Assessing Space Criticality in Sequencing and Identifying Execution Patterns for Construction Activities Using VR Visualisations

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Abstract:

Current practises of construction project planning involve a number of methodologies/techniques that model dependencies and sequencing of project activities. Among these techniques are the bar charts, network diagrams, and time-chainage diagrams. None of these techniques has the capabilities to model and visualise both sequencing and execution pattern of activities.
It has been recognised from CAD applications in manufacturing that simulation of sequencing production activities using 3D models integrated with schedules prior to execution could lead to better understanding and evaluation of production processes before site operations commence. Therefore, the construction industry needs to implement new approaches to planning on-site project activities and for better judgement and communications of schedules among project teams. The purpose of this paper is to discuss the development of a methodology to achieve the objectives of the research and in particular 4D space planning and structuring CAD project information for the purpose of integration and visualisation.

Keywords: 4D CAD, construction activities, space modelling.

Research Background:

The construction of a building is a process that requires many individual activities to be planned and managed. Traditional techniques for planning these activities have involved text description and a number of 2D technologies including bar charts and network diagrams [Morris, 1994; Woodward, 1975]. Based on CAD application in manufacturing, there is recognition that simulation of sequencing and identifying execution patterns of activities in construction projects using 3D models prior to execution could strengthen the management of construction projects.

Although project managers consider workspace in their planning resources, it is defined as in the form of offices, accommodation and stage spaces for materials, i.e. a static space [Armstrong-Wright, 1969]. A spatial analysis of a pilot case study was performed on a £6 million construction site at the University of Teesside indicated that there is about 30% of non-productive time on site due to the lack of detailed and space planning. It was concluded that the lack of space planning of activities resulted in space conflicts, long journey paths, unavailability of access to rooms, inefficient utilisation of time [Dawood et. al., 2000]. Virtual Reality (VR) visualisations and analysis allows the exploration of 'what-if' scenarios and could identify problems of space configuration in the early stages of project planning.

Research Problem:

A number of authors have referred to the phenomenon of 4D (3D + time) space planning and have proposed methodologies for linking 3D models with time [Retik and Adjei-Kumi, 2000; Fischer et. al., 1996, 1997; Morad and Beliveau, 1991]. Many of the 4D-CAD systems proposed by these authors are being developed with the purpose of examining constructability, buildability, and scheduling. All of these systems are based on linking finished products to time elements and they do not offer the industry any assistance in examining and rehearsing the product development processes. Riley and Sanvido [1995] and [Riley, 1998] described various patterns of construction workspace that underpinned some space properties such as paths, operators, access points, storage/unloading areas, and so on, which interfere with tasks in-progress. In this context, the purpose of our study focuses on the inclusion of such dynamic spatial attributes of construction activities while rehearsing the sequence to execute these activities. Therefore, the objective is to re-produce construction schedules with least spatial clashes between work-packages and to include space as a resource in a similar representation to Work Breakdown Structure (WBS) [Pilcher, 1992].

Research Aim:
The aim of this research is to develop a methodology and a tool that allows construction planners to sequence and assess execution patterns of construction activities and identifies spatial conflicts using visualisation and analytical tools. It is intended to assist those professionals responsible for the planning of a construction project by improving their skills in sequencing project activities. The study will include a survey of the current techniques and project planning methods and the development and verification of the tools.

The main objectives of the research are:

1) A thorough review of the previous and current state-of-art research to identify problems with space planning and space-time conflicts on construction sites.
2) Study different construction execution patterns to extract space related information.
3) Identify the WBS for activities and establish the best-interconnected hierarchy between CAD model components and its spatial attributes in relation to work progress to rehearse construction work patterns.
4) Develop a computerised model using 2D and/or 3D model of a building space that analyses space utilisation and investigates activity interference/clashes in a workspace, and to identify conflict-evidence in the work.
5) To evaluate the developed model in construction practice and direct future strategies for general applications.

Research Methodology:
Research methodology of this research project is as follow:

a) Revision of state-of-the-art literature in the area of 4D-CAD models.
b) Site observation to determine the relationships between the spatial configurations of work being carried out on-site and work activities.
c) Data capture and collection of project resources including CAD drawings, schedules method statement, as-built programme and therefore constructing a detailed analysis of activity-space relationships.
d) Identification and mapping of specification and processes of the proposed tool. In particular establishing dynamic relationships between resources and building objects.
e) Investigation of suitable software, programming language and tools for the research.
f) The development of the prototype 4D simulation model according to building components and spatial attributes through the utilisation of VIRCON database (project database being developed as part of an EPSRC research project). This will enable planners to explore different execution patterns while planning project activities.

g) Testing and validation of the prototype on other case studies and recommend further modifications.

