Theme:

Title: **Registering Space Requirements of Construction Operations Using Site-PECASO Model**

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Abstract: *The profession of construction project planning is facing new challenges due to the complexity in architectural and engineering design, short deadlines, enormous pressure from clients, and the need to build faster. Such challenges become problematic especially in large projects where construction operations shape complex spaces. The problem in current project planning techniques is that they do not include spatial requirements of construction operations as a resource in their schedules. In this paper, we report on the recent development of Site-PECASO model (Patterns Execution and Critical Assessment of Spatial Organisation) as part of our on-going research. The technique of 'registering' space can be divided into three parts: Extraction of geometrical information from CAD model; Application of space operation module developed in VBA; and structuring of CAD physical components in a hierarchy of Space Breakdown Structure (SBS) model. We show the current state of implementation and demonstrate the integration between the 3D-CAD model and the construction operations in the project schedule. In this context, Site-PECASO will provide project planners with a product-oriented simulation tool that highlights spatial clashes and interference between construction operations in real-time 4D (3D + time) environment.*

Keywords: *4D-CAD, execution patterns, space model, product modelling, product simulation*

Literature and Theoretical 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 simulations of the sequencing of activities in construction projects using 3D models prior to execution could strengthen the management of construction projects. Theoretically speaking, project managers do consider workspace in their planning resources. However, 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 pilot case study[1] was performed on a construction site at the University of Teesside that indicated 30% an average non-productive result. The insufficient planning for space properties while/before a project is in progress resulted in: space conflicts, long journey paths, unavailability of access to rooms, time lost, and therefore lack in performance (Dawood et. al., 2000; Harris et. al., 1998).

Considerably, 4D-CAD visualisations are gaining more popularity in the construction industry. It allows project planners inspection of 'what-if' scenarios before commencing work execution on site. Akbas (1999) confirmed that workspace and time-space problems are hard to spot in the bar chart schedules. Songer (1997) investigated the communication shift from 2D-paper information to 3D animations. Adjei-Kumi, 1997 made use of VR Planner (AUTOPLAN) to visualise the linking between a construction schedule and graphical representations of a building. Other 4D systems have been covered thoroughly like: OSCONCAD integrated construction environment (Marir et. al. 1998); CONPLAN (Hassan, 1997) is a knowledge based system which identifies and analyses buildability or constructability problems; 4D tools developed by CIFE which automates the visualisations of construction schedules (McKinney, et. al. 1998).

[1] The author as part of his on-going PhD research undertook this pilot study.

There are considerable number of process/resource simulation research that integrate simulation and expert systems. For example, SimEarth simulation system that provides realistic estimates of haulers' travel time in earthmoving operations (Marzouk and Moselhi 2001); CYCLONE (Halpin and Woodhead 1976) is an example of a process-oriented simulation; STROBOSCOPE (Ioannou and Martinez 1998) allows its users to model construction processes at an acceptable level of detail. However, a gap exists in these simulation approaches between the product, the simulated object, and the simulation model (Xu and AbouRizk 1999). A summary of shortcomings from process/resource simulation is listed below:

1. The available information from CAD systems are not used in the simulation which makes the computerised simulation non-cost effective.
2. The abstract notation of representing the construction operations increases the complexity of the simulation model.
3. Tedious effort is required to analyse data and information from phase to another (which is already available in the CAD models).
4. The simulation results lack the ability to generating meaningful reports, which project engineers are familiar with (e.g. CPM, estimating and animation).

Hypothesis and Proposed Problem Solution

Riley and Sanvido (1995; 1997) presented a manual method for planning construction execution patterns in a multi-storey building. Their study described construction space-types like: areas occupied by work, paths for loading/unloading materials, staging areas, storage areas, work areas, and so on. For the purpose of this study, we propose a broader concept of registering spatial requirements of construction operations. From one perspective, it offers a preliminary insight on the way we construct and organise 3D-CAD product models for future implementation in 4D-CAD product-oriented simulation (Xu and AbouRizk 1999). In another perspective, it identifies properties of construction execution patterns as an important input to analyse spatial usage while planning construction activities.

