



***Virtual Construction Site
Project***

Task 6 Report

Visualisation Development

(Whole Building Visualisation)

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This research is funded by the Engineering and Physical Sciences Research Council's research program award no. GR/N00876 as part of the Innovative Manufacturing Initiative

Published by
Centre for Construction Innovation Research
School of Science and Technology
University of Teesside
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Executive Summary

The objective of this report is to introduce and discuss research work completed to-date (March 2001- Jan 2003) and plans for further development on task 6, visualisation development: whole building components visualisation of the VIRCON project. To complement the visualisation of the whole building, a parallel visualisation development of special trade is being carried by the University of Wolverhampton under task 7 of the VIRCON project.

As stated in the case for support and the subsequent discussion and elaboration on the methodology with the VIRCON team, the objective of task 6 was to develop a methodology for integrating standard scheduling software with the 3D models of the whole building and activities based models for the visualization purposes. Based on the current development of tasks 5 (Prototype CSA) and 2 (data capture), task 6 seeks to develop a methodology for visualising and extracting weekly space availability for construction tasks throughout the site construction operations.

The main focus of this report is the development of the *ProVis* visualisation tool. The tool, developed using VBA for Windows, accessing the integrated products and processes from the *VIRCON database* and produces 4D (3D+time) and space visualisation in AutoCAD environment.

In order to achieve the visualisation processes, a number of developments were undertaken:

- A methodology for establishing a dynamic link between WBS (work breakdown structure) and CPM with 2D/3D visualisation of the building was developed and based on the Uniclass approach.
- A space visualisation methodology was developed.
- A software application to facilitate integration (translation) between propriety CPA applications and the database was developed. No commercial 4D visualisation software was used to achieve the visualisation process. This development methodology that solely built on the current industrial tools was seen to be a major achievement of task 6.

The report is organised into five chapters. Chapter 1 introduces the objective of Task 6, scope and input requirements for the visualisation development. Chapter 2 details information and process flowchart for the visualisation development following the ProVis approach. Chapter 3 describes the ProVis prototype and discusses visualisation results obtained from running the ProVis using the School of Health as a case study. Chapter 4 compares the approach being used in the visualisation development with current research initiatives in USA, UK, EU, and Australia. Finally, chapter 5 summarises the progress achieved to date and future work.

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Chapter 1 Introduction

1.1 General

As a part of Virtual Construction Site (VIRCON) project funded by Engineering and Physical Sciences Research Council (EPSRC)'s research programme award no. GR/N00876, this document reports on the progress and deliverables of Task 6: Visualisation development of building architectural components managed by University of Teesside. This task is a continuation effort from the work carried out in Task 2 in which construction product and process data of the School of Health Project, University of Teesside were captured and stored in a specific-purpose-developed database called 'VIRCON Database'.

The main objective of this task is to develop a methodology and an economic desktop tool to visualise both building products being constructed and space availability for construction processes at any stage according to the preliminary schedule. It is envisaged that the users will be able to visually detect problems related to logic of schedule and time-space conflict by the assistance of this tool. It should also be noted that this task has been undertaken in parallel with Task 7, which its visualisation development specifically focuses on building services and groundwork operations.

1.2 Scope and Input Requirements

The building architectural components being included in Task 6 are all foundations, columns, beams, floors, walls, roofs, doors, and windows of the Teesside School of Health Project. To enable the visualisation development of these components, this task uses product and process data initially gathered and stored in the VIRCON database. These data include 2D CAD drawings, geometrical data (width, length, and coordinates), and program of work (Work Breakdown Structure, activity start and end dates, etc).

However, during the course of this task, additional meetings were held with a representative of AMEC Capital Projects who was the general contractor responsible for the whole building construction of the project. Supplementary information including utilisation and space requirements of resources such as labour, materials, equipment, and temporary supports were discussed, recorded, and populated in the VIRCON database. Furthermore, site layout, construction methods and execution patterns were interpreted from the contractor's progress reports so that the visualisation development can intimately reflect the real scenario.

As the input requirements to the visualisation development, Figure 1.1 to 1.4 presents 2D CAD Drawing, Work Breakdown Structure, Resource Utilisation and Allocations, and Population of Resource Information in the VIRCON Database respectively.

