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Framework for Safe Site Layout Planning in Hilly Regions

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ABSTRACT

Construction site planning affects the construction progress, safety, and functioning of various resources especially in hilly regions where space is always limited. In hilly regions, proper allocation of space for various resources keeping in view the site safety is difficult due to the involvement of number of resources and interlinked constraints. This affects site layout planning, influence construction progress and safety related issues. In order to utilize the available site space and to enhance the safety and productivity of construction operations, sufficient number of site layouts are generated and analyzed in advance, generally ignoring safety related issues. The present study proposes a framework for safe site layout planning in hilly regions in identifying the optimum positions of various resources. The site layout elements which affect safety and progress on construction site layouts have been also explored.

Key words: Safety, Construction site layout planning, Temporary Facilities, Geographic information system (GIS)

INTRODUCTION

In the construction industry, the success of a construction project depends on the effective and efficient management of construction resources. Traditionally, in construction six resources are used: money, machines (equipment), men (labour), material, time and management [1]. Unlike these resources, space on which all these construction resources depend is not considered much. The consideration of space as a limited resource provides a new viewpoint to the construction professionals in terms of schedule of activities, cost, quality and safety. The space is most crucial resource on which action and interaction of project resources depend. The importance of space can be well understood by allocating a temporary place to fabricate and store structural steel components on the construction site. Both fabrication and storage require a certain amount of space. The overlapping of such tasks creates the space conflict.

The construction professionals carry out construction projects in the form of a camp. The camp is planned so that work progresses efficiently with minimum interruptions, to a great extent. The arrangements made for the construction camp is known as site layout which depends on site space. The arrangement of site space with respect to resources so that they are accessible and functional during construction is known as site layout planning [2]. It identifies locations of the various temporary facilities (TFs) to support construction operations, determines their sizes, shapes and places them within the given space [3]. In congested sites such as hilly regions where site space is less, layout needs to be planned carefully and efficiently. When space is less, there is a close interaction between construction resources on sites. On the other hand, if site space is large, the proper arranging of site facilities with respect to one another shall impact aspects such as material handling, travel cost etc. In both the instances space is crucial affecting the progress of construction work, besides influencing safety of resources [4].

Despite the fact that space has crucial role, site layout planning is often ignored and construction professionals believe that layout plans are developed by the site engineers with the progress of project [5]. To understand various crucial aspects related with layout planning, the present study provides an overview of various approaches dealing with the site layout planning. These approaches 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 out-dated 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 resulting many accidents, slow down construction progress 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 progresses, more areas are occupied by permanent facilities leaving less space to place supporting facilities [6]. The types and quantities of material being delivered to the site keep on changing throughout the construction. Thus, the areas needed for their storage and fabrication change accordingly [2]. Approach roads that are required during initial phases of construction may not be required during later phases, which generate a necessity for a dynamic layout. The process of creating layouts that change over time and meets the requirements as construction progresses is termed dynamic layout planning. The ever-changing requirements of construction sites make layout planning as dynamic one. Dynamic layout allocates facilities to occupy the space for particular time duration on a predetermined site area.

Allocating site space as per the requirement of 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 space conflicts arise [7]. Tommelien and Zouein [7] suggested space scheduling as a bi-directional interaction between scheduling and construction layout. The basic idea behind space scheduling was to carry out suitable and required changes in construction schedule as and when sufficient space is not available to accommodate all resources on construction site. Later on an improved algorithm for limited space scheduling was formulated [8]. Dynamic layout planning and space scheduling both are limited resource allocation problems involving the inherently two dimensional variable space [9].

Site layout is normally accomplished by site engineers on construction sites. Construction professionals, generally learn to accomplish this task by trial and error in the course of years of fieldwork. The site layout planning problem is generally defined as the problem of identifying the number and size of TFs to be placed, identifying constraints between facilities, and determining the relative positions of these facilities that satisfy constraints between and allow them to function efficiently [10]. TFs are those facilities that serve the construction site but are not being considered a physical part of the structure that is required to be built [11]. Examples of TFs are material stores, fabrication yards, lay-down areas, parking lots, offices and warehouses [12].

