

THE VIRTUAL CONSTRUCTION SITE (VIRCON) TOOLS: AN INDUSTRIAL EVALUATION

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SUMMARY: *Visual 4D planning and scheduling techniques, that integrate 3D CAD models with the timing of construction activities, have proven to be more beneficial than traditional tools and are increasingly being employed on complex projects. In 4D models, project participants can effectively visualise and analyse problems regarding sequential, spatial, process conflicts and temporal aspects of construction schedules, prior to actual construction operations on site. The objective of this paper is to introduce and evaluate innovative visual planning tools that were developed as part of the VIRCON project. The VIRCON project, funded by EPSRC (UK funding agency), developed seven integrated IT tools with the objective of assisting construction planners to make accurate and informed planning decisions with particular emphasis on the allocation of activity's execution space. The successful development of the VIRCON tools was based upon the industrial requirements, real-life project data, and finally evaluated by the industrial collaborators. This paper will briefly introduce the VIRCON tools and thoroughly report on the industrial user evaluation. The aims of the evaluation were to establish the usefulness and usability of the individual VIRCON tools, and to indicate the potential towards commercialisation and real implementation. Ten collaborators from the construction industry evaluated VIRCON through a real-life case study. The space planning approach and visualisation features developed in this project were found to be practical and communicative.*

KEYWORDS: *visualisation, 4D modelling, space planning, user evaluation*

1. INTRODUCTION

The VIRTual CONstruction site (VIRCON) project brings together academic and industrial collaborators in an attempt to push forward the state-of-the-art in construction project planning. The project was funded by the UK government, with the prime objective to develop a strategic decision support system for construction project and space planning within a desktop environment. VIRCON has been developed in response to the realisation that there is a looming skills gap in the construction industry amongst those with the expertise to plan major construction projects. In addition to this, there is a range of technical opportunities becoming available which may make it possible to bring computing to bear on what has until now been a task that is only tractable by experienced and expert personnel.

The VIRCON system allows planners to trade off the temporal sequencing of tasks with their spatial distribution, resulting in a more robust and rehearsed project schedule. Also, the VIRCON visualisation tools allow planners to better understand construction schedules through 4D (3D plus time) simulation and ability to visualise

congestions and hot execution spaces on sites. During the past three years, the system has been successfully developed which was based upon industrial requirements, industrial real-life project data, and finally evaluated by the industrial collaborators. The prime objective of this paper is therefore to provide a background to the overall VIRCON system and to thoroughly report on the industrial user evaluation phase of the research project.

2. CONSTRUCTION SPACE PLANNING: VIRCON PROCESSES AND TOOLS

With increasing pressure for shorter delivery schedules, better utilisation of space resource on construction sites becomes more apparent. The Critical Path Method (CPM), a widely used scheduling technique in construction project management, however, has limitations to serve this need. Its fundamental was not designed to represent spatial and temporal aspects of the construction. Moreover, its underlying complexity creates difficulty to evaluate and communicate the schedule. To overcome these limitations, the Critical Space Analysis (CSA) concept that emphasises on dynamic spatial configuration of task execution, as opposed to static site layout planning, has been developed [refer to Winch (2002) and North & Winch (2002)] and more information about this is given below. A group of tools that supports the implementation of the CSA concept have also been developed, based on the industrial requirements capture [refer to Kelsey et al. (2001)]. Fig. 1 presents an overview of the VIRCON tools and their associated processes. These tools are grouped into four categories based on their functionality and are described and discussed in this paper.

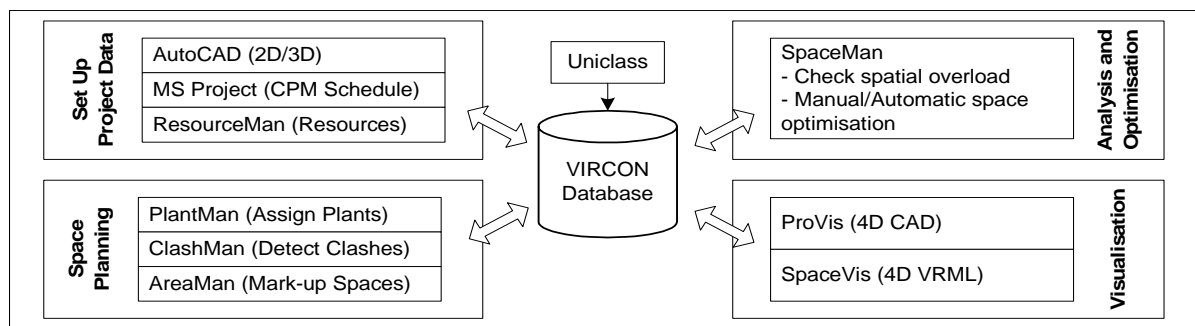


FIG. 1: Overview of the VIRCON tools

2.1 Set up project data

This process is about preparing the necessary data to run other processes and tools in the VIRCON system. Data on PBS is prepared in AutoCAD while WBS is prepared in MS Project. One of the first constraints that we encountered was the lack of standardization by CAD users such as architects and CAD technicians. Standardization is essential if integrated software tools such as the VIRCON system are to support and enhance the capabilities of construction planners to do their job. Set up phase involves four sub-processes including: a) prepare CAD data; b) set-up corporate resources database; c) VIRCON database; and d) populate VIRCON database. Each of these sub-processes is described below.