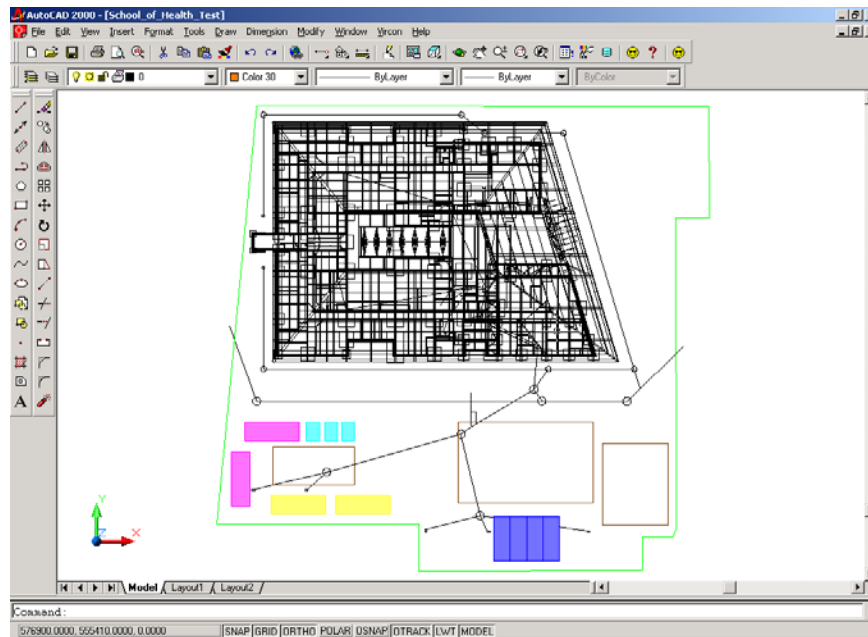


Figure 1.1: 2D CAD Drawing for Site Layout and Building Architectural Components

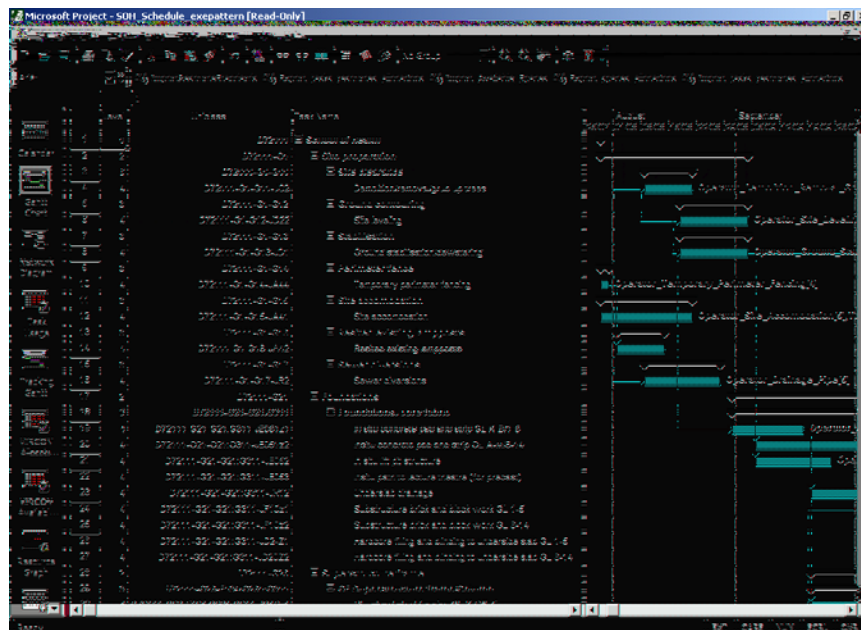


Figure 1.2: Product-based Work Breakdown Structure following Uniclass – Building Architectural Components

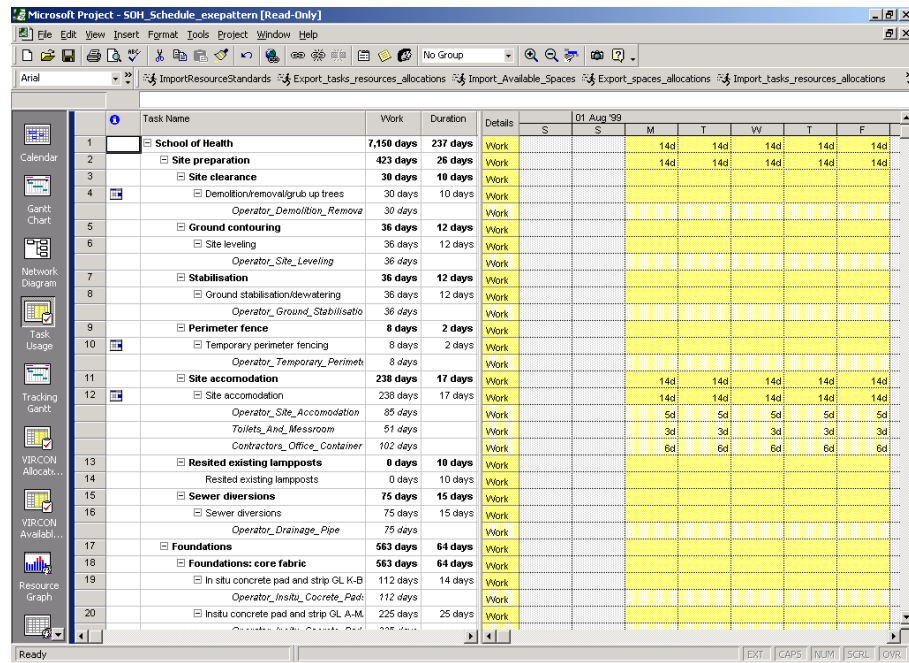


Figure 1.3: Resource Utilisation and Allocations for Each Work Package

The screenshot shows the VIRCON Database interface. The 'Resource Allocation' form is open, displaying the following information:

- Class:** Process/Resource Allocation
- ResourceAllocationID / Task_Name:** Temporary perimeter fencing
- Resource_Name:** Operator_Sewer_Diversion
- Resource_Quantity:** 4

The form also includes a 'Records' section showing 1 of 102 records. At the bottom, there are buttons for 'Exit VIRCON Database' and 'Exit'.