Our focus in this paper is to describe our research vision in registering spatial requirements for construction operations within CAD environment. This vision is central to our conceptualisation of Site-PECASO space model that will be used in the 4D-product simulation. The following section presents a general concept of space and then we decide on the used space terminology throughout this paper. In the next section, we explore in more detail the overall concept in registering spatial requirements. Then we describe an on-going research for implementing the space model within a product-oriented simulation approach to detect spatial clashes. Finally, we present our conclusion and point at future research interest.

Modelling Space in Building Construction

What is Space? In computational syntactic, the definition of space in the construction domain is hardly evident or explored (Ekholm and Fridqvist, 2000). One concept in today's world of science considers space as a relation between things, which is the accepted view now by researchers. In a second concept, space is the emptiness in which things are embedded, i.e., an entity with in immaterial existence. Space has no separate existence but is a property alongside others of the material world. A third significant concept of space has been described by Hillier (1996) in Space is The Machine. Hillier's personal view of social space in urban planning is as entities, which form a puzzling relationship especially in spatial terms. It was Hillier who introduced the concept of space syntax in urban planning and defined shapes of social spaces. It is highly acknowledged that space syntax encapsulates space as a thing relative to some defined attributes (e.g. personal space, spatial enclosure, spatial hierarchy, spatial scale, and so on). Space becomes more significant and vulnerable when tied to other entities that have meaning or description.

This principally proves that there are still some contradictions in space-terms and putting context to classifying building spaces specifically when a product modelling approach is chosen (Papamichael, et. al. 1999).

Space Terminology Used in this Paper

It is essential to explain our space-types[2] terminology that will be used throughout this paper. We will return to describe the relationships between these space-types in the light of our development in constructing the 3D-CAD space model.

- Space Types:
  1. *Product Space:* represents the construction activity component (e.g. Foundation Pad).
  2. *Process Space:* is utilised to reference the proper process components as presented in the project schedule.
  3. *Work Space:* is the location where a construction activity takes place (or work area).
  4. *Equipment Space:* represents the related equipment to the specific construction activity.
  5. *Storage Space:* contains temporary/permanent storage areas (e.g. staging areas).
  6. *Path Space:* contains the loading/unloading path for materials delivery and possibly equipment path (e.g. crane rail).
  7. *Support Space:* is for scaffold and other support facilities.

- *Space Behaviour:* is the measure for assessing space conflict. A highly conflicted space generates a high space behaviour measure, and the opposite is true. In other words, a space is said to be behaving badly because it contains maximum measurement of space conflict.

- *Execution Patterns:* is a concept introduced in this study in order to assist the simulation of construction operations. An execution pattern for a specific construction operation is a harmony of product elements executed in a specific order and flow. The spatial configuration of a specific execution pattern is dependent on the aggregation number (e.g. number of foundation pads) of the specific construction operation.

Registering Spatial Requirements

Site-PECASO Model Architecture

The proposed model architecture for the research prototype is illustrated in figure 1. *Site-PECASO* model has been designed to provide a simulation mechanism as an extension of VIRCON system[3] and therefore highlights spatial clashes/interference between construction tasks in real-time 4D environment (Dawood, 2000). All detailed project planning information, graphical and non-graphical information are stored in the database. As can be seen, the first component in Site-PECASO model relies on the inclusion of VBA control rules linked dynamically to the project database pool. The second component is the simulation mechanism, which acts as the engine for identifying the interference between construction operations. The evaluation component is composed of sequencing strategies with respect to criticality in assessing space conflict types. The main functionality of Site-PECASO creates a dynamic linkage between the project information store and the 4D-CAD visualisation, which will help in the assessment of the spatial clashes. The output from *Site-PECASO* is a rehearsed construction project schedule with least spatial conflicts between the construction activities.

