Theme:

Title: **4D Visualisation Development: Real Life Case Studies**

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Abstract: *Visual 4D planning and scheduling technique that combines 3D CAD models with construction activities (time) has proven benefits over traditional tools, such as bar charts and network diagrams. In 4D models, project participants can effectively visualise and analyse problems regarding sequential, spatial, and temporal aspects of construction schedules. As a consequence, more robust schedules can be generated and hence reduce reworks and improve productivity. Currently, there are several working research prototypes and commercial software that have ability to generate 4D model. However, two major issues arise regarding the current 4D development approaches and the use of commercial software. These are the limited feasibility to large and complex projects, and inflexibility to incorporate more construction problems (nD modelling) especially for process constraints such as spatial conflicts, and availability of information and resources.*

As a part of the VIRCON project, an EPSRC funded research, this paper introduces a pragmatic approach to develop extensible 4D visualisation using two real life case studies. ProVis, a 4D simulator, was developed using Visual Basic for Applications (VBA), accessing the integrated products and processes from the VIRCON database and produces 4D model in the AutoCAD environment. This 4D tool is also integrated with a Critical Space Analysis (CSA) tool (another VIRCON tool) and is able to visualise spatial overload of the construction site. The paper details 4D development process based on the proposed approach and discusses efforts spent to convert general project information (2D drawings and schedules) to 4D models. It is concerned that a little additional effort was needed to develop the extensible 4D model based on the proposed approach. In addition, no commercial 4D software was used to achieve the visualisation process.

Keywords: *4D, Integrated tools, Planning, Virtual Reality, Visualisation*

Introduction

Bar charts and network diagrams are typical means to represent and communicate construction schedules. Individuals having different background and being unfamiliar with these techniques find it difficult to evaluate and communicate the schedules (McKinney and Fischer, 1998). Even a good construction plan often gets misinterpreted by some of the project participants, which can lead to inefficient processes accomplishing the wrong thing. Visual 4D planning and scheduling technique that combines 3D CAD models with construction activities (time) has proven benefits over the traditional tools (Akbas, 1998). In 4D models, project participants can effectively visualise and analyse problems regarding sequential, spatial, and temporal aspects of construction schedules. As a consequence, more robust schedules can be generated and hence reduce reworks and improve productivity. Currently, there are several working research prototypes and commercial software that has ability to generate 4D model as a tool for analysing, visualising, and communicating project schedule. However, two major issues regarding the current 4D development approaches and the use of commercial software are: 1) limited feasibility to large and complex projects; and 2) inflexibility to incorporate more construction problems (nD modelling) especially for non-physical constraints such as availability of information and resources.

As a part of the VIRCON project, an EPSRC funded research, this paper addresses these limitations by introducing a pragmatic approach to develop extensible 4D visualisation using two real life case studies. This has been achieved by employing a compound applications architecture where the VIRCON database is at the centre (Dawood et al., 2001a). ProVis, a 4D simulator, was developed using Visual Basic for Applications (VBA), accessing the integrated products and processes from the VIRCON database and produces 4D model in AutoCAD environment. This 4D tool is also integrated with a Critical Space Analysis (CSA) tool (North and Winch, 2002) and is able to visualise spatial overload of the construction site. The paper details 4D development process based on the proposed approach and discusses efforts spent to generate 4D models from general project information.

ProVis Prototype: A Pragmatic Approach

The ProVis was developed with the overall objective of visualising and optimising the construction process. In this section, the overall approach used by the research team in collaboration with the industrial collaborators is discussed. The main issues raised throughout the development of 4D were: 1) should be based on a clear business process approach; 2) should be 'part of' or 'based on' current software systems used in the industry; 3) should possess scalability and extensibility to cater for more construction process problems; and 4) should be based on real life construction sites. Based on these issues, a compound applications architecture that allows various Windows applications to be integrated through a central database was considered suitable. Two real life case studies including an 8 million pounds, school of health project (SOH) at the University of Teesside and a 1.25 million pounds, Westmorland primary school at Stockport were conducted.

The main input from the case studies consists of 2D construction product models and construction project schedules. Figure 1 shows an overall system architecture of the ProVis that was developed as an 'add-on' in 'AutoCAD 2000'. The ProVis interacts with the VIRCON database (discussed in detail in an accompanied paper in this proceedings (Dawood et al., 2002a)) through 'VBA' modules. The detailed 4D development process based on the ProVis approach is given in the next section.