2.1.1 Prepare CAD and schedule Data

A pre-requisite work for generating visualization model for space analysis is the development of 3D CAD model. The level of details required for the model is very much depending on the nature of project. More complex projects that involve many disciplines (i.e., factory and hospital) would require more detailed and more accurate models to be developed. These detailed models can greatly help designers to ensure perfect interfacing between architectural components, building services, cladding and other building components. Furthermore, the models can be used as a communication tool that facilitates co-ordinations among various construction trades.

There are three types of 3D models that can be used to develop a reasonable planning and visualization system. The first type is called '2.5D model' which basically generated from simple extrusion of 2D CAD from a specified datum (McCarthy 1999). This type of model requires much less work in developing the original CAD model, and is appropriate where a 3D model is not justified for detailed analysis of product performance and clashes between products. The second type is called '3D wireframe or solid model'. This type of model requires true 3D modeling using polylines (wireframe) or solid CAD objects. The third type is referred to the 'IFC model' which is developed using a set of standard objects such as ifcColumn, ifcBeam, ifcWall, etc. This type of

model can be interoperable among different compatible CAD packages. The VIRCON project did not adopt IFC CAD but was potentially compatible with the IFC approach. At present, IFCs are a technology that may or may not achieve diffusion in practice, and there are issues with the level of readiness and completeness of the IFCs. This was true at the start of our research when we had to make the decision, and it remains true today.

A principal objective of our research project as part of the EPSRC/IMI programme was to encourage industry to utilise the tools and this meant using the CAD information that the industry is producing today and rather than what it might produce in 10 years time if IFCs were be adopted. The Teesside team has been involved in two major developments post VIRCON with the objective of producing 4D models for two commercial projects (White City project development with Balfour Beatty and Gas receiving facilities with F&G, project management arm of ATKINS). This would have been difficult if the system were designed to work on IFCs. The team has not yet come across designers, architectures or contractors who have been using IFCs in the UK, apart from on a few initiatives that have been funded by DTI. Our work is fully compatible with IFCs, and so its scientific impact should not be limited should the use of IFCs become diffused more widely. There are, therefore, no problems of lack of standardisation in this respect.

Once the 3D model is developed, each type of the product must be organized properly in separate layers. For instance, foundations should be in one layer which is separated from column and roof layers. In addition, BS1192-5 1998 was used as the standard for layering CAD drawings.

With respect to schedules and resource allocations, the processes comprise of five steps which are: (1) developing product-based work breakdown structure; (2) grouping CAD products; (3) linking product groups with activities; and (4) population of the VIRCON database. Product-based work breakdown structure is a medium that allows systematic and consistent integration of product and process data. In the case study that was used to for the evaluation process, it was found that the breakdown of activities in the original schedule didn't suit this requirement. Many products were not explicitly mentioned in activities. For instance, installation of extract fan, cable tray, and distribution panel are hidden in 1st, 2nd, and final fix M & E activities. This made it difficult to interpret the association between products and processes. To solve this problem, a product-based work breakdown structure was designed by considering the product layers in the 3D CAD model and activity list in the original schedule. The structure was broken down into four levels including: (1) Level 1 represented project title; (2) Level 2 represented summary tasks; (3) Level 3 represented products; and (4) Level 4 represented activities.

After all product groups are generated, the next step is to link these CAD groups with activities in MS Project. To enable this linking process, a new text field called 'Product Group' was created in MS Project. Considering the associated activity, the name of product group was then input into the Product Group field accordingly.

2.1.2 Set-up Corporate Resources Database

A stand-alone database management tool for legacy collection of resource data and space requirements was developed. The database holds information about plant and equipment that are available for the company to use and/or for the supply chain. Part of this information can come from manufacturers which include operation and space requirement data. Other information about efficiency and utilization can come from the company and its supply chain (Heesom and Mahdjoubi, 2001). ResourceMan is a relational database with a very user-friendly interface.

2.1.3 VIRCON Database

An integrated relational database that serves as a core infrastructure for the VIRCON system. The structure of the database was standardized in two ways. Firstly, we adapt the UK standard for the layering of CAD files, BS 1192-5. Secondly, we adapted the UNICLASS standard for construction project information using the principles of ISO Technical report 14177. The UNICLASS standard facilitates the integration of construction product and processes (Dawood et al. 2003). The initial product data input the VIRCON database comes from AutoCAD and process data comes from MS Project. AutoCAD data can be either 2D or 3D, and provide data on all components that makes up the facilities. All product information is populated to the database using a VB routine which has been developed in the course of this research dubbed DataExtractMan. Each table in the database represents a type of a product (i.e., foundation, first floor columns, etc) and all products coordinates and stored digitally in the database.

Populate VIRCON database: DataExtractMan – an AutoCAD macro that automatically interprets CAD layers (BS1192-5) and extracts 2D/3D product data into the VIRCON database. Using the layering standard, DataExtractMan creates a table in the VIRCON database for each layer in AutoCAD and reads all digital information in that layer and store them in the table, (Dawood et al. 2003). This is a fully automated routine and will save huge amount of time and efforts of the project manger providing that product information have been properly layered in CAD using BS1192-5.

