A Simulation Environment for Construction Site Planning

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Abstract

This paper presents the design of a simulation environment for the modelling, visualisation and optimisation of construction site layouts. This construction site workspace application aims to support the site planning task by analysing space and risk on the site and generating automated site layouts which satisfy a combination of cost, efficiency and safety criteria.

The construction site simulation environment forms part of an EU funded project called DIVERCITY (Distributed Virtual Workspace for enhancing Communication within the Construction Industry). This involves 9 commercial and academic institutions from 5 European countries, and is concerned with the development of virtual simulation prototypes to support the client briefing, design review, and construction planning stages of the construction process. The site analysis module comprises a safety analysis component, a space analysis component, and an optimisation component. The safety analysis component is a generic model for the graphical and numerical representation of risk/hazard spaces. The space analysis component represents and classifies the various spaces on the construction site according to their relative importance in terms of accessibility and visibility. The optimisation component takes safety and space analysis information, and performs site layout optimisation according to travelling distance minimisation, risk minimisation, and space use maximisation criteria.

1. Motivation

Site planning in terms of organising the site layout to facilitate construction activities is among the most challenging tasks of the construction planning process, and involves several steps of human interpretations and manipulation of data and knowledge. Despite the significance of this stage, the spatial organisation of the construction site layout in terms of the allocation and arrangement of the different spaces on the site has not been satisfactorily accounted for by IT modelling tools. This task tends to be carried out manually by planners, despite the implications of an increased cost and risk of activities at the site. Efficient simulation tools are therefore needed to support site planners/mangers to better analyse the site layouts in terms of space and safety, and generate improved site plans accordingly.

Recent research at UCL [13] suggests that 20% of reported construction accidents can be attributed to poor site logistics and that low productivity is highly linked to inefficient space planning and conflicts between subcontractors. Other studies, in South Africa, have shown that a substantial loss in materials and productivity occurs due to the lack of integrated planning systems and optimisation of site construction activities [10]. The spatial domain is critical to construction projects and efficient tools to handle the changing spatial arrangement on the site, over time, is still yet to be developed. The placement of the temporary facilities on site, a key site layout planning task, is still carried out by planners based only on their experience and intuition usually resulting in increased transportation costs, loss of time, and inefficient use of resources [11]. Another issue which has become continually apparent to the construction industry in the UK and elsewhere, as being critical to the construction activity is safety on the construction sites. In the last 25 years, 2,800 people were killed on UK's construction sites as a result of construction activities and many more have been injured or made ill [8]. An estimated cost of £760 million each year results from injury and ill health caused by work, and from accidental damage to property and equipment. Site operatives falling from height is the largest cause of accidental death in the construction industry and accounts for over 50%

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of those accidentally killed. Other major accidents involve people being hit by falling objects, or accidents involving vehicles and plant. These causes are closely related to the use of space on the construction site, and could therefore be reduced considerably through better organisation of the site layout. Therefore, IT tools are required to support planners with the early evaluation of spatial organisation of the site and its time, cost and safety implication on the construction activities, and to assist with providing enhanced site layouts, hence, more efficient and safer workspaces on construction sites.

2. Aims of the construction site simulation environment

This work aims to design a modelling and simulation platform for supporting the construction site analysis stage, and allow the evaluation and optimisation of the construction site layouts. In particular, it addresses the space planning aspects by assisting with the representation and management of spatial requirements on the construction site.

The key objectives of the site simulation environment are the graphical and numerical representation of spaces on the construction site from the perspectives of safety and efficieny of space use, and the application of optimisation to assist site planners with the multi-criteria issue of organising the site layout.

3. The state-of the-art technology

New tools for constructions site planning could benefit from the significant advancements in computer graphics, simulation and artificial intelligence. VR technology has started to emerge as a powerful and useful tool for construction applications, as it can produce realistic and interactive presentation of buildings. Extending to 4D simulation, where 3D objects are assigned behaviour and relationships to each other can enhance the simulation of the construction activity by displaying the construction progress over time. Fisher [4] discusses the benefits of 4D CAD beyond the visual simulation, in terms of providing the ability to collaboratively produce and evaluate design proposals.

New techniques for the analysis of spatial patterns of access and visibility known as space syntax have been developed and are now being applied in design decision support. Space Syntax is an approach for mathematically representing and analysing spatial patterns and properties, which could reflect on the potential for seeing and accessing space [7]. Space syntax establishes spatial relationships between objects and treats a spatial configuration as a global system in which local changes produce global effects across the system. These methods offer the potential to quantify the relative significance of different spaces within a construction site.

Site planning could also benefit from advancements in probabilistic optimisation to generate automated site layouts. Techniques such as genetic algorithms and simulated annealing [6] [9] can perform fast and efficient search through a very large number of possible solutions for enhanced site layouts according to multiple criteria that would otherwise be computationally too expensive, or sometimes prohibitive, to solve using traditional search methods.