Findings related to space-time conflict characteristics:
The research has been able to point out at particular reasons of space-time conflicts that might occur on construction sites:

- The project planning applications currently in use in the construction industry do not model spatial properties of construction activities. As a result, construction activities might share work areas in the same timing and that produces insufficient free space to work.

- A number of issues should be considered while producing a construction schedule. These are the execution pattern of work packages, the allowable amount of overlapping between these patterns, and the workflow direction within locations of work execution (zones).

- Spatial dynamics of activities lead to complex spatial problems and should be a major part/issue of the 4D model. Such addition of dynamic space requirements (i.e. activity process and resources) in the 4D simulation should enhance the process of rehearsing project sequence.

Work development to date:

- A review of the existing project planning strategies, relevant published documents, and state-of-art- 4D tools in relation with improvements of spatial issues in construction sites was undertaken. The study revealed that there is a substantial need for improvements in the area of space analysis on construction sites. We were able from the literature review to decide on the proper simulation model approach and methodology. The full review of current state of the 4D modelling has been achieved and we were able to formalise the construction knowledge required for structuring the 3D CAD model.

- A pilot case study was performed on a construction project. It explored spatial configuration on a construction site, the relationships between the executed work and improving productivity and performance.

- Significant progress was achieved in populating the graphical (3D CAD model) information into the VIRCON project database. The space requirements for the studied project activities have been captured from the CAD drawings, project schedule, and therefore constructing a detailed analysis of activity/space relationships was established. The geometrical properties of all CAD components in the project's drawing was extracted and stored in a database (see figure 1). The developed technique uses Visual Basic for Applications macros to read related space information from the CAD building components to be used for future manipulation. This VBA routine enables the representation of CAD graphical components in terms of object location and object size. Therefore, the geometrical representation of building spaces was automated and linked to its non-graphical information (MS Project schedule and resources) in the database.

- Major development from this research was in structuring the components of the 4D model in a standard layering convention. Our layering methodology is compatible with the British Standards 1192-5 for structuring the CAD information. Moreover, the research has implemented a hierarchical arrangement of 3D CAD components and the layers in such a way to harmonise with Project Breakdown Structure (PBS) and Work Breakdown Structure (WBS) of a building project. We called this central concept as *Space Breakdown Structure* (SBS), which will benefit the 4D visualisations in later stages in.

- The research developed a concept for creating 3D objects automatically by defining specific rules. This reduces the tedious process in modelling some of the support activity components (e.g. form work, excavation, construction areas, zones, and workmen freedom range). We present three developed types of CAD objects as follows:

    1) Rule one allows the automatic generation of an *Approximation Envelope* (AE) CAD component that has a ratio relationship to the related building component. For example, a surrounding box (or AE) component is generated automatically to occupy the area required for the formwork or steelwork around a pad foundation.

    2) Rule two incorporates resources like workman size, tools, equipment, and then an activity component is displayed and included in the visualisation. For example, the extra workman area object for pad foundation is displayed by extending the pad foundation component area plus the workman area.

    3) Rule three utilises space takeoff or extraction routine and subsequently visualises the occupied spaces by both finished activities and activities in progress.

Conclusion:

This paper has presented the methodology for developing a tool to assist project planner in sequencing project activities. The research included an in-depth literature review of the state-of-art in 4D visualisations, construction management planning strategies, approaches, methods, and technologies. We were able from our literature review to decide on the proper approach for the visualisation model. Not only we illustrated the logic and techniques behind constructing the 3D model, but also we described the level of detail required in order to match with the project schedule. Hence, a week-by-week model was constructed and project activities were linked with its 3D CAD model components.

Although the industry utilises its own convention of organising information in CAD layers, this research ensured that CAD layering corresponds with the British Standards 1192-5. The layering system has been integrated with the processes in MS Project.

The current CAD model has been simplified for our specific 4D visualisations. Three important features were considered in the developed model that could help reducing modelling efforts: one is the use of a unified method for drawing building components as in closed polylines; two is to arrange 3D building product in a hierarchical relationships; three is the inclusion of rule-generated CAD components.