It should be mentioned that not all project information is available at the pre-construction stage and sub-contractors might be reluctant to release information and commit them-selves and in particular their resources availability. Nevertheless project managers should be able to operate in this type of environment and VIRCON system was designed to be quick and intuitive and work with limited information. VIRCON database can also act as an IFC server and in this case the VIRCON tools can be used if and when IFC supported AutoCAD systems are increasingly used in practice (see Sriprasert, 2004).

2.2 Space planning processes and tools

Once the project data has been set up, it can be read for the purpose of the execution space planning for the project, the main sub processes of space planning are:

- **Assign Plant and Temporary Works to Weekly 2D Plan**
This process is about incorporating spaces needed for plant and equipment that are deployed in a given week into a weekly 2D plan of the completed facilities. A software prototype dubbed PlantMan was developed to achieve this process. It reads VIRCON database to produce weekly 2D plans of the completed facilities and then incorporates space requirement for plant and equipment from ResourceMan. PlantMan incorporates ClashMan tool which checks clashes between the assigned plant and temporary installations using raw detection collision detection algorithm. This is particularly important function as one of the important planning issues is to avoid conflict between temporary facilities and plant. PlantMan is a stand-alone software and communicates with VIRCON and ResourceMan via ODBC and produces 2D weekly drawings of the finished facilities with marked-up spaces for plant and equipments (Heesom and Mahdjoubi, 2002). This is then stored as DXF files to be accessed by another tool for marking-up space availability dubbed AreaMan. This is discussed below.
- **Mark-up Available Spaces**
Once 2D DXF files produced by PlantMan are ready, planners can access these weekly files to mark-up available spaces. Planners have to use their knowledge and experience to identify space availability in terms of location and size. A mark-up tool dubbed AreaMan was developed for this purpose. By simply clicking on the 2D plan, the actual space available in the week under consideration can be identified by the planner and their area can be calculated. This data are then read back to the VIRCON database. Project activities are allocated to the available spaces from AreaMan through a dialogue box written in MS project, [Refer to North and Winch (2002)]. All data in MS Project are then read back to the database. It should be mentioned that Space is treated in this project as a resource and space planning process is about identifying and allocating spaces to tasks and this was not automated as the industrial collaborators in this project preferred to see projects managers are 'engaged' in the process of space planning rather than leave the system to do it for them. It was thought that project managers will have more confidence in the planning process. The outputs of this process are WBS tasks which are allocated to available spaces. This is stored in the VIRCON database and ready to be accessed by analysis and optimization process. This is discussed below.

2.3 Analysis and optimisation tools

2.3.1 Identify Critical Space and Time

Given the allocation of potential execution space requirements to activities, this process involves identification of spatial loading using the SpaceMan tool. An example of this critical space analysis is illustrated in Fig. 2. Since tasks have different start and end dates within the life span of the spaces, spatial overload occurs when the spatial requirements of all tasks allocated to an available space are summed (when executing concurrently), and found to match or exceed the size of that space.

Once the SpaceMan tool has completed its analysis task, it automatically populates the spatial loading of each zone and in each period in the VIRCON database.

2.3.2 Optimize Critical Space and Time

If a situation where the spatial requirement of tasks allocated to the available space currently selected exceed the available spaces (right light red in the space man interface) or/and currently selected task is on the critical path (left light red, see Fig. 3) then SpaceMan allow users to optimize the schedule. In the case of manual optimization project managers can resolve conflicts by change the start of activities or/and changing tasks durations though altering resources. SpaceMan also allows the application of a simple 'brute force' algorithm to optimize the loading of tasks execution spaces. These algorithms try first to reduce space congestion though changing start dates of activities before trying more drastic solutions like changing tasks durations and resource allocation. A space congestion has been resolved for a particular period of time, SpaceMan updates VIRCON database with all space allocation data. After each optimization session, project mangers can visualise space congestion in 4D models of the project under consideration.

Fig. 2 illustrates the space planning and the CSA concept used in the VIRCON project. Using a new school project at Stockport, UK as a case study, plant and temporary objects were assigned and available spaces were marked. Since tasks have different start and end dates within the life span of the spaces, spatial overload occurs when the spatial requirements of all tasks allocated to an available space are summed (when executing concurrently), and found to match or exceed the size of that space. For example, space 1 in week 8 appears to be overloaded by concurrent execution of Task A and Task B.