Figure 1.4: Population of Resource Information in the VIRCON Database

Chapter 2 Visualisation Development Processes: The ProVis Approach

2.1 General

The proposed aim of the VIRCON project is to develop a strategic planning support system for evaluating, visualising and optimising construction schedules within a desktop environment. To achieve this aim, a system architecture encompassing a core repository of construction product and process data (VIRCON database), a 4D simulation and visualisation tool, and a space-time analysis tool (SpaceMan) has been initially deliberated.

This chapter explains research methodologies of construction visualisation which have been developed for the VIRCON project on an easy-to-follow step-by-step basis. The section is organised in two main subsections namely populating the VIRCON database and 4D visualisation process. The first subsection provides users with processes to appropriately prepare construction data (CAD drawings and construction plan) for populating the VIRCON database. The later subsection explains the methodology to integrate product and process data as a prerequisite for the 4D visualisation. Technical descriptions for the 4D visualisation in both AutoCAD and VR environment are also discussed.

2.2 Populating the VIRCON Database

The Task 2 report (Dawood et al. 2001) introduced and discussed data capture and VIRCON database development. The objective of this section is to detail the process of populating the VIRCON database for both products and processes.

This section complement the Task 2 report and intends to provide users with a holistic understanding on how the construction product and process data (from the source documents) should be manipulated and populated to the VIRCON database. Incorporating with systematic flowcharts and an example of a Ground Floor Column, the processes for populating product and process data are elaborated and discussed. The following subsections illustrate the processes of populating construction products and construction processes.

2.2.1 Process for Populating Product Data

In broadest perspective, construction product data cover all information related to products' attributes and characteristics. The product data can be classified into two categories: 1) graphical data such as dimensions and spatial data derived from drawings; and 2) non-graphical data such as specifications, method statements, bill of quantities, and product costs. However, for the purpose of space-time conflict analysis and visualisation, only CAD drawings produced by the industrial collaborations of the VIRCON project were used to populate the database.

The process map for populating the CAD drawings to the VIRCON database is shown in Figure 2.1. Although only one example of a Ground Floor Column is presented, the process map is drawn in general and therefore applicable to every product in the database.

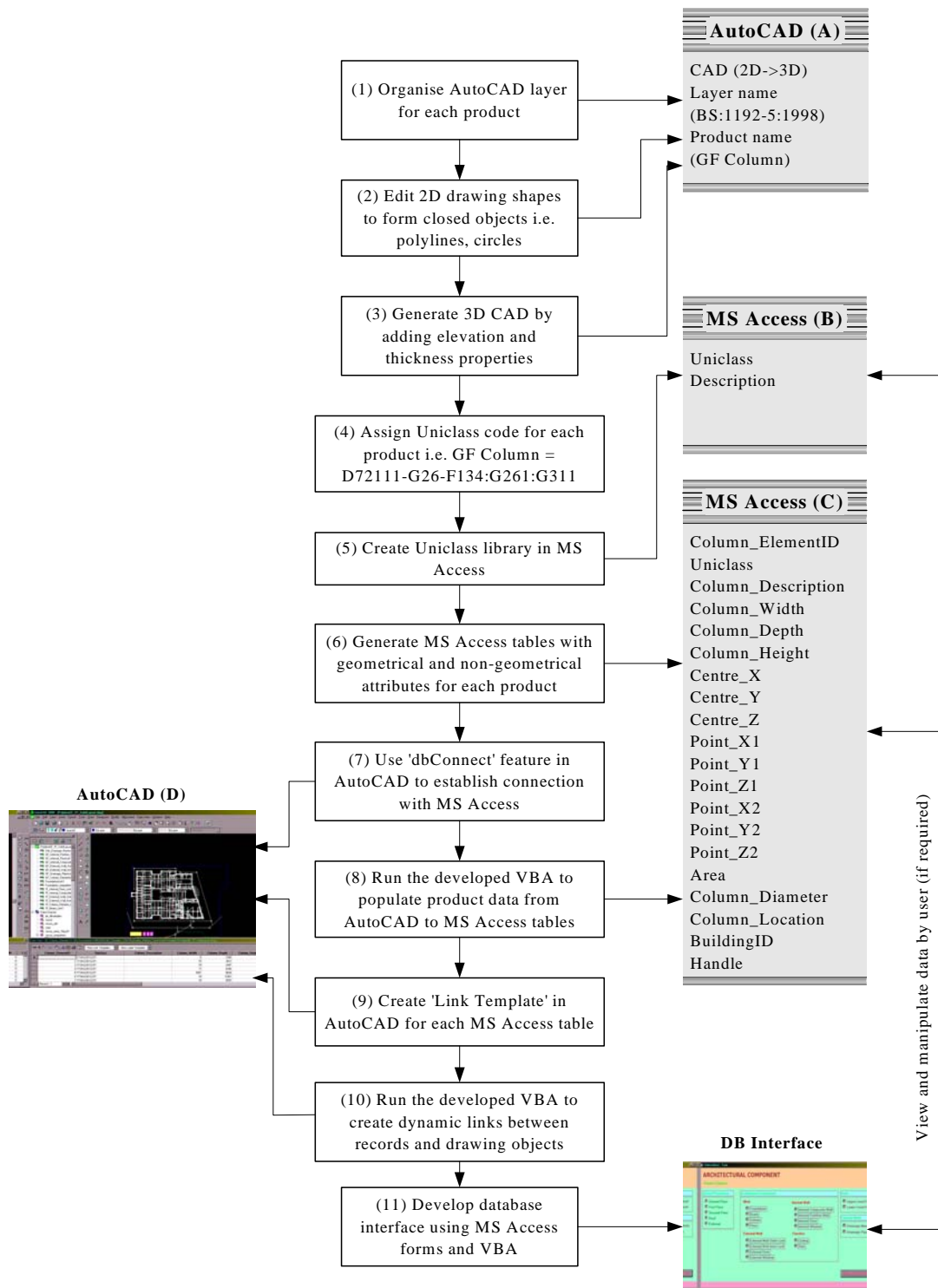
The populating process consists of eleven steps and five intermediate and final outputs in total as shown in the figure. The details of each step are described below:

- 1) In most circumstances, the layering conventions are varied from one design organisation to another. In this research project, standardisation of layering has been made through the use of the BS 1192-5: British Standard for Construction Drawing Practice (BS 1998). To systematically reorganise layers in the original AutoCAD drawings, one layer should contain only a specific type of product in a specific area, for example, Ground Floor Columns. After that, a layering convention based on the British Standard should be given to each layer i.e. A-G261-M-01_F-Column for the layer of Ground Floor Columns.
- 2) If the original CAD drawings are drawn using variety types of lines i.e. broken lines, curbs, blocks, the shapes of the drawings have to be edited to form a set of closed objects using Polylines or circles. It should be noted that this step could enormously consume time and efforts. In order to avoid this problem in future population of the database, an agreement with design firms in producing all drawings in the closed objects manner and following BS conversion should be made at the first stage.
- 3) In most cases, the CAD drawings are usually produced in two dimensional (2D) format. However, generating a very accurate and detailed 3D CAD of the whole project requires a team of professional CAD drafters and apparently a sound investment. For experimenting purpose, this project employs a simple technique using '*Change Properties*' command in the AutoCAD. The elevation and thickness values of each product are input which result in a simple 3D CAD. The main outputs by this step are schematically shown in "AutoCAD (A)" in the Figure 2.1.

The outcome of the above three processes is a 2D-3D AutoCAD model of construction products organised according to the BS 1192-5 layering convention.

- 4) Based on the Unified Classification for the Construction Industry (Uniclass) published by the Construction Project Information Committee (Construction 1997), a Uniclass code is assigned each construction product. For instance, the Ground Floor Column is represented by the Uniclass code of D72111-G26-F134:G261:G311. The code component D72111, G26, F134, G261, and G311 represents the university building, the frame structural element, the ground floor, the columns, and the core fabric of frame, respectively.
- 5) The Uniclass code is then added to the database field to create the Uniclass code library as an intermediate output as shown in "MS Access (B)", Figure 2.1. The Uniclass library acts as a unique code in the relational database to identify MS Access tables that represent construction products.
- 6) For each construction product, an MS Access table is created to record all geometrical data of all elements in a construction product, including the width, length, depth, and the co-ordinates of the AutoCAD bounding box (including one centre and two points), and others as schematically presented in "MS Access (C)", Figure 2.1. This represents spatial records for products in the database.

- 7) The '*dbConnect*' feature in AutoCAD is used to link AutoCAD and MS Access through Open Database Connectivity (ODBC). The details to complete this step are available in the VIRCON database development manual and AutoCAD help file.
- 8) To utilise the above function of AutoCAD, a VBA code was developed by the Teesside research team to extract the above mentioned geometrical data and write to the MS Access table automatically. An example to show the display of AutoCAD drawings, and the MS Access data files is given in "AutoCAD (D)", Figure 2.1.
- 9) Each file in a MS Access table should be linked to an AutoCAD object to form a link template. The detailed procedure for creating the link template is described in Dawood et al. 2001.
- 10) A VBA subroutine is developed to create dynamic links between a pair of data record and drawing object. This allows users to access data of a particular drawing object by simply click at that object. Vice versa, while the users are browsing through each data record, the matching object will be zoomed in.
- 11) To enhance the user friendliness in navigating the database, interfaces are developed using Access forms and VBA codes. An example interface is shown in Figure 2.1 as entitled "DB Interface". Through this interface, the user is able to view the database and manipulate the construction data by updating the AutoCAD files and re-populating the database by running the developed VBA code. Some of the drawings of the School of Health (roof structures and foundations) were not available electronically. Therefore, the Teesside research team had to spend additional efforts in drafting those products in AutoCAD and then populated them to the database. Complete data of the whole building are vital for the visualisation process.



**Figure 2.1: Process for Populating Product Data to the VIRCON Database
(An Example of Ground Floor Columns)**

2.2.2 Process for Populating Process Data to the VIRCON Database

In this report, construction processes are defined as “site and work-face activities that are required to construct a product”. Three major types of the construction process data namely time, resource, and space are classified and described as follows:

- a) Time data of each activity consists of duration, start and end dates, preceded and succeeded activities, critical activity, and total slack.
- b) Resource data of each activity includes utilisation and allocations of manpower and equipment.
- c) Space data of each activity includes areas required for the construction processes such as product areas, workman areas, and equipment areas.

