or shape. Unlike other optimization techniques or algorithms that give only one solution at a time, GAs provide multiple solutions [18]. Zouein et al [19] formulated a genetic algorithm for solving the site layout problem with unequal-size and constrained facilities.

3.4 Expert Systems

An expert system is a computer system that emulates the decision-making ability of a human expert. Expert systems are designed to solve complex problems by reasoning about knowledge like an expert. One of the early innovative expert systems (SightPlan model) for construction site layout planning mimics how people lay out construction sites and encodes the domain knowledge they apply in site layout process [20]. Consite, an expert system, developed by Hamiani [13] solve site layout problems; it has ability to define multiple constraints for facilities.

3.5 Virtual Reality Models

Virtual Reality (VR) is an advanced human-computer interface that simulates a realistic environment and allows participants to interact with it [21]. VR is a class of user interface which attempts to present large amounts of information in a natural manner, allowing the user to manipulate it using a more interactive method than the traditional graphical user interface [22]. VR tools might be used to simulate the experience of moving through and interacting with a 3D site layout environment [9]. Site planners and engineers on construction site through graphical displays are able to see a construction site layout in progress along with the superimposed images of the proposed TFs.

3.6 Fuzzy Set Theory

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Fuzzy set theory deals with vague, imprecise, and uncertain problems that are not statistical in nature. A quantitative approach based on fuzzy logic approach suggests that to enhance site safety and to increase productivity, three aspects must be considered during site planning: defining the necessary TFs needed for safety reason on construction sites; defining proper safety zones around the construction space; and considering safety in the process of determining the optimum placement of facilities within the site [10].

3.7 Neural Networks

Neural Networks solve problems by simple and highly interconnected computing elements called neurons. Neural networks (NN) are particularly effective for predicting events when the networks have a large database. A hybrid type of neural networks called Annealed Neural Networks (ANN) was also used in site layout planning [23]. ANN inherits features of both NN and simulated annealing. The main advantage of NN during site layout problem is that it is capable of accommodating multiple constraints. The major drawback of NN for optimization problem is getting trapped in local optimum. Simulated annealing a search algorithm solves optimization problems. Random changes made in the simulated annealing techniques help to escape the local optimum, however long computational time is required [23].

3.8 Integrated Techniques

When layout problem is solved by using two or more techniques together, the process is called as integrated technique. A non structural fuzzy decision support system (NSFDSS) integrates both experts' judgment and computer decision modeling, making it suitable for the appraisal of complicated construction problems. The MovePlan model of temporary construction facilities is a graphical and interactive decision-support tool for constructing dynamic layouts to suit resource site space demands as dictated by an activity schedule. The model enables users to explore alternative layout strategies and assess whether or not satisfactory layouts are available to accommodate the space needed by construction resources over time. The tool illustrates how coarse layout data can be taken into account during early activity-level planning of a project, when a CPM-like schedule is augmented with spatial resource data. It is thus a prime tool to assist field practitioners with the layout of TFs on site either before commencement of construction or during construction.

Osman et al. [24] developed a CAD-based model that integrates the powerful capabilities of CAD systems and optimization abilities of genetic algorithms for the purpose of solving the site layout problem. It is capable of dealing with irregular site shapes as well as considering GAs along with the CAD environment to optimize the location of TFs [3].

3.9 Spreadsheet Solutions

A simplified spreadsheet model for optimizing the placement of facilities on a construction site represents a construction site by using a group of adjacent spreadsheet cells. The spreadsheet model is general and adaptable to any user's needs. A comprehensive system called EvoSite was developed by Hegazy and Elbeltagi [3] for site layout planning uses an intuitive spreadsheet representation of the site and facilities, and automates the evolution of layout solutions.

3.10 Building Information Modeling (BIM)

Sulankivi et al. [25] suggested that four-dimensional building information modeling (4D-BIM) can be used as central technology for construction site safety related planning activities. Study illustrates that 4D site layout and safety related planning activities can improve occupational safety by connecting the safety issues more closely to the construction planning, providing more illustrative site layout and safety plans, providing methods for managing and visualizing up-to date plans and site status information, as well as by supporting safety communication in various situations, such as informing site staff about upcoming safety arrangement or warning about risks.

3.11 GIS-Based Approach

GIS improves construction layout planning and design process by integrating location-based and thematic information in a single environment. Cheng & O'Connor [12] developed an automated site layout system for temporary facilities called *ArcSite*. It integrates a database management system (DBMS) and GIS. The main objective of the system is to automate the planning tasks required for facility layout. This is performed through the identification of areas suitable for assigning facilities in order to minimize construction conflicts and improve project efficiency. *ArcSite* developed

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by Cheng and O'Connor [12] integrated GIS with DBMSs to assist designers in identifying areas to locate TFs. The system only provides design layout in two dimensions.

4 Conclusion

The paper sensitizes construction professionals regarding the importance of IT-based advancements in layout planning, attempts are made to explore the capabilities of various IT-based applications in layout planning that shall ensure the progress of construction work without interruption ensuring the safety of resources.

Literature suggests that the use of IT-based advancements in layout planning shall help in effective and efficient management of construction resources. It shall further enhance the safety, productivity, and operations of construction resources especially when space is less and largely influence material handling and travel cost when sites have abundant space availability.

Review indicates that introduction of IT-based advancements in site layout planning shall be useful in identifying various facilities required to support construction operations, determine their sizes, shapes and places them within the available site space. It shall facilitate the construction process, hazards identifications and accordingly safety planning.

The paper shall act as a guide to various constructions professional to complete the construction projects, keeping in view the available space, construction resources, facilities required to support construction operations, and safety aspects. IT advancements will not only help in managing the construction resources effectively and efficiently but also reduce construction injuries, accidents and work related health and safety problems and within budgeted cost and without any delay.

The use of IT shall provide a unique and precise solution to the site layout planning. It shall provide a clear picture that which facility is to be located where and why? The locations of facility with the help of IT not only identify appropriate location, and reduce travel time but also reduce cost and ensure construction safety.

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