A number of applications have emerged from the increasing realisation of the potential advantages of the aforementioned techniques for construction site planning. Work carried out at Stanford University [1] uses a 4D CAD construction model for the detection of construction activity conflicts in 4D, and the categorisation of those conflicts according to different types of time-space conflicts into design conflicts, congestion, safety hazard, and damage. However, this time-space analysis approach only accounts for the "micro" level activity space requirements. Therefore it was limited to the spaces required within the proximity of components being installed and not large-scale spaces located across the site such as cranes, vehicles, temporary facilities, etc.

VIRCON is an ongoing project [3] that aims to develop a prototype application for evaluation, visualisation and optimisation of construction schedules within a VR interface. It is intended to address construction planning in terms of its temporal and spatial requirements with respect to the site layout, and spatial dynamics of plant, people and material movement around site. VIRCON aims to provide spatial analysis of construction tasks around the site, by adopting a space analysis tool such as space syntax, for the analysis of construction spaces. Work carried out by Mahachi et al. [10] develops site layout plans using the genetic algorithm optimisation (GA). The planning of the site layout focuses on the organisation of the temporary facilities such as site offices, tool sheds, and storage areas so as to reduce the travelling distance between them and the other facilities [11]. The GA approach seeks to minimise the travelling distance, hence reducing the construction material handling cost. It performs a global search of solutions with different facility positioning arrangements.

4. Formalisation of the virtual construction site workspace

The virtual construction site workspace is a simulation platform that aims to model and optimise the construction site layout, by accounting for various spatial safety and their requirements. The objective is to present a support tool to the site planners/managers for improving the efficiency and safety of task execution on the site.

Detailed end-user requirements for this module were identified during the requirements capture stage of the DIVERCITY project, as follows:

- The use of a user interface and/or GIS data, to initialise construction site layouts in terms of the building space, vehicle space, logistics and equipment's spaces, temporary works space, temporary facility spaces, etc.
- Assessing the spatial configuration of the site layout and its implication on accessibility and visibility of the vehicles, personnel and equipment in the site.
- Safety evaluation of the construction site by simulating the hazard zones surrounding the different spaces.
- Evaluating the distribution of the temporary facilities on the site and its implication on the travelling cost (time) of workers and materials.
- The incorporation of an optimisation approach for improving construction site layout with respect to a combination of the aforementioned efficiency, safety, and cost criteria.
- The visualisation and the interaction with the simulation by using a VR interface.
- Linking the construction site workspace to a buildability schedule so as to obtain time-varying site layouts.

The construction site analysis tool forms part of the research carried out by the virtual prototyping, at the centre for Virtual environments, Salford University, which involves the use of Virtual Reality, 4D Buildibility simulation, and constraint-based modelling, space analysis and probabilistic simulation, for creating virtual construction planning modelling systems. The Buildibility simulation module facilitates the visualisation of the building construction sequence according to a construction schedule [12]. The user interacts with the VR environment by selecting and adding building components to the model. A geometric constraint based module [5] defines the relationships between building components and applies algorithms to perform constraint recognition and handling between the components, which allow for automatic recognition of collisions and allowable movements. The project's schedule is linked with the virtual display of the construction sequence, which allows the visualisation of the construction sequence to be carried out over time.

5. Design structure

The site planning workspace evaluates the spatial organisation of the construction site and provides for ways to generate enhanced site layouts. The following steps represent the main design functions that would be carried out by this site planning module (see figure 1):

- Site layout initialisation: initial layout is generated by the user interacting with a VR environment and populating the construction site with different spaces (vehicles, building components, temporary facilities, etc), taking into account schedule information. Alternatively, an initial site layout is constructed from GIS or CAD data.
- Safety analysis: determines the hazard zones of site spaces such as cranes, vehicles and equipment, according to their variable degree of risk and dimensions.
- Space analysis: defines movement paths and fields of vision for people and vehicles, and evaluates accessibility and visibility on the site.
- Optimisation: the generation of a favourable spatial arrangement of the site using an optimisation algorithm, a user defined risk minimisation, space use -efficiency-maximisation and travelling cost minimisation criteria.
- The Buildibility schedule provides information on the changing spatial dimensions of objects on the site over time, such as the size of the building or the material store, etc. This information could then be fedback to the site modelling and optimisation modules, to evaluate the site layout at different stages of the construction period on site.

