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

Nashwan Dawood, Eknarin Sriprasert, Zaki Mallasi and Darren Scott
Centre for Construction Innovation Research, University of Teesside
*n.n.dawood@tees.ac.uk*

SUMMARY

Implementation of the emerging information technologies in the construction industry has been relatively slow in comparison with other industries. Many research and development projects conducted by academia have not been tested and implemented successfully in the real practices. Considering this issue, the VIRtual CONstruction site (VIRCON) research project, funded by the UK government, was developed. VIRCON is a strategic decision support system for practical use to manage construction schedules, and in particular space planning. The successful development of the system was based upon the industrial requirements, real-life project data, and finally evaluated by the industrial collaborators. This paper briefly introduces the VIRCON system and thoroughly reports 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 commercialisation and implementation of VIRCON tools in real practices. 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 practical and communicative.

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 is 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 held only 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. During the past two years, the system has been successfully developed based upon the industrial requirements, industrial real-life project data, and finally evaluated by the industrial collaborators. The prime objective of this paper is therefore to briefly provide a background to the overall VIRCON system and to thoroughly report on the industrial user evaluation phase of the research project.

CONSTRUCTION SPACE PLANNING: VIRCON 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)]. 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)]. Figure 1 presents an overview of the VIRCON tools. These tools are grouped into four categories based on their functionality and are briefly described as follows.
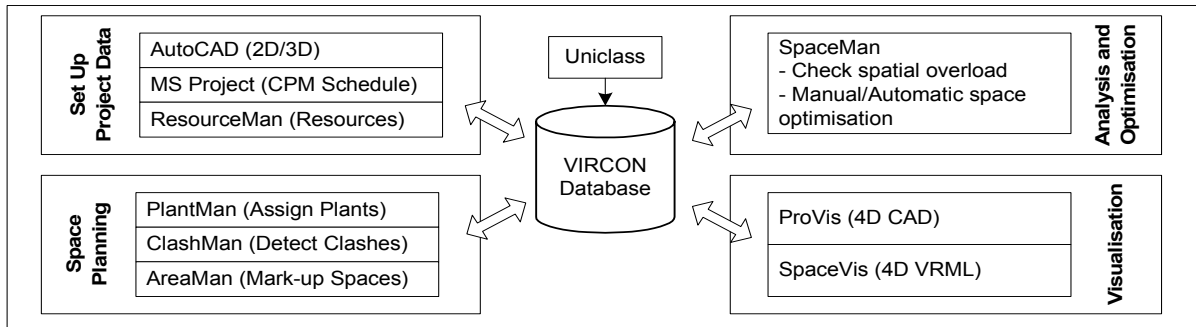
Figure 1 Overview of the VIRCON tools

Set up tools

Set up phase involves two operations including: a) population of product and process data in the VIRCON database; and b) establishment of the corporate resource database. Three tools were developed to enable these operations. These are as follows:

1) *VIRCON database*– a relational database that serves as a core infrastructure for the VIRCON system. The database is designed in corresponding with the Uniclass standard for the purpose of construction product and process integration. Refer to Dawood et al., (2002a).
2) *DataExtractMan* – an AutoCAD macro that automatically interprets CAD layers (BS1192-5) and extracts 2D/3D product data into the VIRCON database. Refer to Dawood et al., (2002a).
3) *ResourceMan*– a stand-alone database management tool for legacy collection of resource data and space requirements. Refer to Heesom & Mahdjoubi (2001).
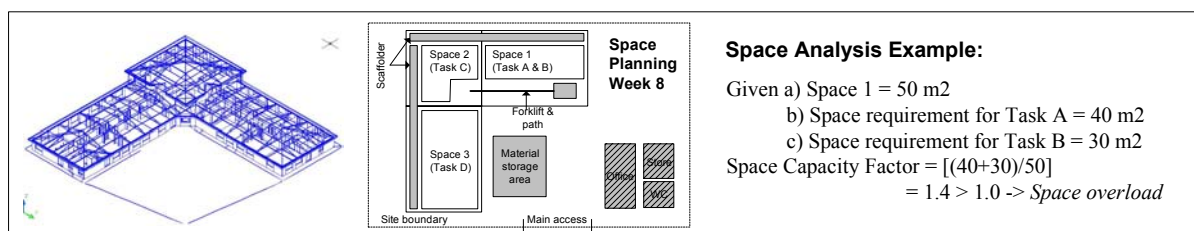
Space planning tools

A number of tools and a customised interface within MS Project have been developed to allow planners to perform weekly space planning in a 'quick and dirty' manner. These tools are:

1) *PlantMan* – a tool for allocating plants/temporary objects to 2D plans. Refer to Heesom & Mahdjoubi (2001).
2) *ClashMan* – a tool for detecting clashes between plants/temporary objects and construction products. Refer to Heesom & Mahdjoubi (2001).
3) *AreaMan* – a mark-up tool for identifying available spaces. Refer to North and Winch (2002).
4) *Task-Space Allocation Interface* – a customised interface developed within MS Project that enables planners to allocate tasks to spaces in addition to resources. Refer to North and Winch (2002).