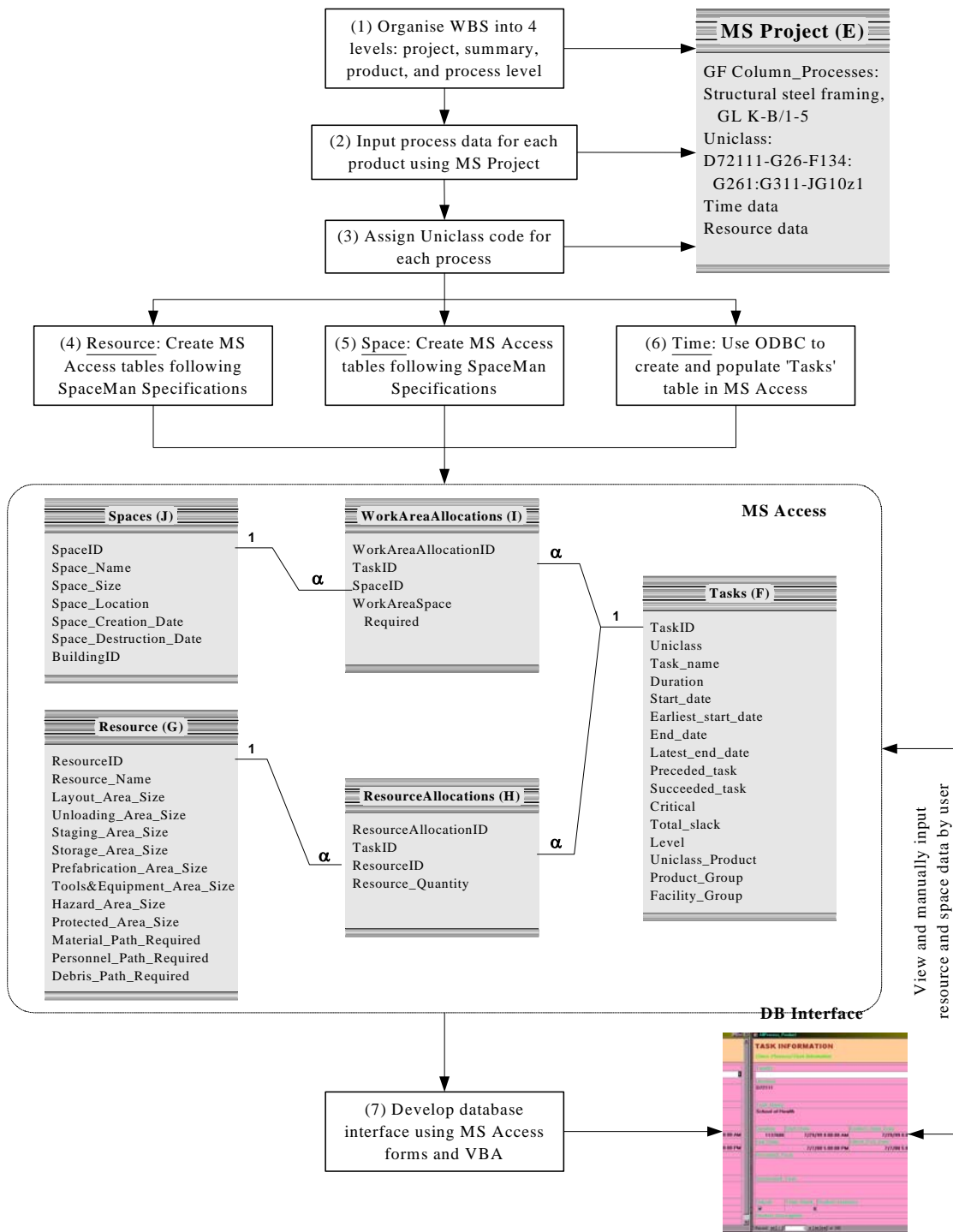
Figure 2.2 represents the process for populating the construction process data to the VIRCON database. This is illustrated by taking the ground floor columns as an example. The whole process for populating construction processes is divided into seven steps as numbered in Figure 2.2. With the operation of populating the construction process data to the database, three outputs are produced. These outputs are the Ms Project (E), MS Access records, and DB Interface as shown in Figure 2.2. The seven operation steps for populating VIRCON database are described as follows:

- 1) Based on the principle of Uniclass, a product-based work breakdown structure (WBS) approach is used to systematically break down the project activity hence enables integration of product and process data. The original schedule produced by AMEC was reorganised into four levels: 1) construction project i.e. School of Health, 2) brief summary of the construction product i.e. Superstructure, 3) construction product i.e. GF Column, and 4) construction process i.e. installation of GF Column.
- 2) Based on the WBS in step 1, time and resource data of each activity is input into MS Project. It should be mentioned that other construction project scheduling software that can export data via ODBC such as PowerProject and Primavera could also be used.
- 3) A Uniclass code is assigned to each construction process. A part of this code represents the Uniclass code of the construction product to be constructed. For example, the Uniclass code D72111-G26-F134:G261:G311-JG10z1 represents the construction process, structural steel framing, to construct the ground floor columns, and it is coded as D72111-G26-F134:G261:G311.