Our methodology in this research compliments the existing research in 4D analysis and techniques (Thabet and Beliveau, 1993). It is why we have chosen to implement the integration approach of specific software applications. This included AutoCAD 2000, MS Project as the scheduling software, and MS Access as a relational database (Dawood et. al., 2001). As one of the main objectives of this research is in

[2] The author in defining these terminologies is expanding on the concepts of space described by Riley & Sanvido (1995).

[3] VIRCON is an EPSRC funded joint research between University of Teesside, UMIST and the University of Wolverhampton.

focusing on modelling construction processes and integrating them with project activities, it was decided to use Visual Basic for Applications (VBA) as the programming language. The connectivity between the graphical components in AutoCAD application and the data storage will be through the utilisation of ODBC. A special VBA code was developed in order to populate the CAD graphical components in the database through the DBCONNECT protocol in AutoCAD 2000.

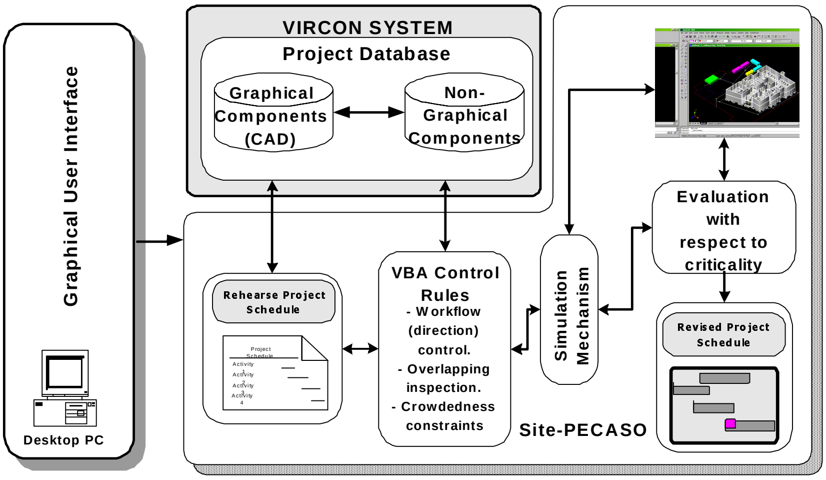

Figure 1: An Overview of Site-PECASO Model Architecture

Extracting Information of Space Types Requirements

The geometrical representation of building components in CAD drawings requires automated procedures to extract their spatial requirements. In order to accomplish this requirement, CAD design drawings were disintegrated and remodelled in various techniques. Here, the separated 2D Lines were converted into closed 2D Polylines. Further development here uses VBA macros to read space properties of CAD building components and store them in the project database. This information included object location (x, y, and z co-ordinates), object size (width, length, height, and area), and centre of the component's *Bounding Box* (Centre_x, Centre_y, and Centre_z). Therefore, the geometrical representation of building spaces was automated and linked to its non-graphical information (project schedules and resources) in the database.

Space Operations Modules

Undoubtedly, we view the solution to space conflicts between construction operations is by obtaining snapshots of space occupancy occurring at sequenced time intervals. Space operation modules delivered in this study assist Site-PECASO simulation method with needed information about space occupancy. We present five developed types of VBA modules as follows:

Module 1: allows the automatic generation of an Approximation Envelope box *(AE)* CAD component that has a ratio relationship to the related building component. Each *AE* construction component represents product or process activities that are not available in the CAD model (e.g. pad foundation formwork).

Module 2: is implemented in order to incorporate hazard space value while executing a specific activity (see figure 2). Depending on varied hazard space inputs by an experienced planner (e.g. pouring concrete or plastering a wall), and including required tools or equipment sizes, an array of that building component activity is displayed to symbolise the extra hazard space area. For example, the extra hazard space area object for pad foundation is displayed by extending the *AE* pad foundation component area to the added hazard space.