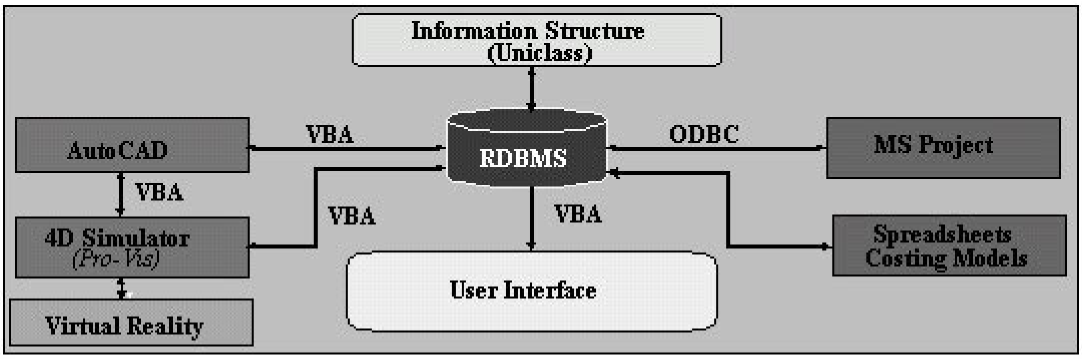


Figure-1: System Architecture

Detailed 4D Visualisation Development Process

This section discusses methodology of the 4D visualisation development which was specifically designed and employed in this research. Figure 2 presents the overall construction visualisation approach utilising ground floor columns of the school of health as an example. Assessment of this methodology against other construction visualisation research projects is provided in the next section. The following describes the visualisation development process.