Finally, a trial 4D simulator has been produced and developed by Visual Basic for Applications routines. The simulator is integrated with the VIRCON relational core database [Dawood et. al., 2000]. The computerised simulator is responsive to the space needs for project activities. When entirely automated and visualised in VR, it is believed to enhance communication between the project team and to develop space-planning methods in sequencing construction tasks.

Future work:
Future work will involve the development of scheduling strategies using the above graphical interface to rehearse different project plans. The research will investigate the possibilities of visualising the 3D model in virtual reality technologies. For example, viewing the 3D model in VR desktop and other immersive VR technologies like CAVE, and hemispherium environments.

We envisage expanding our scope about space verticality and horizontality. This task requires expanding the research strategy to include the horizontal and vertical activity spaces in the simulation model. It is believed that it would have a direct correlation with space takeoff analysis and further simulation of the construction execution patterns.

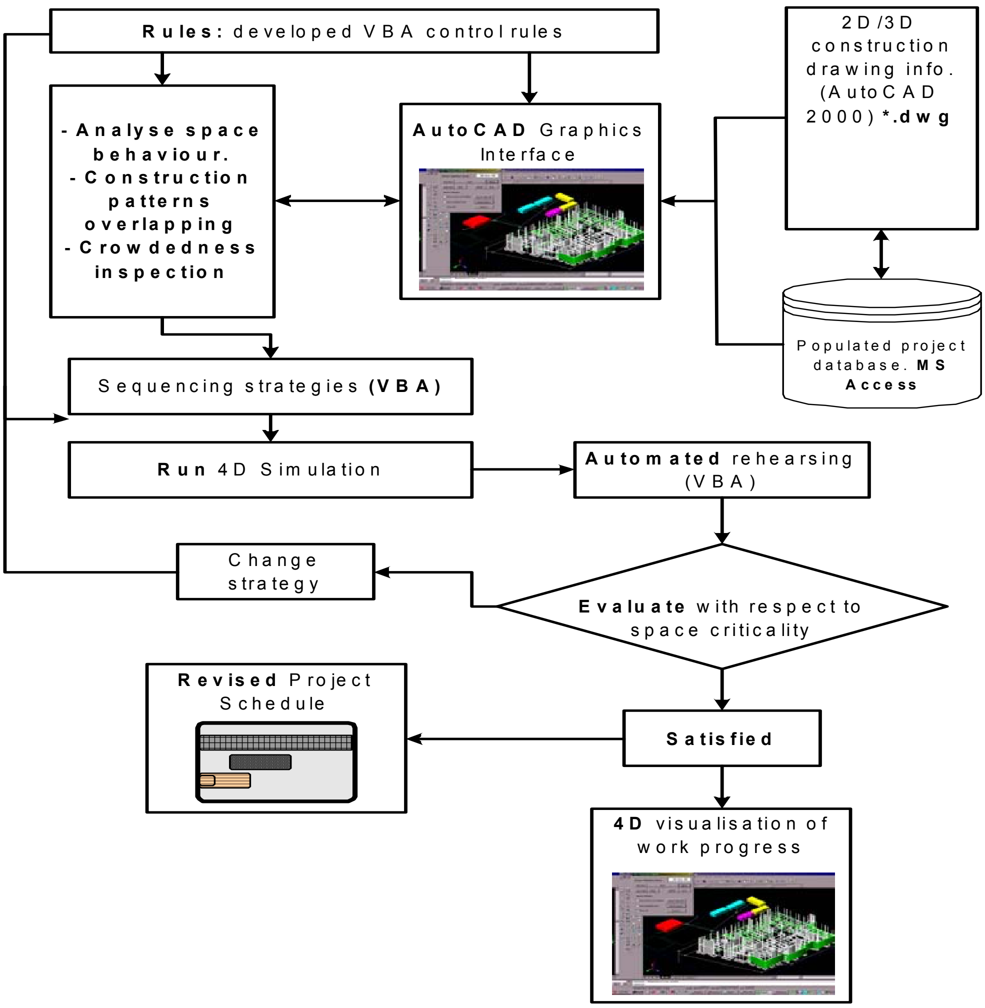

Figure 1: Flow chart of the visualisation environment for the space model

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