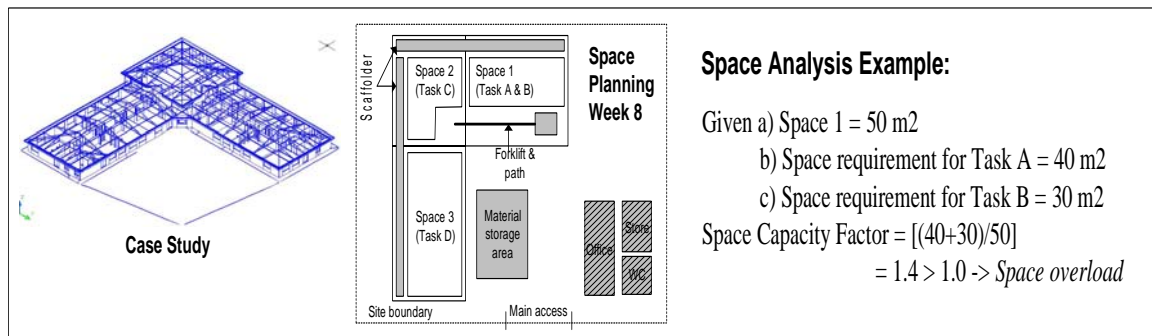


FIG. 2: Construction space planning and critical space analysis: VIRCON approach

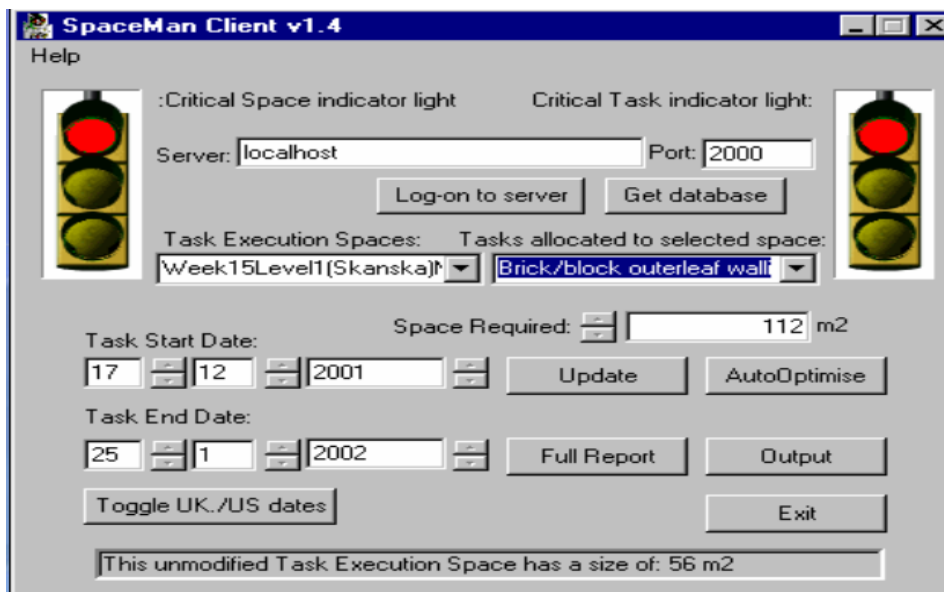


FIG. 3: SpaceMan Interface

2.4 Visualisation tools

Visual 4D planning and scheduling technique that combines 3D CAD models with construction activities (time) has proven benefits over the traditional tools in terms of better evaluation and communication of activity dependency as well as spatial and temporal aspects. Two 4D tools were developed in VIRCON project not only to visualise the construction products but also to visualise movement of plants/temporary objects and highlight spatial overload. These tools are:

1. *ProVis* – a 4D tool developed as a plug-in to AutoCAD 2000 and AutoDesk Architectural Desktop (ADT 3.3) for visualising traditional CAD or IFC 1.5.1 products. The tool also highlights locations of spatial overload as identified by SpaceMan. Refer to Dawood et al. (2002b). See Fig. 4.
2. *SpaceVis* – a 4D tool for visualising construction products and movement of plants/temporary objects in VRML, VR web-enabled format. Refer to Heesom and Mahdjoubi (2001).