Outputs of steps 1, 2, and 3 described above will be a MS Project schedule of a construction project populated with resources.

- 4) Following the SpaceMan Specifications (North 2001), MS Access tables are created to record the resource information for each construction process.
- 5) Similarly, other MS Access tables are created to record the spaces required by each construction process, including the spaces for construction labour crew, equipment, and materials as well as the space for hazard prevention. Both resource data and space data need to be manually input into the database.

- 6) All time related data of construction processes are created and populated in an MS Access table using ODBC connected to MS Project. The contents of MS Access tables for recording the resources, spaces and time are shown in Figure 2.2 as “Resources (G)”, “Space (J)”, and “Task (F)”, respectively. The MS Access file Tasks is connected with the MS Access resource and space tables through another two MS Access tables “Resource Allocations (H)” and “Work Are Allocations (I)”, respectively.
- 7) As described in section 2.2.1, MS Access is well developed for the creation of user-friendly database interfaces. Both MS Access forms and VBA codes are utilised and an example is shown in Figure 2.2 as entitled “DB Interface”. In addition, the user is also able to view the construction process data in the database, and update the construction process data such as the resource data and space data.



**Figure 2.2: Process for Populating Process Data to the VIRCON Database
(An Example of Ground Floor Columns)**

2.3 4D Visualisation Process

This section discusses the methodology of 4D visualisation development specifically designed and employed in this research. Comparison of this methodology with other construction visualisation research projects being conducted worldwide can be found in Chapter 4.

For this research, the overall construction visualisation approach is shown in Figure 2.3, which includes ten operation steps, and six intermediate and final outputs. Same as in the earlier section, the ground floor columns are used to illustrate the case. The following steps describe the visualisation process.

- 1) Section 2.2.1 explains how to revise the original AutoCAD layers in 2D to 3D. Based on the updated AutoCAD layers as shown in “AutoCAD (D)”, Figure 2.1, construction products are divided into a number groups. According to the way in which these products are built and for the purpose of visualising execution patterns, the grouping process is done in AutoCAD and linked to activities. Both the Uniclass code and the group names are linked to the construction scheduling in MS Project as well as in MS Access table.
- 2) Each construction product group is integrated with construction activities in MS Project, and a group name of products is assigned to each construction activity. For example, in the prototype system (to be described in detail in Chapter 3), one group of the columns at the ground floor coded as “GFColumn_Group1” is integrated with the construction process “steel framing GL K-B/1-5”. Similarly, another group of the columns at the ground floor coded as “GFColumn_Group2” is integrated with the construction process “steel framing GL A-M/6-14”.
- 3) The MS Access table “Tasks” is then updated with the information discussed above by adding items from the construction scheduling in MS Project as shown in Figure 2.3, “MS Project (E)” using ODBC. The contents of the MS Access table Tasks is shown in Figure 2.3, “Tasks (F)”.
- 4) To prepare data to be used by the 4D simulator, all MS Access tables including all construction products, construction schedule, resource data and others are then integrated using the Structured Query Language (SQL). The sample items to be integrated are listed in operation (4) of Figure 2.3. Additionally, an example depicting relationships among these tables is given.
- 5) At this stage, the information in the VIRCON database is ready to be accessed by SpaceMan for spatial analysis. The SpaceMan can feed back to construction engineers and automatically update the construction scheduling if needed.
- 6) A 4D (3D+time) has been developed in the course of this research, called ProVis. A VBA code has been developed to access data in the VIRCON database and present 3D of the building at any time during the construction process in AutoCAD environment. The ProVis was developed to simulate and mimic the process of construction products on site. The simulation shows space needed at work face as well as 3D products. A

screen capture of the ProVis and a simulation output is shown in Figure 2.3, “AutoCAD visualisation”.

- 7) By referring to the space data required by resources, the ProVis performs the visualisation of construction spaces to confirm the occupied spaces, available spaces and potential space conflicts. Users can experience space changes as the construction simulation progresses.
- 8) In addition to the visualisation of construction products and construction spaces, the visualisation of construction process is also possible for the construction engineers to visualise the construction sequence, pattern, and progress according to the construction scheduling.
- 9) To carry out the visualisation in the VR environment, a VR explorer titled as DDToolz4.0 developed by Eindhoven University of Technology is utilised (Eindhoven 2001). This allows a direct conversion from CAD to VR through basic 3D file transfer. A 3D AutoCAD file is imported to the VR explorer as a 3D studio file.
- 10) If a 3D drawing at a given date is imported to the VR explorer, it can be visualised and navigated through the VR model as shown in “VR Visualisation” so that the conflict problems can be easily detected.