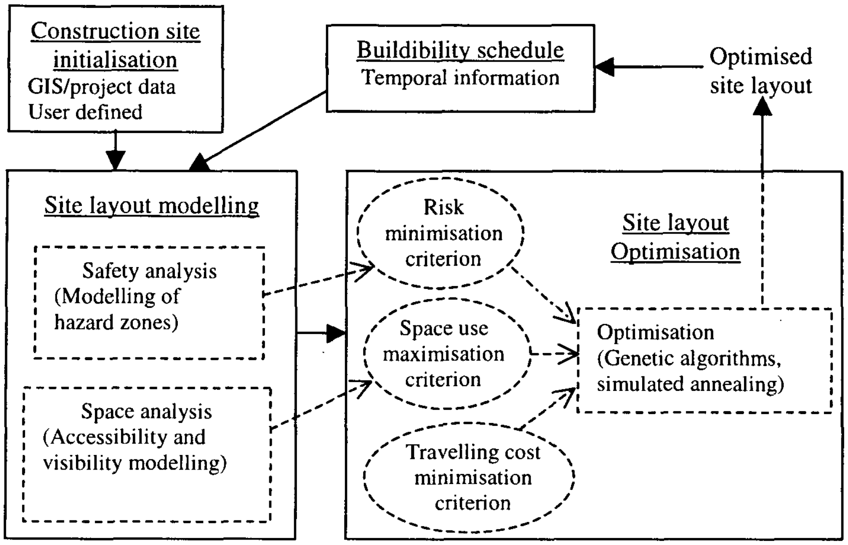


Figure 1. The design components of the construction site planning module

6. Results

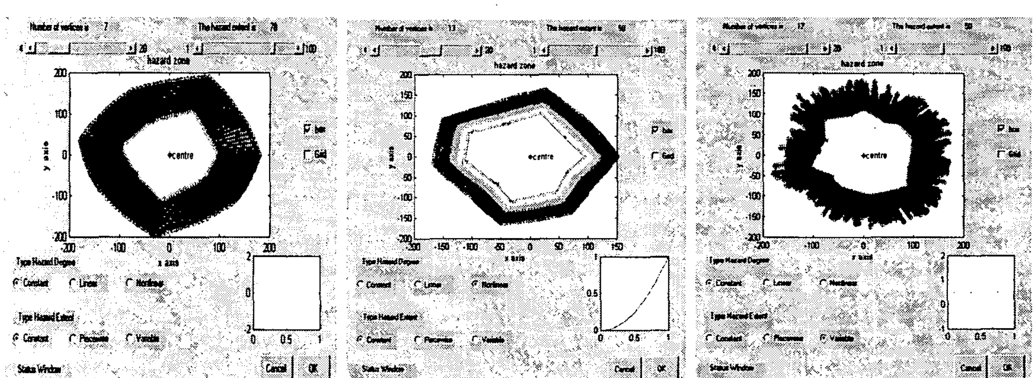
The following results represent progress to-date on the safety analysis, space analysis and optimisation parts, for which 2D analysis and visualisation (i.e. top-view of the construction site layout) is currently adopted.

6.1. Safety analysis

Hazard zones are represented by regions that vary in terms of the size of the hazard area surrounding a space and the distribution of the degree of hazard across these regions. Figure 2 shows examples with a constant hazard distribution (Fig. 2-A), a hazard zone with different levels of hazard (Fig. 2-B), and a hazard zone with variable extents of hazard around a space (Fig. 2-C). This allows the generation of hazard zones of different dimensions and complexity for different spaces on a construction site.

6.2. Space analysis

The space analysis component relies on analysing the spatial layout of a site using isovists or fields of vision. The idea of space analysis using isovists were first introduced by Benedikt [2], and are also used as one of space syntax's modelling techniques. The isovist of a point in space is the visible field from that space, and can be thought of as the geometry obtained by casting light rays in all directions from that point.



A- Constant hazard distribution   B- Variable hazard levels   C- Nonlinear hazard distribution

Figure 2. Hazard zones with different types of distribution

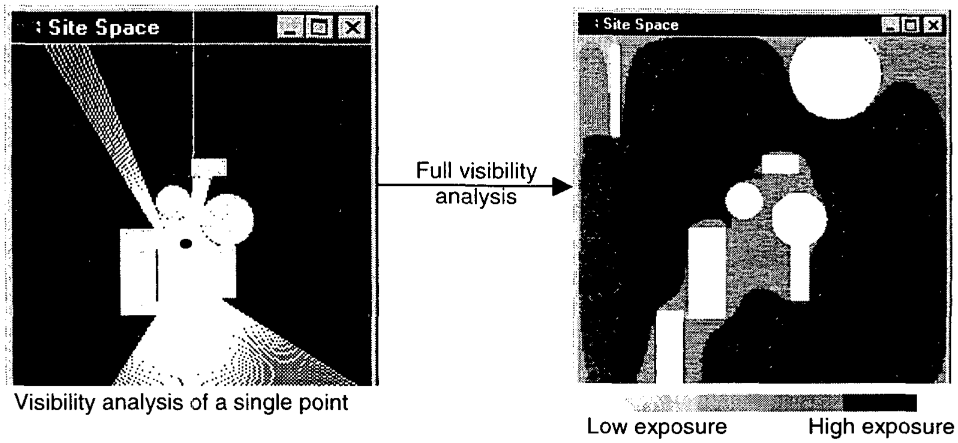


Figure 3. Visibility analysis of site space using fields of vision (isovists)