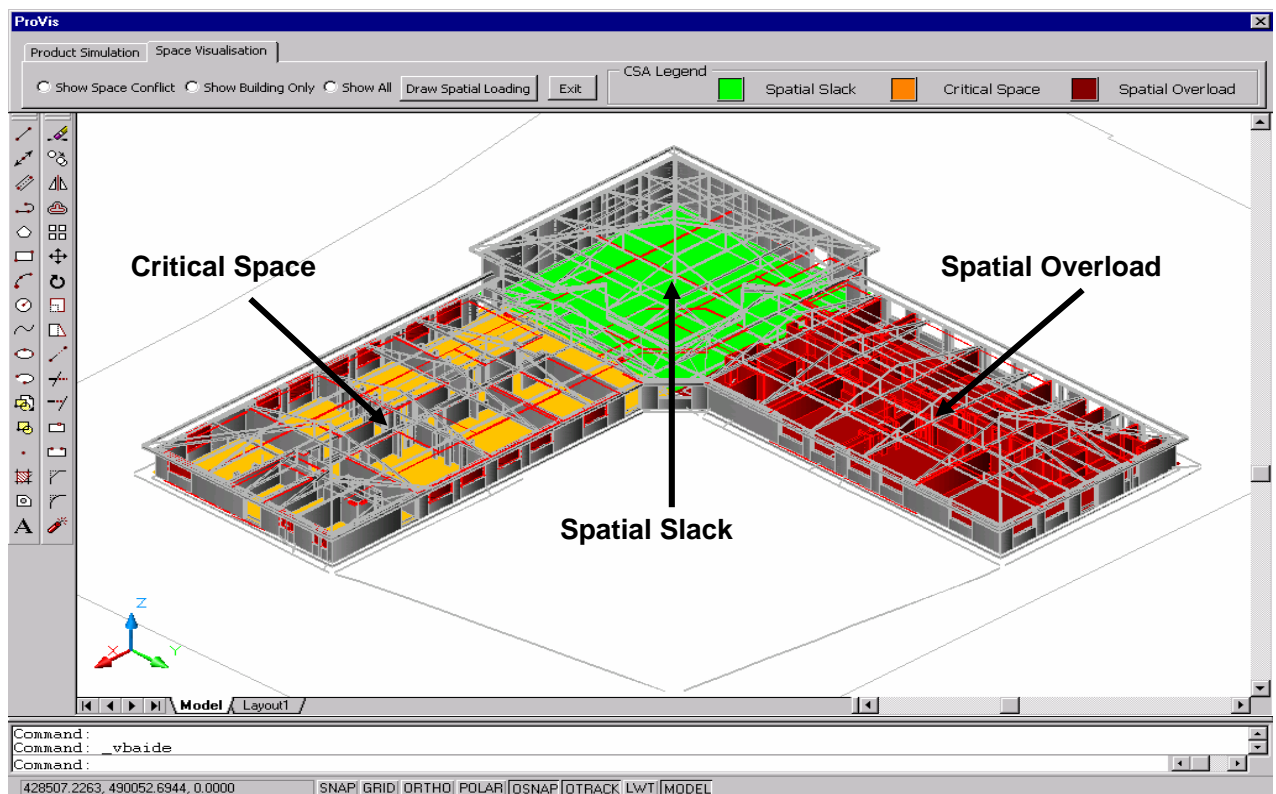


FIG 4: Visualisation of Stockport School case study using ProVis software.

3. USER EVALUATION

One of the main tasks of the VIRCON project is to conduct user evaluation using a historical case study supplied by one of the industrial collaborator. The aims of this evaluation are to establish the usefulness and usability of the VIRCON System, and to indicate where changes to the system might be needed. Previous literature by Borenstein (1988) and Bolois (1997) argued that one of the most important user assessment strategies is the field test, where evaluators assess developed software with actual case studies.

3.1 User evaluation design

Through pre-evaluation discussions with industrial collaborators, the user evaluation strategy was designed (i.e. the evaluators were identified, and the evaluation method and protocol chosen) to address the given aims.

Typical end users, such as civil engineering planners and project managers, of VIRCON were considered the most qualified to be expert evaluators. Such experts would be able to evaluate the system based upon their own experience of planning projects, and appreciation of how VIRCON may be implemented into their company.

Ten experts (many of whom hold senior positions within their company) were chosen to evaluate the system. An overview of their background is shown in Table 1 below.

TABLE 1: Overview of Evaluators

Position held	Company	Company Details
Project Planner	Skanska Construction	Leading Contractor; Current turnover is £1.3 billion with 17,000 employees worldwide.
2No Project Planners	Balfour Beatty	Leading Contractor; Current turnover is £1.44 billion with 25000 employees worldwide.
Professor of Construction Project Management	University	Academic with substantial experience in construction planning
3No.Project Planners	AMEC	Leading Contractor; Current turnover is US\$ 8 billion with 50,000 employees worldwide.
Project Manager	Ferguson McIlveen LLP	Leading Contractor; Current turnover is £8.77M with 190 employees worldwide.
Director of Production	MotEngil	Leading Contractor in EU.
Civil Engineer	VSS Civil Engineers	Consulting Engineers; Turnover £800K.

The setting was to be five separate sessions where each evaluator could interact and use the system and to be supervised by the VIRCON development team. Each session followed the three-step procedure as noted below.

3.2 Evaluation Session - Three step procedure

3.2.1 Step 1 – Introduction to VIRCON and the Case-Study

Each of the evaluator was given a brief tutorial on the use of the VIRCON system, and given an introduction of the real-life case study used in the evaluation (SKASKA Project).

Briefly, the case study comprised the £1.25M construction of a new school building, to replace Westmorland Primary School in Brinnington, Stockport, UK. The structure was constructed using the CLASP system (a rapid-build component-based method of construction for schools and other public buildings in the UK). The project also incorporated new environmental innovations such as recycled rubber floors, natural lighting, ventilation and heating recovery systems. The construction phase was seven months. The Contractor who carried out the works was Skanska Construction.

3.2.2 Step 2 - User Evaluation and Browse Session

In order to determine the usability of the system, detailed task instructions were prepared for the evaluator to work through, using the Stockport project as an example. The tasks were divided into four main phases, these being 1) set up phase, 2) space planning phase, 3) analysis and optimisation phase, and 4) visualisation phase. Fig. 4 below illustrates these phases within the VIRCON evaluation protocol.