RESEARCH JUSTIFICATION AND OBJECTIVE

The site layout problem requires locating a set of facilities on the construction site to optimising layout objectives and satisfying a set of layout constraints. The allocation of space to TFs is a complex construction task. There are many factors that need to be taken into account. Construction professionals depend on trial and error method and the use of partial layouts from previous job sites for constructing layouts that meet a project and its site requirements [13-14]. 2D drawings are used to convey the site layout principles throughout construction but are rarely updated as construction progresses. Because so many changes take place over time, updating drawings 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 conceptualisation skills [15]. Dynamic visual aids and more standard layout methods can facilitate visualisation, interpretation and identify beforehand any health and safety problems that may occur during the construction period. Dynamic visual aids make it easy for construction professionals to visualise components of the site layout problem [16]. Elbeltagi and Hegazy [17] have 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 [18] 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 pragmatic layouts. The three entities support the functional requirements needed for a site layout. These entities affect the way site engineers approach the site layout problem. Objects refer to anything that exists on site and occupies space such as: equipment, material, temporary support facilities, buildings, lay down areas and working areas. Site properties that affect the final layout on construction site are permanent items on site like: trees, buildings etc. The areas like ponds, steep slopes are known as constraints on the construction site and are problematic and unsafe for locating facilities.

Literature indicates that there is a dearth of responsive tools and resources to assist construction professionals in addressing safety while planning layouts. Site layout and safety related planning improve occupational health and safety by connecting the safety issues more closely in layout planning. Generally, proper planning for site layouts ensuring execution of construction activities safely and efficiently is a manual and time-consuming process. It is crucial to generate and analyse possible site layouts in advance, so that the available site space is more safely and efficiently utilized. Moreover, efficient construction site layout planning involves the synchronized assessment of schedule and site layout to use site space more safely, efficiently and perpetually [19]. A well-defined framework for evolution of a safe site layout has not been explored in the existing literature. Therefore, the main objective of the present study was to develop a framework in evolution of safe site layout.

SITE LAYOUT PLANNING TECHNIQUES

Researchers solved site layout planning problem by heuristic methods and mathematical optimization. Heuristic methods are based on knowledge-based expert system and recently on artificial intelligent concepts. Mathematical optimization procedures have been designed to produce optimum solutions. Heuristic methods are used to produce good but not optimal solutions. However, the mathematical optimization is not generally used for large-scale projects due to the involvement of huge calculations and efforts. Various techniques solving layout planning problem are briefly discussed in Table 1.

Table-1 Description of Various Layout Techniques

Technique	**Description**	**Merit/demerit**
Heuristic Technique	Depends on expert's knowledge and experience, expressed in a systematic form, place the facilities in a loosely packed manner [12].	Used in situation when spaces are permitted between facilities [5]
CAD-Based Techniques	It introduces a geometric reasoning approach to analyze site space for finding an optimum or near-optimum location for facilities which facilitates easy visualization of the site planning process and encourages user participation [18].	support visualization and facilitate user-system interaction for defining the required site objects and constraints
Genetic Algorithms	Users specify locations of facilities, algorithm assign facilities in their best locations to minimize the total travel distance between facilities.	The algorithm only addresses the static layout problem.
An Expert System	It solves complex problems by reasoning about knowledge, like an expert.	System has ability to define multiple constraints for facilities.
Virtual Reality Model	Virtual Reality (VR) is an advanced human-computer interface that simulates a realistic environment and allows participants to interact with it [20].	VR attempts to present large amounts of information in a natural manner.
Fuzzy Set Theory	Fuzzy set theory deal with vague, imprecise and uncertain problems.	System does not support problems that are statistical in nature.
Neural Networks	Neural networks are effective for predicting events when the networks have a large database. The drawback of NN for optimization problem is getting trapped in local optimum.	NN is capable of accommodating multiple constraints.
Integrated Techniques	When layout problem is solved by using two or more techniques together, the process is called as integrated technique.	Integrated approaches obtain the close relationship values between various facilities in a construction.
Spreadsheet Solutions	The spreadsheet model is general and adaptable to any user's needs.	Spreadsheet facilitates evolution of layout solutions.
GIS Based Approach	GIS improves construction layout planning and design process by integrating locational and thematic information in a single environment.	GIS with DBMSs assist designers in identifying areas to locate TFs.

SAFETY CONSIDERATION IN SITE LAYOUT

Proper site planning is vital for reducing injuries, and to provide a safe work environment on construction sites [21-24]. Injuries or accidents on construction sites can be minimized by giving adequate consideration to health and safety issues during the early stages of site layout planning [21]. Consequently, causes of construction site hazards such as falls, falling objects, site transportation, site layout and hazardous substances can be controlled through creating an efficient site layout plan [17]. Therefore, construction professionals should address several health and safety issues during early stages of site layout planning. During the project life many layouts are required to be created to accomplish the site requirements while ensuring the safety of resources. Site layout planning considerably regulates construction ways and means to health, safety and progress throughout construction work on a site. A properly planned site is a safe site with high morale, few disputes, and good maneuverability.

