# Planning Construction Site Layout in the Hilly Regions Using GIS

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## Abstract:

In hilly region workspace is always a limited resource. The proper allocation of workspace to various resources is difficult due to the change in topography, involvement of number of temporary facilities, and interlinked constraints. Space constraints present on hilly regions affect the site layout planning, influence productivity and safety issues. To use the available site space and enhance the safety and productivity of construction operations, number of site layouts should be generated and analyzed in advance. Workspace available on construction sites should be allocated according to schedule, productivity, and space constraints. A GIS-based methodology was developed for allocation of workspace on a construction site. It identifies the suitable locations of various temporary facilities. The developed methodology was tested for assessment of construction site layouts of a building located on a hilly terrain of Jawaharlal Nehru Government Engineering College (JNGEC) Sundernagar, Himachal Pradesh.

Keywords: Construction site, Temporary Facilities, GIS

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Introduction
The success of a construction project depends on the effective and efficient allocation of workspace to various facilities on construction site known as site layout planning. Site layout planning identifies various facilities to support construction operations, determines their sizes, shapes and places them within the available site space [1]. The congested sites such as hilly regions where workspace is limited need to be planned carefully and efficiently as workspace being crucial affect the production and safety of facilities [2]. Despite the crucial role played by the workspace, site layout planning is often neglected, and construction professionals believe that it will be done by the site engineers as the project progresses [3].

As the project grows, more and more space is occupied by permanent facilities leaving less space to position supporting facilities [4]. Site layout is normally accomplished by site engineers on construction sites. Site engineers 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 numbers and sizes of temporary facilities (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 [5].

TFs are those facilities that serve the construction site but are not being considered as a physical part of the facility to be built [6]. Examples of TFs are material stores, fabrication yards, lay-down areas, parking lots, offices and warehouses [7]. All construction projects require considerable number of TFs. The various types of TFs required are: space for site office, welfare facilities such as canteen, toilets, rest area etc., storage of materials such as cement, sand, bricks etc., and storage and fabrication of reinforcement etc.

Various techniques are used in developing the site layouts which differ from one another. The problem solving techniques range from mathematical models to knowledge-based heuristic methods. The mathematical models produce optimum solutions, whereas, knowledge-based heuristic methods produce good solutions. Heuristic technique depends on expert’s knowledge and experience of site planning expressed in a systematic form [7]. CAD based Systems introduce a geometric reasoning approach to facilitate easy visualization of the site planning process and encourage user participation [8]. For solving the site layout problem with unequal-size and constrained facilities Genetic Algorithms (GAs) are formulated [5]. GA along with the CAD environment optimizes the location of TFs on site [3]. GA is search algorithm based on the mechanics of natural selection and natural genetics [9].

Li and Love [10] presented a GA for facility allocation. 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, Virtual Reality (VR) technique is used [11]. VR is an advanced human-computer interface that simulates a realistic environment and allows participants to interact with it [12]. VR simulates the experience of moving through and interacting with a 3D site layout environment [13]. Neural networks (NN) solve problems by simple and highly interconnected computing elements called neurons. Annealed Neural Networks (ANN) a hybrid type of neural networks inherits features of both NN and simulated annealing [14]. Cheng & O’Connor [7] developed an automated site layout system for temporary facilities called ArcSite.
Anumba and Bishop [15] indicated that significant amount of time is lost due to work-related health and safety problems on construction sites. Now a day, construction industry around the world is implementing safety management systems to reduce injuries, and to provide a safe work environment on construction sites [16]. The researchers believe that proper site layout planning considering health and safety issues is important for reducing accidents on construction site [15, 17]. The understanding of safety considerations has facilitated in reducing the impacts of even environmental risks during and life time of a facility [18]. Safety hazards also affect human beings, and therefore their harmful effects should be prevented or at least mitigated. The facilities, which are positioned adjacent to neighbors of high harmful effects, pose health hazards especially when placed next to low/medium overhead service line and step-up transformer. Therefore, area adjoining these facilities requires due consideration. These areas should be prevented from being allocated to any TFs and should be referred to as restricted areas.