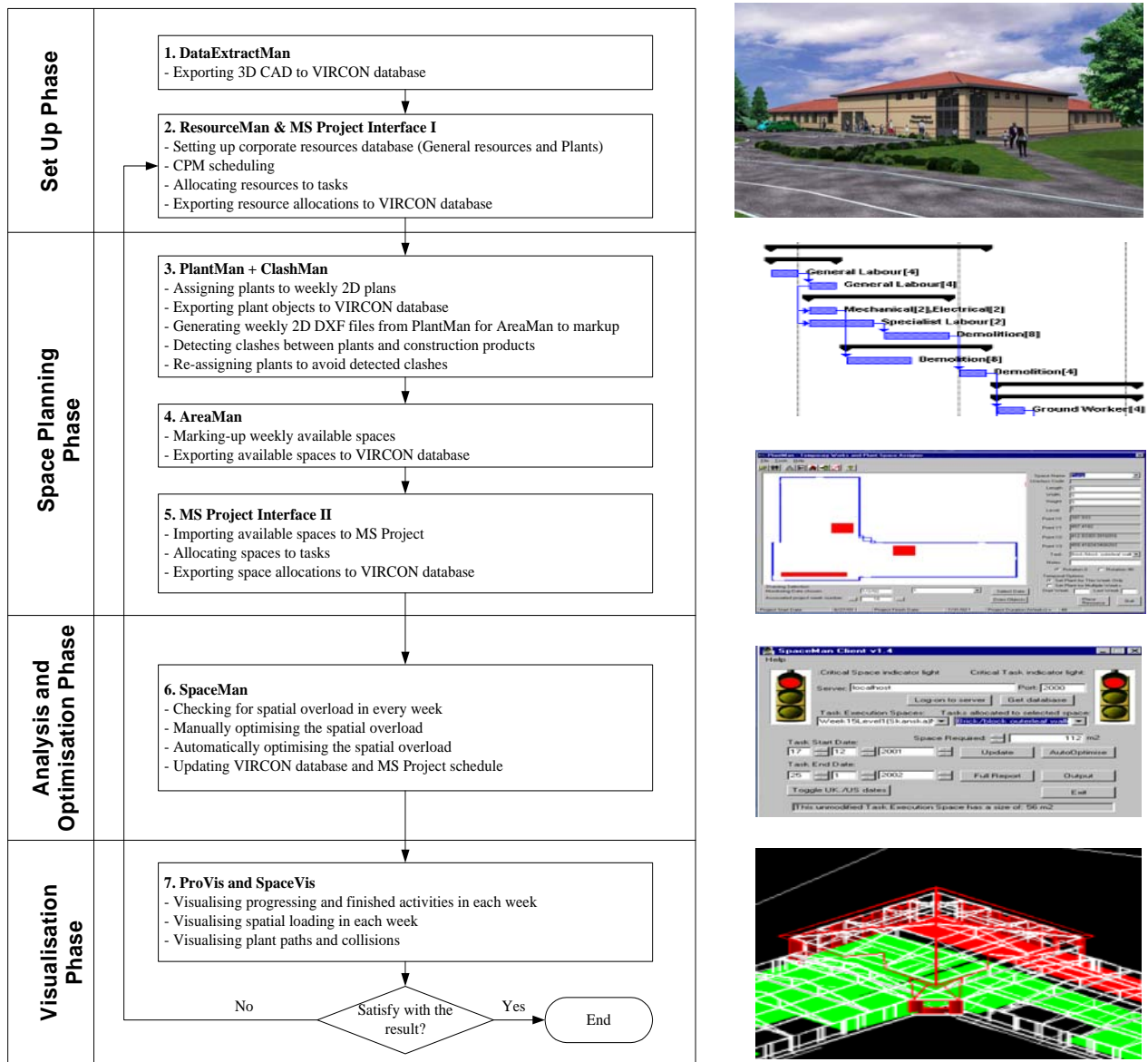


FIG 5: VIRCON Evaluation Protocol (and typical VIRCON screenshots)

The evaluators, under supervision, followed the step-by-step instructions, but were given the freedom to change input values as desired, or explore the system to follow any points of interest. They were also encouraged to try to resolve any problems encountered without assistance. The tasks assumed a level of knowledge regarding the packages being used and industrial experience in the subject area. The questions on the usability of the system were interspersed between interactions with the system. The Evaluator gave answers in the form of 'Likert' scales - a value from 1 to 5 (easy to very complicated respectively), and was encouraged to propose specific recommendations on each tool.

3.2.3 Step 3 – Evaluation through questionnaire and semi-structured interview

Finally, the evaluator was asked to evaluate the overall usefulness, benefits and perceptions of future implementation and improvements on the VIRCON. The questions covered various aspects including potential benefits of using VIRCON as a strategic decision support planning system and communication tool, any cost implications and barriers for implementation into industry.

4. USER EVALUATION RESULTS AND COMMENTS

The results from the user evaluation and browse session are shown in Table 2.

TABLE 2: Evaluation Result

Item	Easy				Very Complicated
	1	2	3	4	
SETUP PHASE					
1.1 Appraisal of DataExtractMan					
Exporting 3D CAD to VIRCON Database	90%	0	10%	0	0
2.1 Appraisal of ResourceMan					
Setting up corporate resources database	50%	40%	10%	0	0
2.2 Appraisal of MS Project Interface I					
CPM scheduling	33%	45%	22%	0	0
Allocating resources to tasks	40%	50%	0	10	0
Exporting resource allocations to VIRCON database	70%	30%	0	0	0
SPACE PLANNING PHASE					
3.1 Appraisal of PlantMan					
Assigning plants to weekly 2D plans	29%	29%	13%	29%	0
Exporting plant objects to VIRCON database	56%	33%	11%	0	0
Generating weekly 2D DXF files	50%	50%	0	0	0
Re-assigning plants to avoid detected clashes	No values as no clashes were detected				
Detecting clashes between plants and construction products	38%	62%	0	0	0
4.1 Appraisal of AreaMan					
Marking-up weekly available spaces	60%	20%	20%	0	0
Exporting available spaces to VIRCON database	100%	0	0	0	0
5.1 Appraisal of MS Project Interface II (Allocation of spaces to tasks)					
Importing available spaces to MS Project	22%	56%	22%	0	0
Allocating spaces to tasks	22%	45%	22%	11%	0
Exporting space allocations to VIRCON database	44%	44%	11%	0	0
ANALYSIS AND OPTIMISATION PHASE					
6.1 Appraisal of SpaceMan					
Checking for spatial overload in every week	56%	33%	11%	0	0
Manually optimising the spatial overload	25%	25%	25%	12%	12%
Automatically optimising the spatial overload	44%	44%	11%	0	0
Updating VIRCON database and MS Project schedule	78%	22%	0	0	0
VISUALISATION PHASE					
7.1 Appraisal of ProVis					
Visualising progressing and finished activities in each week	56%	44%	0	0	0
Visualising spatial loading in each week	56%	44%	0	0	0
7.2 Appraisal of SpaceVis					
Visualising progressing	0	100%	0	0	0
Visualising plant paths and collisions in each week	No values as no clashes were detected				
Total Percentage of all Tasks	52%	35%	9%	3%	1%