SITE LAYOUT ELEMENTS AND THEIR CODAL PROVISIONS

A poorly planned site causes accidents resulting from falls of material, collisions between workers and plant or equipment [25]. The layout of the construction site should be carefully planned keeping in view the various requirements of construction activities and the specific constraints in terms of size, shape, topography, traffic and other restrictions. A well planned site layout should enable safe, smooth and efficient construction operations while allocating spaces required for TFs. As per the NBC [26] guidelines, the site layout should take into considerations the factors:

- Easy access and exit, with proper parking of vehicle and equipment during construction,
- Properly located material stores for easy handling and storage,
- Adequate stack areas for bulk construction materials,
- Optimum location of plants and equipment (batching plants, etc.),
- Layout of temporary services (water, power, power suppression unit, hoists, cranes, elevators, etc),

- Adequate yard lighting and lighting for night shifts,
- Temporary buildings; site office and shelter for workforce with use of non-combustible materials as far as possible including emergency medical aids,
- Roads for vehicular movement with effective drainage plan,
- Construction safety with emergency access and evacuations and security measures,
- Fabrication yards for reinforcement assembly, concrete pre casting and shuttering materials and
- Fencing, barricades and signage.

Beside this prior to the work starts on a site thought needs to be given to: approach roads should be free from obstruction and from exposure to hazards such as falling materials, materials-handling equipment and vehicles. Edge protection should be at the edge of floor openings and stairs, and wherever there is a drop of 2 metres or more [26]. Materials need to be stored as close as possible to the appropriate workstation, e.g. sand and gravel close to the cement-batching plant and timber close to the joinery shop. If this is not practicable, it is important to schedule the arrival of materials. For site security, the site should be fenced to keep out unauthorized persons, children in particular and to protect the public from site hazards. To evolve a safe and efficient site layout, various site layout elements along with their codified provisions are given in Table 2.

Table-2 Safety Provisions for Site Planning and Layout

Activity	Hazard	Safety precautions
Excavations	Most construction work involves some form of excavation for foundations, sewers and underground services.	• Excavated material shall be kept away from edge of a trench in order to provide a clear berm width of not less than 1/3rd final depth of excavation. • In special cases where disposal area is limited, the minimum berm width should not be less than 100 mm [26].
Adjoining buildings	Wherever possible, an excavation should not be as close and deep as to undermine any adjacent building or structure.	• The stability of a building or structure may be affected by excavation work in progress. At least 305mm clearance from the adjoining building shall be maintained [26].
Edges	Danger may be caused either by materials falling on those working below, or by increased loading on the surrounding ground so as to cause the timbering or supports to the sides of the excavation to collapse.	• Material and equipment should not be stored, or moved, near the edge of an excavation. Spoil and waste heaps should similarly be kept well away from the edges of excavations. • Every excavation on site located 1524 mm or less from street lot line shall be enclosed with a barrier not less than 1829mm [27]
Vehicles	Heavy equipment (excavating machinery, truck, dumpers etc.) spoil sides of trenches.	• A distance not less than the depth of trench or at least 6000 mm for trenches deeper than 6000 mm shall be maintained [26].
Access	This is of particular importance when there is a risk of flooding and rapid escape is essential.	• Pathways in no case shall be less than 1219 mm [26, 27]. • Street width of abutting building shall not be less than 12000 mm.
Buried or underground services	Striking electric cables may cause death or severe injuries by electric shock or severe burns. Broken gas pipes will leak, cause a fire or explosion, create sudden risks by flooding an excavation or collapse its sides.	• Once the approximate position of a buried Electrical cable is known, power tools should not be used within 500 mm of a cable, and mechanical excavators within 500 mm of a gas pipe should not be used.
Confined spaces	Every year there are fatal and serious accidents caused by persons entering confined spaces.	• A horizontal barrier on both sides of the power lines should be at least 6000mm.
Open space	Ensures safety, security and ventilation.	• open spaces on all side the building should be at least 6000 mm.
Obstructions	Material and equipment shall not be placed or stored so as to obstruct access to fire hydrant, manholes or normal traffic.	• Material or equipment shall not be located within 6096mm of street intersection [27].