The concept of providing proper safety zones around a facility under construction is another consideration. Proper safety zones around construction areas prevent harm from falling objects. Various building codes/regulations in this regard should be explored and implemented for the achievement of this concept. The provision of safety zones should be made in adequacy with regard to relevant building codes/regulations like NBC [19], OSHA [18], and UBC [20]. The third issue regarding consideration of topography is vital if a facility is to be developed in a hilly terrain. The inclusion is important due to the unsafe interaction between placements of building material such as sand, course aggregate, reinforcement etc. and natural runoff of water from site. NBC [19] indicated that areas within 2 metres from natural runoff shall be excluded from placing of any material on construction site located in the hilly region. The wrong placement of material particularly sand may lead to huge wastage due to washing away along with natural runoff. Therefore such material should be kept at a safe distance from natural runoff. A safe distance as per building codes provisions/regulations should be maintained between runoff and material. The important issues, which shall be included in the present study, are: restricted areas, construction safety zones, and minimum distance between natural runoff and material. Proper site layout planning, therefore, is a good opportunity for construction professionals to address several health and safety issues early in the construction layout planning.

Need for study
In current practice, construction site layout planning is often done in a speedy manner by adjusting previous plans based mainly on the site engineer’s experience and common sense. In almost all techniques used for the site layout planning problem, safety considerations and topographical aspects have been ignored or at least not modeled in an appropriate manner. Also, distances between facilities are not measured properly. These two main limitations lead to impractical modeling of the site layout problem, and hence need modifications to suit real-life situations.

Literature indicates that there is a dearth of responsive tools and resources to address safety issues in layout planning. Simultaneously, GIS is offering new ways to improve the inefficiencies of current processes of site
layout planning. The inclusion of safety considerations in site layout planning along with surrounding topography using GIS can improve occupational health and safety by connecting the safety issues more closely in the construction site layout planning. Therefore, present study is undertaken to explore the application of GIS for incorporating safety in locating temporary facilities on a construction site in a hilly region. In the present study GIS-based conceptual framework is developed to locate TFs. The main objective was accomplished through:

1. Identifying site layout elements and their codal provisions,
2. Modeling restricted areas, construction safety zones, and topography for minimum distances between natural runoff and material,
3. Analyzing the available area for safety considerations to identify the locations of TFs,

Formulation of Conceptual Framework

A schematic framework for developing a layout of a building is shown in Fig. 1. The schematic framework consisted of four steps: resource scheduling, space scheduling, site layout elements, and locating TFs by modelling restricted areas, construction safety zones, and topography.

In step-I, resource scheduling indicated that a project be broken down into N number of activities. Resources like material, labor, and equipment were computed corresponding to each activity. During step-II, area requirements corresponding to each resource besides considering the area requirement of building to be constructed along with internal roads and constraints. Later in step-III, site layout elements with regards to the workshop building were identified and in the step-IV, modelling of restricted areas, construction safety zones and topography was done to finally generate a map of suitable locations. Out of these suitable locations, a best location is chosen to locate first TF on construction site and the process is again repeated for locating second, third TFs and so on.
When a certain number of TFs are located for a particular time it leads to the generation of a layout. This process is repeated over the time and many layouts can be generated at various time intervals as per the need of the project. The entire conceptual framework for locating TFs at various time intervals is indicated in Fig. 2.

**Fig: 2-Conceptual framework for locating TFs.**

**Optimum placements of TFs**

Identifying the required number of TFs for a construction project and determining their effective areas is a difficult task for construction professionals as it needs thorough knowledge of safety considerations, restrictions or constraints, topographical conditions and various building code provisions. In existing practices, TFs on construction site are located on the basis of architects or engineers experience and knowledge. The selection or decision of TFs depends on certain considerations like type of construction, type of contract, project size and project location. Also, the identification of TFs depends on manpower available. However, the
type and number of TFs required for a project should be done prior to their sizing and location. The study conducted by Elbeltagi et al. [4] gives the list of common TFs required for a project. Having identified the required TFs and their areas, it is possible to optimize their locations within available site space. The effective locations of TFs within available site space shall help in improving safety of various resources and facilitate the interaction among TFs. In order to develop the framework for the optimum location of TFs, the guidelines were extracted and compiled from different sources, like exploring building code provisions, construction safety and health manuals, technical articles, and from discussion with some members of focused group. The topographical aspects of TFs are assessed and evaluated for various spatial conflicts so that safety of layouts generated at different interval of time can ensured. The process of locating various TFs at different locations and different interval of times generate the layouts. To identify and assess the effect of these TFs, topography of an available area is modeled. The suitable resource locations are general areas where codal provisions are satisfied. The spatial analysis is carried out to select general area that was free from spatial conflict and where codal safety provisions as discussed in previous section are satisfied.