Limitations and difficulties highlighted during the evaluation are outlined in Table 3 and Table 4 respectively. The comments given by the evaluators during the semi-structured interview are drawn upon in section 5.

TABLE 3: Limitations noted with the VIRCON system

VIRCON Tool	Limitations noted within VIRCON system *
<i>Plantman</i>	<ul style="list-style-type: none"> Plant could not be deleted once assigned. There is no error handling facilities. The generation of weekly 2D DXF files was considered slow by some evaluators.
<i>ClashMan</i>	<ul style="list-style-type: none"> The evaluator would have preferred to see the clashes (of products and plant) within the 3D model. The evaluator would have preferred to review the programme upon removal of collisions.
<i>SpaceMan</i>	<ul style="list-style-type: none"> One evaluator wanted to see the picture of spatial overload on the project plan simultaneously. Difficult to allocate space, as you cannot see allocated tasks, resources, spaces, etc. Could optimising options be chosen from a list rather than it be an automatic feature? An evaluator did not consider <i>SpaceMan</i> user friendly in that you had to change dates to one task without viewing its predecessors, successors and the affect on the project critical path and float. Need MS Project open to note manual possibilities.
<i>AreaMan</i>	<ul style="list-style-type: none"> One evaluator questioned why the program did not generate available spaces automatically.

(*Note – system limitations beyond the scope of the project have not been included within this list. Such limitations are highlighted later under Future Development)

TABLE 4: Difficulties encountered with the VIRCON system

VIRCON Tool	Difficulties Encountered
<i>PlantMan</i>	<ul style="list-style-type: none"> Difficult to exit from assignment process. Entering incorrect level of floors made a mistake. One evaluator considered <i>Plantman</i> unreliable due to some bugs and no error handling.
<i>ClashMan</i>	<ul style="list-style-type: none"> On all occasions, no clashes were detected (due to bugs) so <i>ClashMan</i> tasks could not be undertaken.
<i>MS Project Interface</i>	<ul style="list-style-type: none"> An evaluator was uncertain on what spaces had been previously allocated to tasks. Therefore, there was the need to return to <i>AreaMan</i> to review what information was input.
<i>SpaceVis</i>	<ul style="list-style-type: none"> On one occasion <i>SpaceVis</i> could not run the example due to bugs.

5. OUTCOME OF EVALUATION

5.1 Analysis of results

Analyses of the evaluation results show the concept to be relatively clear and the usability easy (85% within score 1 and 2 within the table). The reasons for ‘harder’ tasks were identified as being due to evaluators not being familiar with standard software being used (particularly AutoCAD and/or MS Project), their ability to manipulate the interface, i.e. familiarity with the icons/buttons, and confusion when there were ‘bugs’ noted (particularly within *PlantMan*). The evaluators generally considered that the tasks would be easier should they perform the tasks again.

5.2 Appraisal of VIRCON

Subject to a number of (achievable) enhancements, most of the evaluators considered VIRCON would be a useful strategic decision support planning system, and found the visualisation of the system helpful and informative. Specific areas in which the VIRCON system could add value to the construction planning process were as follows:

1. In the monitoring and optimising resource/plant levels.
2. In the identification and allocating of spaces.
3. As a communication and visualisation tool to describe the project to all parties involved in the project, and maintaining good relationship with the Client.
4. In increasing certainty to the schedule, and hence reduce project overrun.
5. In highlighting and reducing risk (i.e. recognises the constraints prior to construction).

Most of the evaluators found the manual optimising of the spatial overload, within *SpaceMan*, initially confusing. Limitations with *SpaceMan* were also identified which would need to be addressed to improve usability and usefulness. These were not being able to view Gantt chart and schedule information while carrying out manual optimisation, and the auto-optimisation possibly not providing the needed solution. Evaluators also

questioned the realism of the manual optimising of the spatial overload. *SpaceMan* does not consider both horizontal and vertical types of movement and clashes. They advised that spatial overload depends on how good the data input is. VIRCON was expected to paint a blacker picture than real life, because in reality there is often more flexibility, where resources and plant tend to change daily.

Possible barriers to the construction industry adopting VIRCON were identified as follows:

1. Uniclass standard being adopted; and
2. It may be difficult to collect all the data required by VIRCON. At the initial stages of site instruction, for example, Contractors may not have, or wish to disclose all details of resources/plant etc. as this information may be used against him if he is late in completing the works. Contractors tend to keep their detailed schedules and not share it with other parties.