Module 3: utilises space-takeoff extraction routine, and subsequently visualises the occupied spaces by both finished activities and activities in progress (see figure 2). It is important to obtain such information about space occupancy, as it will be used later in the simulation and optimisation of the spatial behaviour and overlaps between construction activities. The module is associated with two selection methods: one is space-takeoff including Hazard_Extension and the other one is space-takeoff excluding Hazard_Extension.

Module 4: is an extension of module 3 space-takeoff described previously. The major functionality of module 4 is to perform *Boolean* operation of *Union* type and therefore combine the occupied spaces together as one space component categorised by each activity. It then places the resulted booleaned component in a new *'ActivityName_Space'* CAD layer. Figure 2 illustrates the complete outcome from applying this rule.

Module 5: checks for the overlapping between occupied spaces. In other words, it compares the position of each combined *ActivityName_Spaces* objects and then generates the intersection areas between *ActivityName_Spaces*. In this rule we employ the *Check_Interference* operation which will be used in the simulation mechanism and therefore highlight the spatial clashes between construction activities (see figure 2).

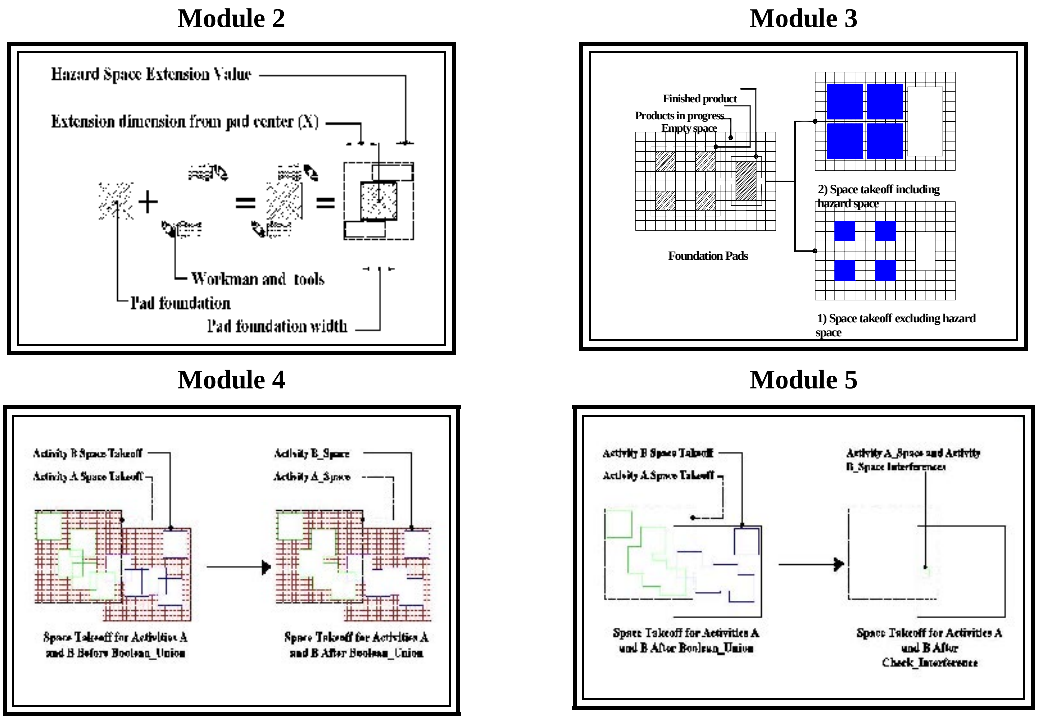

Figure 2: Space Operations Modules

The Space Model Relationships

Figure 3 presents Site-PECASO CAD space model showing the Space_Types in activities A and B. Careful considerations were taken whenever structuring the CAD model in layers. The space model provides a logical hierarchy of the product physical attribute in the CAD model. Such hierarchy furnishes an abstract representation of a Space Breakdown Structure *(SBS)* for the construction activities. The presented space model features an abstract concept in developing Site-PECASO product-simulation: the physical CAD elements are positioned in a special *Space_Type*[4] layers in an automated method.