The workshop building being constructed in JNGEC campus has been used to demonstrate the concepts formulated in the present study. The campus spreads over an area of 2.6726 hectares having elevation ranging from 208 to 328 metres. Initially, for the construction of workshop building in the present context, no formal site layout plan was developed by the contractor. The executing agency mainly depended on the general contractor’s experience in organizing the TFs on construction site.

Validation of Proposed Framework

Based on the project information, a site layout plan using the GIS-based framework was developed in the present study. The developed site layout considers site layout elements shown in Tab. 1 and takes into account the codal safety provisions.

<table>
<thead>
<tr>
<th>Type of entities</th>
<th>Layout elements</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site entities (SE),</td>
<td>Workshop building</td>
<td>As per existing</td>
</tr>
<tr>
<td></td>
<td>Existing Buildings,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power Lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transformer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Septic tank</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Road</td>
<td></td>
</tr>
<tr>
<td>Construction entities (CE)/TFs</td>
<td>Temporary site office</td>
<td>120</td>
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<tr>
<td></td>
<td>Labors rest area</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Rebar fabrication/storage yard</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Tank</td>
<td>20</td>
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<tr>
<td></td>
<td>Long term laydown yard</td>
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<td></td>
<td>Material storage space</td>
<td>100</td>
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<td></td>
<td>Scaffold storage yard</td>
<td>80</td>
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<tr>
<td>Constraint entities (Cons.)</td>
<td>Site boundary</td>
<td>As per existing</td>
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<td></td>
<td>Steep slope</td>
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<table>
<thead>
<tr>
<th>Datasets</th>
<th>Data type</th>
<th>Safe distance required</th>
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</tr>
<tr>
<td>Road</td>
<td>Feature class</td>
<td>4.5 metres (15 feet)</td>
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<tr>
<td>Electric line</td>
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<tr>
<td>Runoff Pattern</td>
<td>Feature class</td>
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<tr>
<td>Existing buildings</td>
<td>Raster dataset</td>
<td>6 metres (20 feet)</td>
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<tr>
<td>Electric transformer</td>
<td>Raster dataset</td>
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</tr>
<tr>
<td>Water tank</td>
<td>Raster dataset</td>
<td>1.2 meters (4 feet)</td>
</tr>
<tr>
<td>Workshop building</td>
<td>Raster dataset</td>
<td>3.05 meters (10 feet)</td>
</tr>
<tr>
<td>Land use</td>
<td>Raster dataset</td>
<td>-</td>
</tr>
<tr>
<td>Tin elevation</td>
<td>raster dataset</td>
<td>-</td>
</tr>
</tbody>
</table>
Development of input datasets
GIS was used as a single spatial database of the various site layout elements consisting basic structures i.e. workshop building to be constructed, TFs facilitating the construction of workshop and Cons. E. These site layout elements consist of the information about existing facilities/utilities like existing buildings, power lines, road etc., required TFs such as temporary site office, material storage etc., and topography. In order to validate the proposed framework that identifies TFs for the workshop building, input datasets were created in ArcGIS. The number of input datasets remains variable and different for different projects. In the present study, ten input datasets along with codal provisions as shown in Tab. 2 were created.
Fig. 4 indicates that construction site of workshop building is adjacent to the electric transformer and electric supply lines. In this case, it is important to keep sufficient distance in providing TFs that may have hazardous effects (such as electrocution, power failure due to falling of materials from heights etc.) from being positioned adjacent or near to such sensitive facilities/utilities. Therefore, a pre-specified area in the construction site layout must be prevented from being allocated to facilities with injurious effects. NBC [19] indicates that an area of 4 feet (1.2 metres) width shall be marked as restricted area along the sides of electric line and transformer to stop the chance of any accident.

Fig: 3-Map showing suitable locations for TFs.
Fig: 4- Safety zones and restricted areas.

The restricted area is shaded in the Fig. 4 for safety point of perspective. Further, if facilities/utilities are provided on construction site without giving due considerations to the distances between them, a minimum distance between such facilities/utilities should be pre-specified.