The evaluators advised that any possible savings in cost and time, made by VIRCON, would depend on the project type and situation. One evaluator advised that the detection of potential conflicts within the execution area could clearly introduce meaningful changes in the field operations and/or procedures. This will definitely save money and reduce/arrest overrun.

Despite the difficulties and limitations encountered by the evaluators, they generally gave favourable comments, showing a positive attitude towards the system. The evaluators could visualise how future extensions of the system would fit into their procedures, and the developers could identify how additions may be included in a final product. Overall, most of the evaluators would consider using the VIRCON system (again, subject to some *achievable* enhancements) within their company.

5.3 Appraisal of the evaluation procedure

The evaluation method adopted was considered suitable for this project. The detailed task instructions and questionnaire proved useful in structuring the subject's responses, and in prompting the evaluators to be as forthcoming as possible.

The mean time for an evaluator to complete the evaluation was 186 minutes (just over 3 hours). Some tasks took longer than others to complete simply because they called for more information to be input. The evaluator's attitude to the time taken to complete the evaluation was good. We understood this was due to their appreciation of the benefits of the system. The evaluators generally considered that the time to complete the tasks would be reduced should they perform the tasks again. As the system is further developed, more of the features are to be automated to further reduce the time taken on the system.

6. LOOKING AHEAD

6.1 Further development of VIRCON tools

In addition to the improvements highlighted in the evaluation, the evaluator's identified a number of areas for system development that are considered to be outside the framework of this current research project. The significant changes and additions to VIRCON were to:

1. Allow interaction with Primavera (Planning Software);
2. Include tasks that are not represented within the AutoCAD model. For example – cleaning and snagging items;
3. Adjust the structure program menus/toolbars to be in the order that the tasks are carried out;
4. Store the resource library alphabetically in *ResourceMan*;
5. Allow visualisation of process clashes within the 3D AutoCAD model;
6. Improve the accuracy of the drawing tools, zoom, etc. within *AreaMan*; and
7. Incorporate safety issues in the space analysis.

6.2 Future evaluations

It is envisaged that further evaluation, utilising both historic and real-life cases will be undertaken once the VIRCON system has been implemented into a company's working procedures. Our Centre is currently in the early stages of optimising VIRCON for use with a major Contracting organization in the UK. At such a time, the learnability of the system may be assessed. This would be measured by the time and effort required to reach

a specific level of user performance. In addition to supplying help manuals, it has been agreed that a level of training and support will be given. Further technical evaluations are also required to address the 'bugs' noted within VIRCON tools.

7. CONCLUSIONS

The objective of this paper is to introduce the VIRCON tools and processes and discuss the industrial evaluation of the tools.

It is concluded that this evaluation phase by industrial collaborators was successful in establishing the usefulness and usability of the system, and in prompting further changes to the VIRCON tools. Even though some limitations and difficulties were identified, the evaluators could visualise how the tools and future extensions of the system would fit into their procedures, and the developers could identify how additions may be included in a final product. The main reason for the success of the evaluation is that the industrial evaluator's identified the potential benefit in adopting such a system. The usefulness of the research has been proven through a leading Contractor investing into further work for the VIRCON system to be introduced into their working procedures.

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9. REFERENCES

- Boloix G., (1997). System evaluation and quality improvement, *Journal of Systems and Software*, 36(3), 297-311.
- Borenstein D., (1998). Towards a practical method to validate decision support systems, *Decision Support Systems*, 23(3), 227-239.
- Dawood N., Sriprasert E., Mallasi Z., and Hobbs B. (2002a) Development of an integrated information resource base for 4D/VR construction process simulation and visualisation, *Proceedings of CIB w78 Conference, Aarhus, Denmark*, 210-217.
- Dawood N., Sriprasert E., Mallasi Z., and Hobbs B. (2002b). 4D visualisation development: Real life case studies, *Proceedings of CIB w78 Conference, Aarhus, Denmark*, 53-60.
- Dawood, N., Sriprasert, E., Mallasi, Z., and Hobbs, B. (2003) Development of an integrated information resource base for 4D/VR construction processes simulation, *Automation in Construction*, 12(2), 123-131.
- Heesom D. and Mahdjoubi L. (2001). Task 7: Visualisation development, *VIRCON Project Report*, University of Wolverhampton.
- Heesom, D. and Mahdjoubi, L. (2002). Visualisation development, *University of Wolverhampton, a VIRCON project report*.
- Heesom, D., Mahdjoubi, L. and Proverbs, D. (2003). A dynamic VR system for visualising construction space usage, *Proceedings of third ASCE Construction Research Congress, March 2003, Honolulu, HA*.
- Kelsey J., Winch G. and Penn A. (2001). Task 4: Understanding the project planning process: Requirements capture for the virtual construction site, *VIRCON Project Report*, University College London.
- North S. and Winch G.M. (2002). *VIRCON: A proposal for critical space analysis in construction planning*, *Proceedings of the fourth European Conference on Product and Process Modelling in the Building and Related Industries (ECPM)*, Portoz, Slovenia, 359-364.
- Sriprasert, E. (2004). A multi-constraints construction planning system, *PhD thesis*, University of Teesside, UK.
- Winch G. M. (2002). Planning the use of spatial resources on projects: The case of construction, *Proceedings of PMI Research Conference, Seattle, Washington, USA*.
- McCarthy, T. (1999) *AutoCAD Express NT*, London: Springer.