Visualisation Process (Example of GF Column)

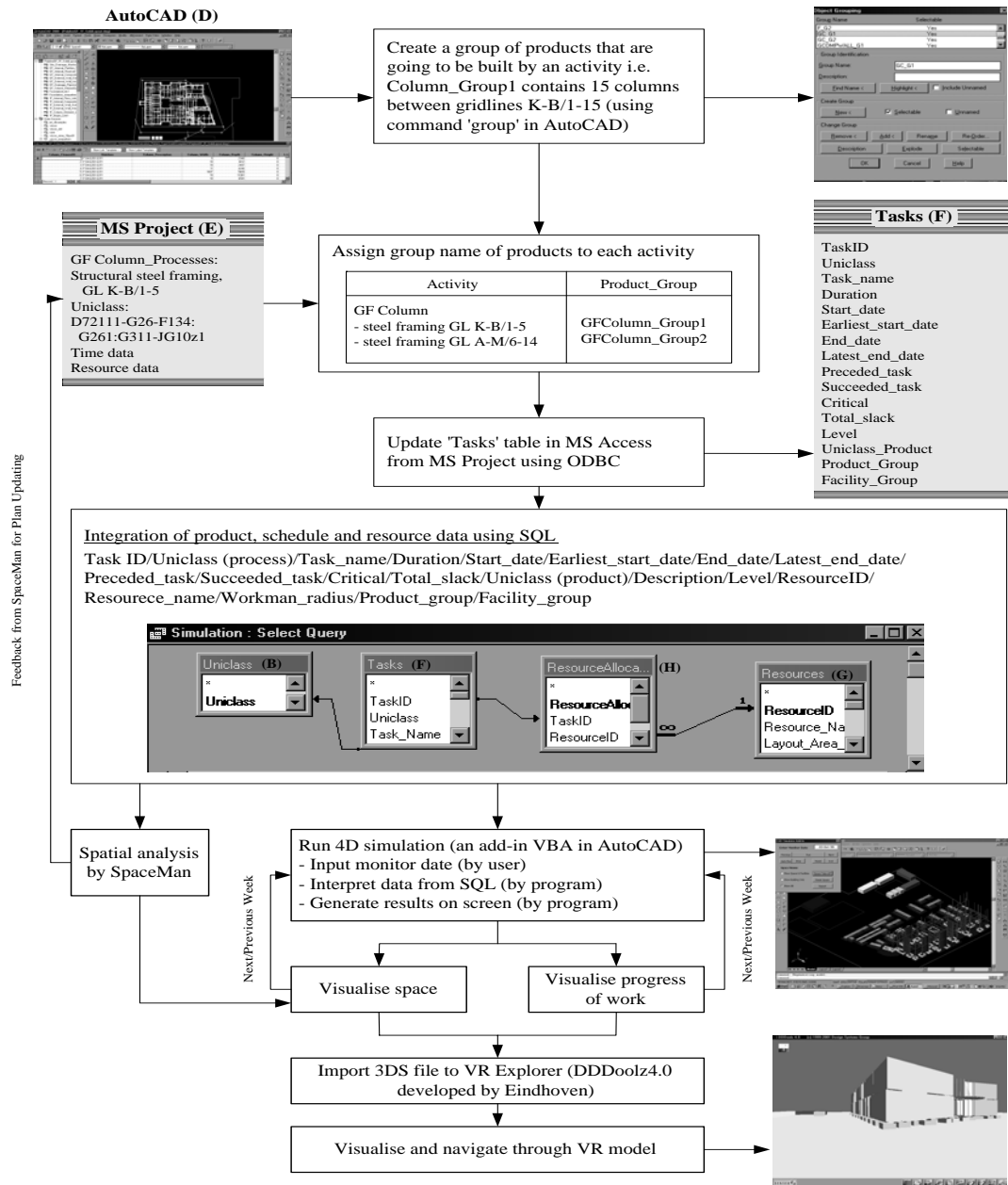


Figure 2.3: 4D Visualisation Process (An Example of ground Floor Columns)

Chapter 3 The ProVis Prototype and Visualisation Results

3.1 General

In order to examine the proposed construction visualisation methodologies in practice, the construction project of School of Health, University of Teesside (entitled the Centuria Building) is selected to develop the prototype visualisation system (ProVis). This project with a six million pounds investment is a three-story steel framework structure purpose-built for the teaching and research targets in medical science. The construction started in July 1999 and completed in July 2000.

Based on the input requirements earlier described in Section 1.2, four new AutoCAD files are further prepared to assign the characters of building components and services in the ground floor, the first floor, the second floor, and the roof, respectively. Initially, all layers in these four files were of two dimensions only and the values in the vertical direction were not denoted. Therefore, all layers have to be revised from 2D to 3D individually and manually. All these layers of AutoCAD drawings are used to establish the geometrical data of construction products. The construction scheduling created by the construction engineers in MS Project is used to generate the process data of all construction products.

This chapter presents the conceptualised GUI of ProVis 4D-CAD simulator, the general framework, and the implementation methodology for visualising construction activities.

3.2 The 4D User Interface and Components

The researchers at Teesside University who produced the ProVis were determined to produce an easier and more intuitive GUI for construction tasks space visualisations. A key part of achieving this was designing the GUI to look as an AutoCAD 2000 Add-on, which integrates the visual elements of the graphical user interface with the 4D simulation model of the Centuria Building.