Analysis and optimisation tools

Once the weekly utilisation of space on construction site has been planned, the next step is to check for spatial overload and update the MS Project schedule to avoid the overload. A particular tool called '*SpaceMan*' was developed for this purpose Refer to North and Winch (2002). Figure 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.

Space Analysis Example:

Given a) Space 1 = 50 m2
      b) Space requirement for Task A = 40 m2
      c) Space requirement for Task B = 30 m2
Space Capacity Factor = [(40+30)/50]
              = 1.4 > 1.0 -> *Space overload*

Figure 2 Construction space planning and critical space analysis: VIRCON approach

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).

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).

USER EVALUATION

One of the main tasks of the VIRCON project is to conduct user evaluation using a historical case study supplied by an 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 Boloix (1997) argued that one of the most important user assessment strategies is the field test, where evaluators assess developed software with actual case studies.

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.

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	UMIST -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	Mota & Companhia, sa.	Leading Contractor.
Civil Engineer	VSS Civil Engineers	Consulting Engineers; Turnover £800K.

Table 1 Overview of Evaluators

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.
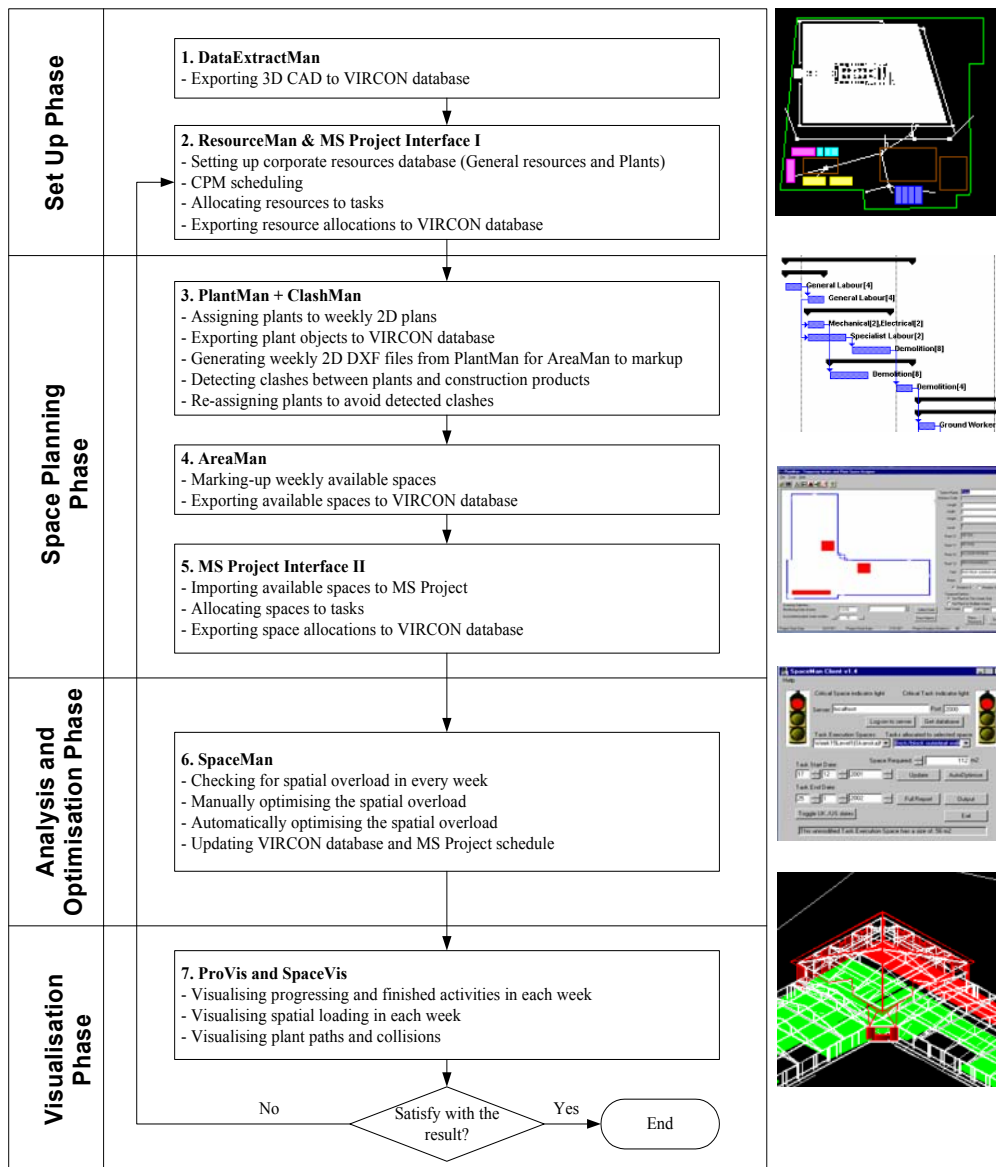
Evaluation Session - Three step procedure