The minimum distance is user-defined and should be carefully chosen from building code/regulations to prevent dangerous interaction between facilities. Building code provisions regarding such TFs considered in the present study were modeled in ArcGIS.
Safety zones act as a buffer to protect any person who might be injured by the fall of materials, tools, or equipment being raised or lowered. The uniform building code [20] indicated that at least 10 feet (3.05 metres) clearance from buildings/facility shall be kept clear. Driveways shall be at least 15 feet (4.50 metres) wide and free from accumulation of rubbish. Further, codes/regulations indicated that inside buildings under construction materials shall not be placed within 6 feet of any hoist way or inside floor opening. In the present study, a distance of 3.05 metres (10 feet) around workshop building was buffered as safety zone. Other input datasets considered in present study were also assigned with safe distances to create safety zones around them as appended in Tab. 2 and these safety zones were modeled in ArcGIS.

The understanding of topography facilitates the placing of building material such sand, coarse aggregate, bricks etc. reasonably at flat surface away from natural flow of water. This further help in reducing the wastage of material like sand, gravel etc. In the present study, TIN of the JNGEC campus created in ArcGIS was utilized for identifying the alignment of natural streams of water in the campus. Further, a distance of 2 meters was buffered around these natural runoff streams for the purpose of excluding this area for consideration while locating TFs.

Analysis
Later, Geo-spatial analysis was carried out to generate a map displaying suitable locations for locating first TF (Fig. 3). The datasets derived from the input datasets are: slope from TIN elevation, distance from boundary of the campus, distance from electric line, distance from existing buildings, distance from workshop building under consideration, and distance from transformer. Deriving slope from TIN elevation was utilized to identify the alignment of natural streams. Besides this, the idea of deriving distances from various aspects considered clearly indicated that how far a facility is from a particular point. It helped in finding out the Euclidean (straight line) distances from workshop building considered in the present study. The values in derived datasets were floating points, continuous, and in different ranges. It is not possible to combine these datasets as such in present form to get a meaningful solution in locating TFs. To combine the derived datasets, these need to be set to a common measurement scale, such as 1 to 10. The common measurement scale helps in determining how suitable a location is for any TF. Higher values indicate more suitable location for TFs. Using the Reclassify tool functionality available in ArcGIS; the values of each derived dataset, were re-classified to a common scale of 1 to 10. Higher scale values (SV) were given to attributes which were more suitable and lower values to the least suitable attributes. For example, slope dataset was reclassified by slicing the values into 10 equal intervals. A higher SV was assigned to the most suitable range of slope (0-2°) i.e. flat terrain and lower SV to the least suitable range of slope (29-35°) i.e. hilly terrain in the present case study. To evaluate the natural flow of water in a region, stream order dataset was reclassified and highest SV was assigned to the horizontal surface, lowest SV was given to the steep sloped area. Now all input datasets are changed to a common measurement scale and ready for combing and weighing. These datasets are called as reclassified datasets.

With the use of Weighted Overlay tool functionality available in ArcGIS, reclassified datasets were combined at a point. These reclassified datasets are assigned scale values from 1-10, no data and restricted area. The detail
of the scale values and restrictions assigned to various datasets is given in Tab. 5. The land use dataset is also combined in its original form to weight the cell values as a part of the weighted overlay process. Values representing roads, existing building, restricted areas, safety zones around buildings and buffed zones around natural streams are changed to no data and restricted areas. Potential area is assigned the highest value. The input datasets shown in Tab. 2 were assigned percentage of influence which is variable with choices of architects or engineers evaluating the locations of TFs. In case of all data sets are equally important, equal percentage of influence can be assigned to the input datasets considered. In the present study, locations of various TFs are considered to be affected variedly by different input datasets. Hence various datasets are assigned different percentage of influence. Higher percentage of influence is assigned to datasets having more influence in locating TFs.

Conclusions
In hilly region due to scarcity of workable space layout planning is significant. This study overviews different approaches and techniques of site layout planning and outline the factors that contribute to unsafe sites conditions. A GIS-based framework developed facilitates in identifying the suitable positions of various TFs. The number and sizes of construction entities entirely depends on the availability of site space e.g. in hilly regions number of construction entities/temporary facilities shall be less as compared to plain areas. The concept of considering space as most crucial resource especially in hilly regions provides construction professionals with new perspective in terms of locating various construction resources more effectively. The study sensitizes construction professionals regarding the importance of various critical elements of layout planning. GIS-based framework facilitates in minimizing construction conflicts and improves project efficiency. Study highlights that consideration of safety issues minimizes the chances of errors during construction stage, helps in completing the project with less cost and ensuring safety of various construction resources. Inclusion of safety consideration during layout plan facilitate in reducing the risk of various hazards during and life time of a building. It highlights that consideration of topography helps in reducing the wastage of building material.

References