[4] We have explained the seven Space_Types used in the space model at the beginning of this paper in space terminology section.

Representation of drawing components through structuring the information in layers in accordance with the current British Standards 1192-5 was established. The relationships between these *Space_Types* have a major role in linking the product simulation with the construction sequence.

AutoCAD 2000 has a static layering interface. In other words, there are no hierarchical relationships (parent/child) between layers. For such reason it was necessary to provide one layer for each activity (*e.g. Pad Foundation Layer*). Also, sub-layering creation method was automated in order represent space types for process and resource. The manual re-grouping of CAD components in the *Product Space* layer has an appropriate potential in describing sets of construction operation (on a weekly basis). Finally, the space model with its defined spatial attributes for the building *Space_Types* provides Site-PECASO with space-conflict taxonomy[5] to classify interference between construction operations.

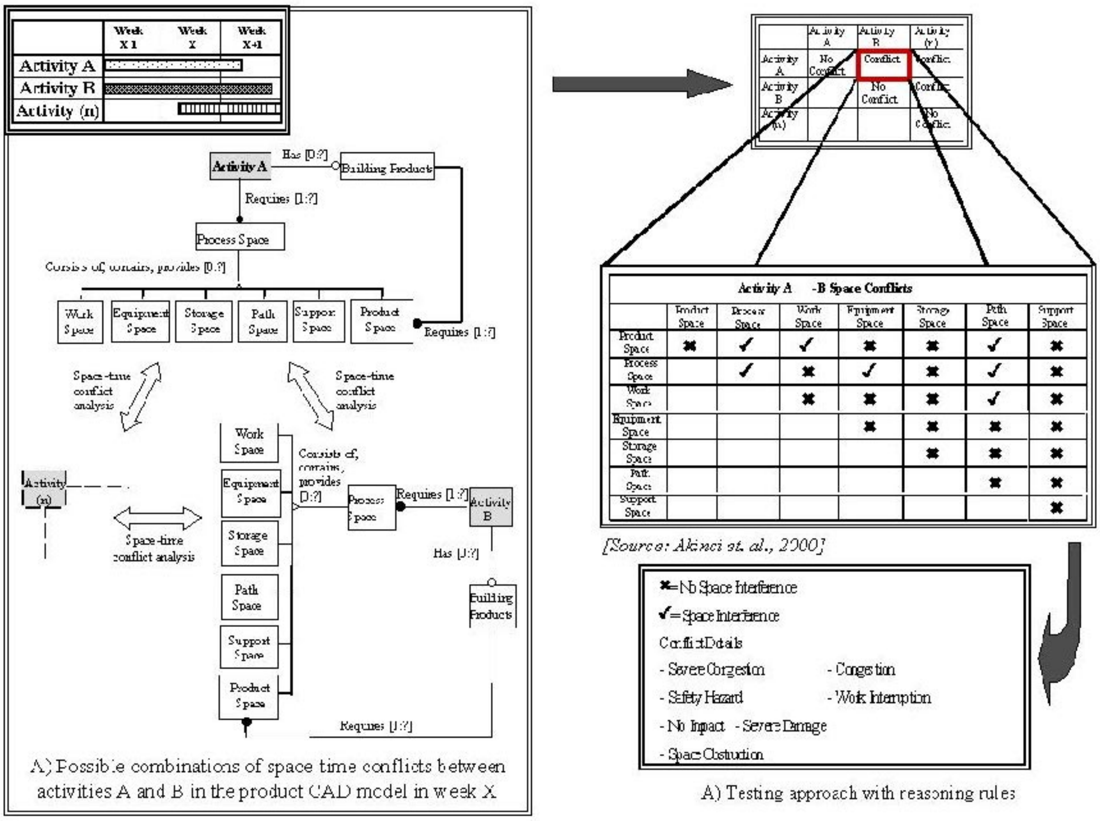

Figure 3: Space_Types Hierarchy Model and Space Conflict Taxonomy Implementation Strategy