Figure 3 shows the result of applying visibility analysis using isovist on a proposed site space layout to visualise regions in the site, which offer higher visibility. Spaces with higher levels of "exposure" can then be used by the site planner to take more informed decisions regarding to the positioning of the different types of temporary facilities such as staff rooms, parking spaces and installations, in strategic areas on the site.

6.3. Optimisation

Figure 4 gives an example of the potential use of mathematical optimisation for the positioning of temporary facilities (TF)s on the site. Figure 4-A shows a site layout and a number of pre-occupied spaces with their corresponding hazard zones, the user then proposes a distribution of 4 temporary facilities such as in figure 4-B.

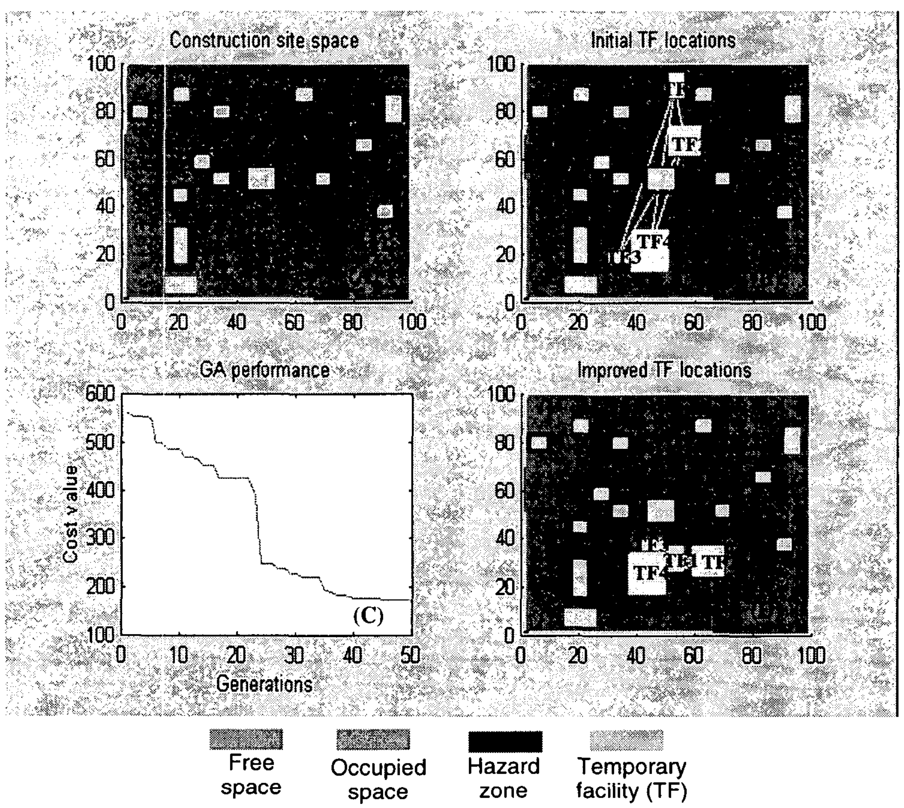


Figure 4. Distance minimisation between temporary facilities using genetic algorithms

For the case of this example, a -single- distance minimisation criterion between the locations of the TFs with the constraint being avoiding pre-occupied spaces and hazard zones. A Genetic Algorithm (GA) [6] is applied on an initial population of possible solutions including the user's initial solution, together with the optimisation criterion and solution constraints, to evolve it over a number of generations into a population of (low-cost) high-performance solutions (Figure 4-C) with regard to the optimisation criterion. After 50 generations, the best solution of the GA population presents a layout for which the travelling distance between the temporary facilities is minimised (Figure 4-D).

7. Conclusions

The aim of this paper was to present a simulation application for the evaluation and optimisation of construction site layouts. The objective was to allow the user to perform efficient spatial evaluation of site layouts, and then generate spatial configurations for construction sites optimised with respect to the combined cost, and safety aspects of the site planning task. The idea was to facilitate the visualisation, modelling and optimisation of the site layout from a variety of spatial requirement perspectives that planners would normally consider in a real site layout design case.

Future work will focus on carrying out a case study on a construction site so as to test the site analysis and optimisation functionality with 'real-world' site layout scenarios.

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