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

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.

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. Table 2 below illustrates these phases within the VIRCON evaluation protocol.

Set Up Phase	**1. DataExtractMan** - Exporting 3D CAD to VIRCON database	
	2. ResourceMan & MS Project Interface I - Setting up corporate resources database (General resources and Plants) - CPM scheduling - Allocating resources to tasks - Exporting resource allocations to VIRCON database	
Space Planning Phase	**3. PlantMan + ClashMan** - Assigning plants to weekly 2D plans - Exporting plant objects to VIRCON database - Generating weekly 2D DXF files from PlantMan for AreaMan to markup - Detecting clashes between plants and construction products - Re-assigning plants to avoid detected clashes	
	4. AreaMan - Marking-up weekly available spaces - Exporting available spaces to VIRCON database	
	5. MS Project Interface II - Importing available spaces to MS Project - Allocating spaces to tasks - Exporting space allocations to VIRCON database	
Analysis and Optimisation Phase	**6. SpaceMan** - Checking for spatial overload in every week - Manually optimising the spatial overload - Automatically optimising the spatial overload - Updating VIRCON database and MS Project schedule	
Visualisation Phase	**7. ProVis and SpaceVis** - Visualising progressing and finished activities in each week - Visualising spatial loading in each week - Visualising plant paths and collisions	
	No ←——— Satisfy with the result? ———→ Yes → End	

Table 2 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) [Munshi (1990)], and was encouraged to propose specific recommendations on each tool.

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.

USER EVALUATION RESULTS AND COMMENTS

The results from the user evaluation and browse session are shown in Table 3. Some of the evaluators were unable to complete all tasks due to small 'bugs' noted within the VIRCON tools. In the first occurrence plant could not be assigned within *Plantman*. The second occurrence *SpaceVis* did not allow visualisation of progressing/finished activities or plant paths/collisions for specific weeks.

Item	1 *Easy*	2	3	4	5 *Very Complicated*
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%**

Table 3 Evaluation Results

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

VIRCON Tool	Limitations noted within VIRCON system *
Plantman	• 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.
ClashMan	• 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.
SpaceMan	• 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 *SpaceMan* 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.
AreaMan	• 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 Limitations noted with the VIRCON system

VIRCON Tool	Difficulties Encountered
PlantMan	• Difficult to exit from assignment process. • Entering incorrect level of floors made a mistake. • One evaluator considered *Plantman* unreliable due to some bugs and no error handling.
ClashMan	• On all occasions, no clashes were detected (due to bugs) so *ClashMan* tasks could not be undertaken.
MS Project Interface	• An evaluator was uncertain on what spaces had been previously allocated to tasks. Therefore, there was the need to return to AreaMan to review what information was input.
SpaceVis	• On one occasion *SpaceVis* could not run the example due to bugs.

Table 5 Difficulties encountered with the VIRCON system

OUTCOME OF EVALUATION

Analysis of the 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.

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.

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.

LOOKING AHEAD

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.

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 (as under VIRCON Task 12) are also required to address the 'bugs' noted within VIRCON tools.

CONCLUSIONS

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.

ACKNOWLEDGEMENTS

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.

Heesom, D. and Mahdjoubi, L. (2001) *Task 7: visualisation development*, VIRCON Project Report, University of Wolverhampton.

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.

Munshi, J. (1990) *A Method for Constructing Likert Scales,* Sonoma State University.

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 (ECPPM), Portoz, Slovinia, 359-364

Winch, G. M. (2002) *Planning the use of spatial resources on projects: the case of construction*, Proceedings of PMI Research Conference, Seattle, Washington, USA.