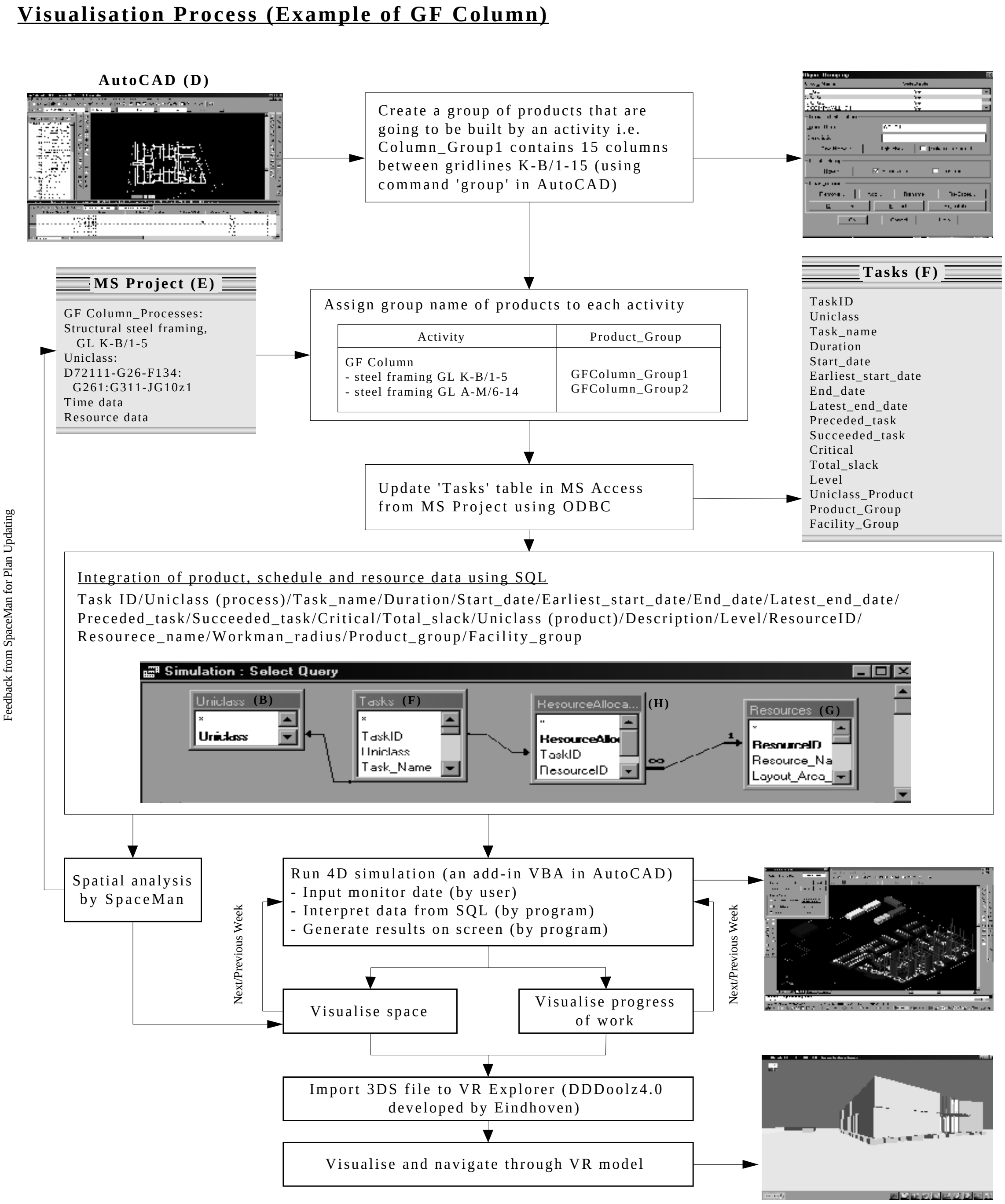


Figure-2: The Visualisation Process

1) Grouping of construction products is the first step for the 4D visualisation development. Using the 'group' command in the AutoCAD, each product can be grouped based on the level of detail generated in the project schedule and identification of zones/stages of the construction. For example, GF columns of the SOH were divided into two groups including GFColumn_Group1 for gridlines K-B/1-5 and GFColumn_Group2 for gridlines A-M/6-14.

2) To link product groups identified in the AutoCAD with construction activities in the MS Project, each product group name is assigned to associated construction activity(ies). For example, "GFColumn_Group1" is linked to "steel framing GL K-B/1-5" and "GFColumn_Group2" is linked

to "steel framing GL A-M/6-14". In this case, the product group name can be assigned in a pre-prepared MS Project field (Text1 field) called "Product_Group".

3) The grouping and linking information in the MS Project is then exported to the table "Tasks" in the VIRCON database via Open Database Connectivity (ODBC) feature. Attributes of the "Tasks" table are shown in "Tasks (F)" box.

4) To prepare 4D data for the ProVis, all MS Access tables including all construction products, construction schedule, resources data and others are then integrated using the Structured Query Language (SQL). The list of items to be integrated and the query map among these tables is given in Figure 2.

5) Given the 4D data in the VIRCON database, the users can run the ProVis (Product Visualiser), an add-on VBA in the AutoCAD, and visualise the construction sequence, pattern, and progress at any monitor date. Figure 3 illustrates snapshots of the 4D visualisation through different stages of construction process.

6) In addition to the product visualisation, the ProVis obtains output from a spatial analysis tool called 'SpaceMan' (North, 2001). Consequently, the ProVis can visualise occupied spaces, available spaces and potential space conflicts. Users can experience space changes as the construction simulation progresses.

7) To carry out the visualisation in the VR environment, a VR explorer titled 'DDDoolz4.0' developed by Eindhoven University of Technology is utilised (Eindhoven, 2001). This allows a direct conversion from CAD to VR through a basic 3D file transfer. Alternatively, the CAD model can be exported to 3D Studio rendering engine and converted to immersive VR or VRML models.

Assessment of the ProVis Approach

A comprehensive study was conducted to compare system features and functionality of the ProVis against other 4D visualisation systems. The full work of this comparison can be found in a separate report (Dawood et. al., 2001b). Followings are discussion of advantages of the ProVis and future work for the prototype development.

- Several research projects are utilising special 4D software from Bentley and Jacobus Technology (Koo and Fischer, 2000; and Akinci et al., 2000). In contrast, the ProVis provides an alternative to the industry by performing the 4D visualisation in common software like the AutoCAD. The simulated model (at any given time) can also be directly exported to VR software such as DDDoolz 4.0, which is downloadable from the Internet with no cost. As a result, this could promote the ProVis to be widely accepted in the industry.

- The utilisation of a database as a central information resource base makes it possible and relatively easy to incorporate various information into the 4D/VR model in the future. The additional information can be cost, cash flow, supply chain constraints, and technical information which will make the model more informative and useful.

- The ProVis has an ability to generate textual-based annotations and reports of the 4D analysis. The annotations include the list and schedule information of progressing and finished activities. As the simulated model becomes complex, users can select to visualise particular products while performing the analysis.