A Proposal Towards Product-Based Simulation

Site-PECASO simulation runs take advantage of the developed VBA routines to communicate and integrate the space model and the project schedule. The core concept in the simulation is to highlight *Space_Types* overlaps and to keep a record of the execution pattern in order to alter its configuration in later simulation runs. Figure 4 illustrates an example of Foundation Pads activity which includes two groups: pads_phase1, and pads_phase2. The recorded execution pattern at the beginning of the simulation is pads_phase1, then pads_phase2. In the later simulation runs, the execution pattern is altered and will be pads_phase2, pads_phase1. This recorded trace of the execution patterns is saved as text file (ASCII) for space conflict analysis. This text file is used as a container to advise on the best execution pattern for a specific construction operation. The relationship between the product model and the execution pattern order within project schedule is presented in figure 4. For example, two phases in executing pad

[5] For a discussion on conflict types and its applications see Akinci et. al. (2000)

foundations are an aggregation of Foundation Pads parent-activity. The order or sequence of simulating different execution patterns of a construction operation is linked to the 4D-CAD model (CAD components *group 1* and *group 2*). For this reason, the project schedule must be in the same hierarchy as the product model. Therefore, for each parent-activity in the project schedule there is at least similar CAD component(s) in the product model. In this manner, the simulation is from a building-product point of view referencing process and tying it to the product model (Xu and AbouRizk, 1999).

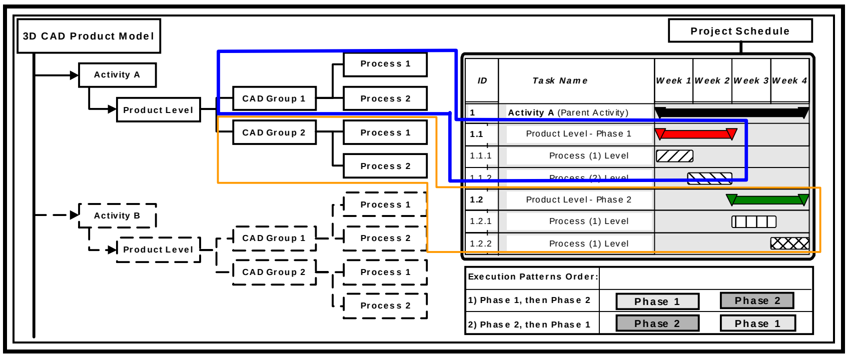

Figure 4: Execution Pattern Order Relationship with CAD Space Model

Conclusion and Future Work

This paper has presented the methodology for registering spatial requirements of construction operations to assist project planner in rehearsing project schedules. The research has defined seven related space types and illustrated the logic and technique in structuring the 3D space model. Most importantly, we have specified the required level of 3D CAD modelling detail 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. At the time of the development, this research ensured that AutoCAD 2000 information corresponds with the British Standards 1192-5 for structuring and exchanging CAD data. This is true, however, the construction industry could appreciate the benefits of IFC-based product models in the near future (especially its release with AutoCAD ADT).

The paper explained a methodology that has been utilised in Site-PECASO space model to develop a product-oriented simulation. The space model presents structured and detailed investigation of including different space types in a product model. On experimental basis, the space model has shown output results describing space occupancy, clashes between construction activities, and a recorded trace of the execution pattern in an ASCII text file. To fully take advantages of Site-PECASO space model and solve the space conflicts, we envisage the inclusion of further heuristic knowledge and rules in the minimisation of space conflicts. Finally, we envisage implementing more strategies within Site-PECASO simulation logic to reduce spatial conflicts based on selection criteria of space-time conflict types that have presented in this paper.

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