DEVELOPMENT OF FRAMEWORK FOR SAFE SITE LAYOUT

The development of safe site layout plan has been discussed below:

Scheduling

The list of various activities that constitute the project is prepared; process called as Work Break Down Structure. The developed schedule is linked with the material, labour and equipment requirements to generate the constant requirement of material, labour and equipment respectively. The dynamic requirements of the resources are used to decide the quantum of space required at a site at different interval of time for different resources.

Resource Scheduling

To execute the construction work in an efficient manner and without wastage of any of the inputs, schedules for various project resources are prepared. These schedules are further examined and resources that require space are identified. Material schedules showing requirements of commodities are prepared from the main schedule to enable storage space to be adequately planned and necessary arrangements to be made for timely delivery of materials. It is prepared either month-wise or week-wise depending on the extent of the project and storage space. Labour schedules depict the manpower requirements of the project in a tabular form for various stages.

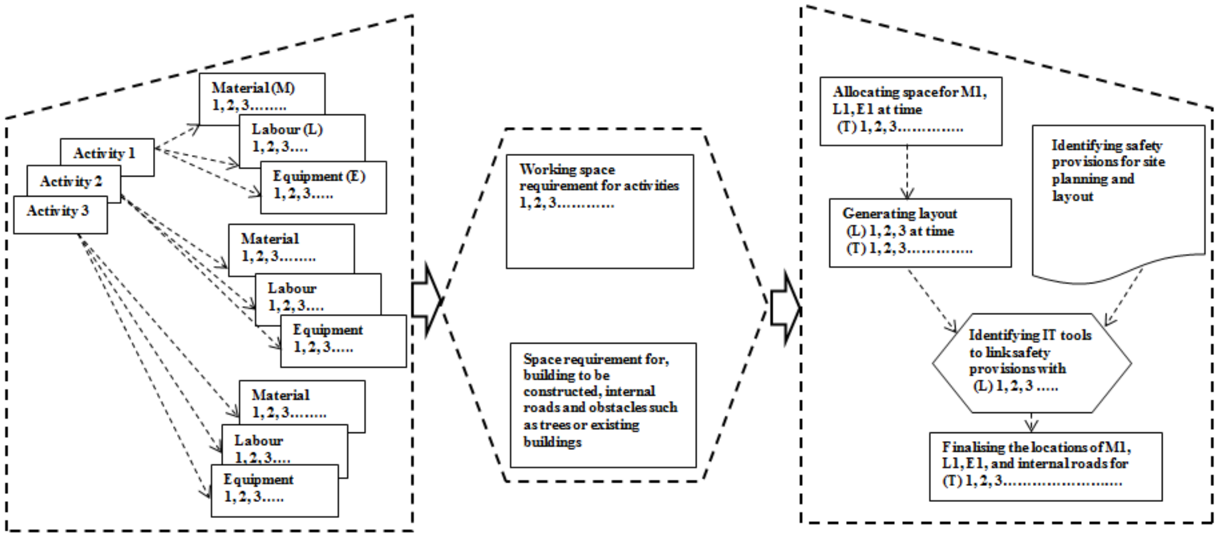

Fig.1 Schematic diagram for the overall frame work for safe layout

Space Scheduling

The resources that generate space requirement are identified as material, equipment and labour and space schedule is prepared activity wise. This is crucial and gives information that which activity require how much space and at what location. Once this space schedule is correlated with time schedule, planners can know beforehand that which spatial resource is located at what position and for how much time. This also provides information that which portion of the building is complete and can be used for space related requirements

Topography

It is concerned with local detail in general, including natural and artificial features. Safe site layout is ensured by adhering to safety codes and placing resources like materials, labour, equipment etc. with respect to topography. Placing of various resources keeping in view the topography of site area reduces wastage of materials against stream flow, avoids placement of resources against roads. It is therefore pertinent that topographical features like slope, elevation etc. have an impact during evolution of site layout. Fig. 1 presents a schematic diagram for the overall framework for safe site layout. It illustrates the step by step procedure to generate space requirements by various activities.

CONCLUSIONS

Due to the involvement of number of resources and interlinked constraints, topography, etc. proper allocation of space is difficult in hilly regions. The study sensitizes construction professionals regarding the importance of critical elements of layout planning and their consequences. The paper shall act as a guiding instrument to construction professionals for addressing safety aspects during site layout planning. The review suggests that there is a lack of responsive tools and resources to assist construction professionals in addressing construction safety issues in site layout planning. The review of the different approaches and techniques of site layout planning helps in identifying factors that contribute to unsafe sites. The proposed framework shall help in identifying the optimum positions of various resources considering topographical features like slope, elevation.

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