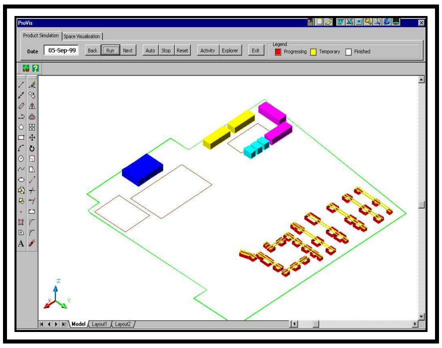
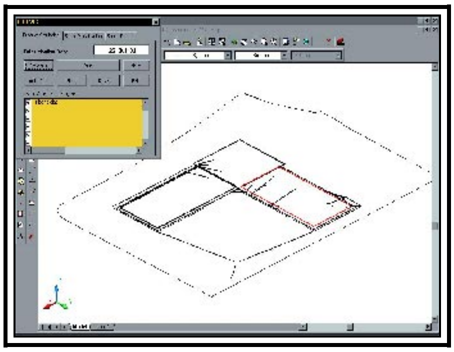
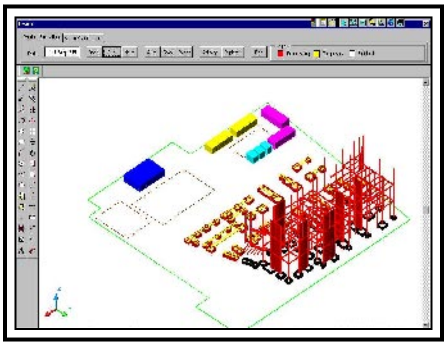
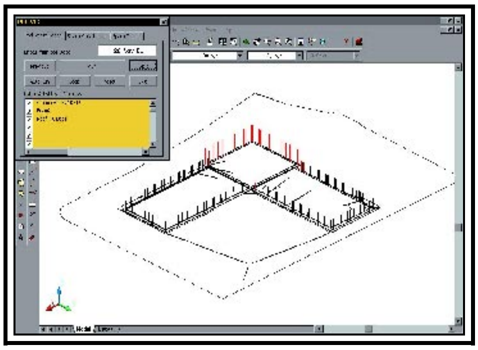
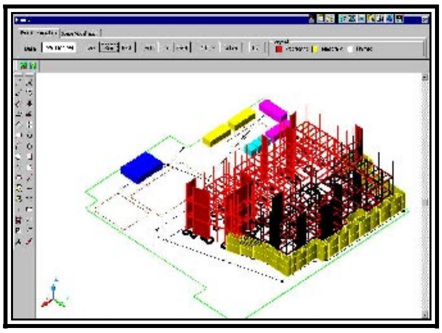
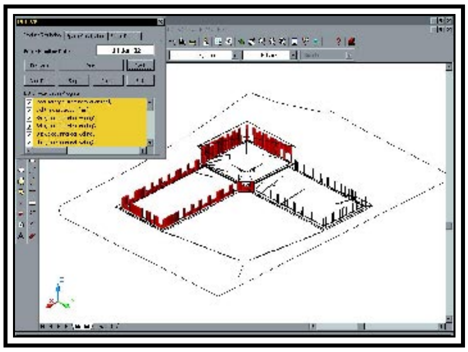
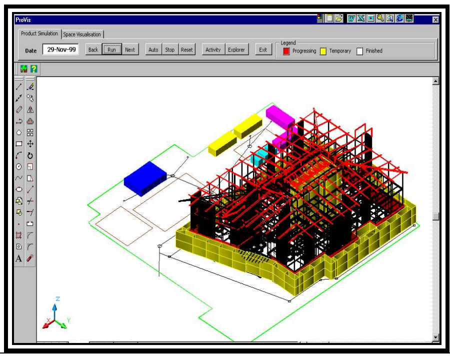
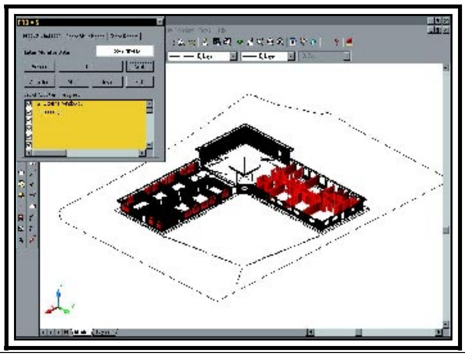
Case Study One – School of Health Project	Case Study Two - Primary School Project
	
	
	
	

Figure-3: Snapshots of the 4D Visualisation through Different Stages of Construction Process

- Since the ProVis has been self developed using Visual Basic Application (VBA) as an add-on for the AutoCAD, it is flexible to customise and improve the prototype in the future. In addition, the ability to use the ProVis in the real practices has been justified by the two real life case studies (the School of Health and the Westmorland primary school projects).

- With the SpaceMan, a critical space analysis and time-space broker engine, developed in the VIRCON project, the schedule can be automatically optimised and updated so as to avoid the time-space conflict. The users can verify the updated schedule by visualising in the ProVis and perhaps manually adjust the schedule as required.

- The research team is aware of recent 4D development projects based on the IFC specification (Fernando et al., 2001; and Serén and Karstila, 2001). These projects focus on the ability to electronically exchange the product and process data between applications and the ability to view the 4D model in the VRML browser. To generate a meaningful 4D model, however, issue regarding classifying and integrating product and process data is equally important. In complementary with the IFC, the research team proposed the utilisation of the multi-facet concept specified in the Uniclass (unified classification system for the construction industry) to classify and integrate product and process data (Dawood et al., 2002b). With the Uniclass, planners can systematically organise the project schedule in the form of product-based work breakdown structure thereby avoid omission of assigning activities to associated products. Once the schedules are generated in the proper manner, process of linking of product and process data will be more straightforward hence allows faster development of the 4D model.

- Apart from the AutoCAD, the ProVis can also be used with the Architectural Desktop (ADT) Version 3.3 that supports IFC 1.5.1. By employing the same visualisation process illustrated in Figure 2, the ProVis can effectively simulate the IFC product model in the ADT environment.

Apart from the advantages, the manual grouping of CAD objects and linking to associated activities can consume time and be cumbersome. The knowledge-based system implemented in other research prototypes (McKinney and Fischer, 1998; and Retik and Shapira, 1999) should be concerned in the future development. Additionally, future development should allow users to interact and assign space objects in the VR environment.

Evaluation of Man-Hours Input

A through evaluation of running the ProVis using two case studies is currently being conducted. The research team have explored and standardised the 3D drafting techniques so as to minimise the modelling efforts and working hours (Dawood et. al. 2001b). A technical comparison between the two case studies based on the man-hours input and the project design type can be seen in Table 1. The first case study is the school of health project that is regarded as complex CAD project. The second case study is a primary school project designed as one ground floor and is classified as a simple CAD design project (L-shaped). The brief summary presented in Table 1 indicates that man-hours increase according to availability of design information. The availability factor of design information, construction details, and suitable CAD files means that we could increase the level of detailed 3D modelling.

Statistically, data acquisition task duration is approximately 12% of total man-hours input. The 3D modelling task took around 77% of the total working hours. It must be noted here that the more complex the design shapes are, the longer the time it takes to construct the 3D model. For example, the roof modelling in case study two took longer time and effort than in case study one by 5% of the 3D modelling task. The man-hours that are needed for restructuring the project schedule data reaches around 11% of the total man-hours.

Table-1: Evaluation of Man-Hours Input of the Two Case Studies

Item Description	**Case Study One**				**Case Study Two**			
	No. of CAD Layers	No. of CAD Objects	CAD File Size	Man Hours	No. of CAD Layers	No. of CAD Objects	CAD File Size	Man Hours
1) Data Acquisition:								
a- construction information				48				12
b- CAD drawings								
2) 3D Modelling:								
a- Architectural components								
• Simple 3D extrusions (walls & doors)	22	2232	2,073 KB	140	17	1384	566 KB	70
• Complex 3D modelling (roof truss & space frames)	5	556		40	9	440		25
b- M&E components	25	6934		105	N/A	N/A		N/A
3) Restructuring Project Schedule Data								
a- Architectural components				24				8
b- Linking 3D CAD components with activities				12				4
Totals:	52 Layers	9722 Objects	2,073 KB	369 Hours	26 Layers	1824 Objects	566 KB	119 Hours

Conclusion

The objective of this paper was to introduce and discuss an on-going research project into 4D-construction process simulation and visualisation. A 4D simulator called ProVis that has extensibility to simulate and analyse construction process problems was proposed. The paper presented detailed visualisation process of the ProVis and discuss its approach against other 4D systems. A summary of the man-hours spent for converting 2D design drawings and processing project specific information to 4D has been described. In that, a motivation can be realised due to the practicality in time/cost relationship with the learning curve factor. We believe that the practical methodology presented in this paper will be an initial step to encourage widely implementation of 4D simulation and visualisation in the construction industry.

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