The conceptual GUI major components are put together in VBA that is shipped with AutoCAD 2000. It provides a supportive interface, which links the CAD 3D model components with VIRCON database records and resources for project activities. A window tabbed-system interface provides the end-user with the GUI major components. The three major parts are explained in the following text.

3.2.1 Products Simulation Tab

Figure 3.1 shows an example of the Products Simulation tab associated with 4D player subcomponents. The users enter a specific monitor date for which the 4D simulation to start. Users are provided with 4D player buttons: next, previous, auto run, stop and reset the simulation. The 4D environment loads the weekly 3D-CAD model when the user clicks on any of these buttons. The simulator displays the 3D geometry with its associated tasks and resources from VIRCON database by using Database Access Object (DAO).

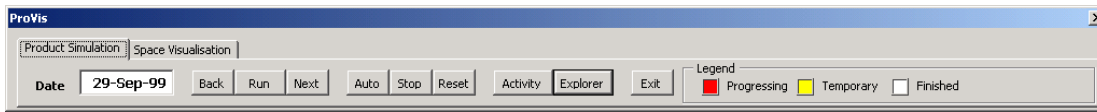


Figure 3.1: Products simulation tab interface

The ProVis visualisation is user-interactive and is substantially improved in the UI elements such as the ‘Activity’ and ‘Explore’ buttons. The UI elements retrieve construction activities information and allow the user to force a selective visualisation to show/hide specific tasks within the 4D visualisation. An example of exploring the project activities can be seen in Figure 3.2 screenshots a, b, and c. A complete description for the ProVis GUI is supplied in Appendix A, and it includes the operation of the 4D visualisation.

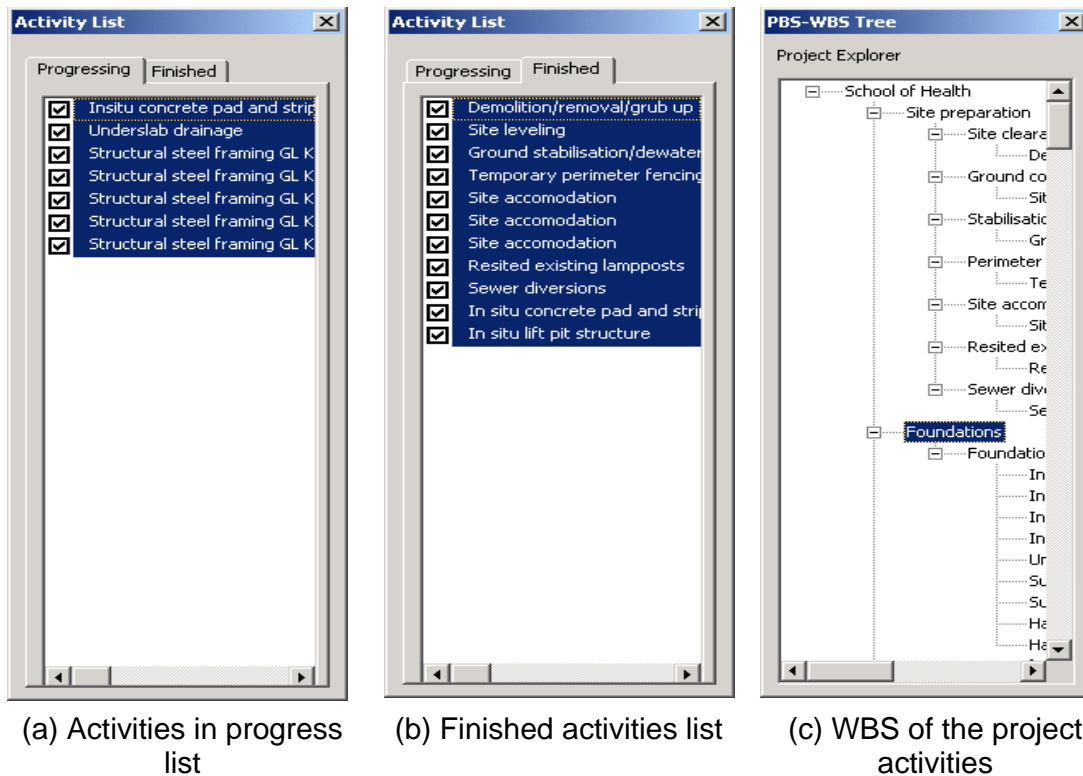


Figure 3.2: Exploring the project activities

3.2.2 Space Visualisation Tab

Figure 3.2 shows the space visualisation tab that gives the user some options in visualising construction activities at a specific monitor time. Firstly, The space viewer part provides the user with hide/show options for viewing different building components of the Centuria 3D model. The ‘Draw Spatial Loading’ button displays the Critical Space Analysis (CSA) results in different colours, as indicated in the ‘CSA Legend’ (Figure 3.4).

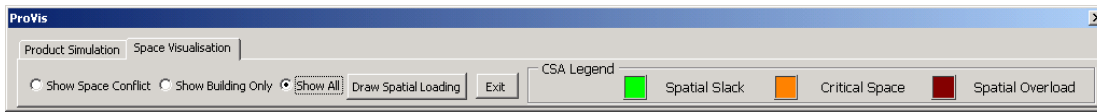


Figure 3.3: Space visualisation tab

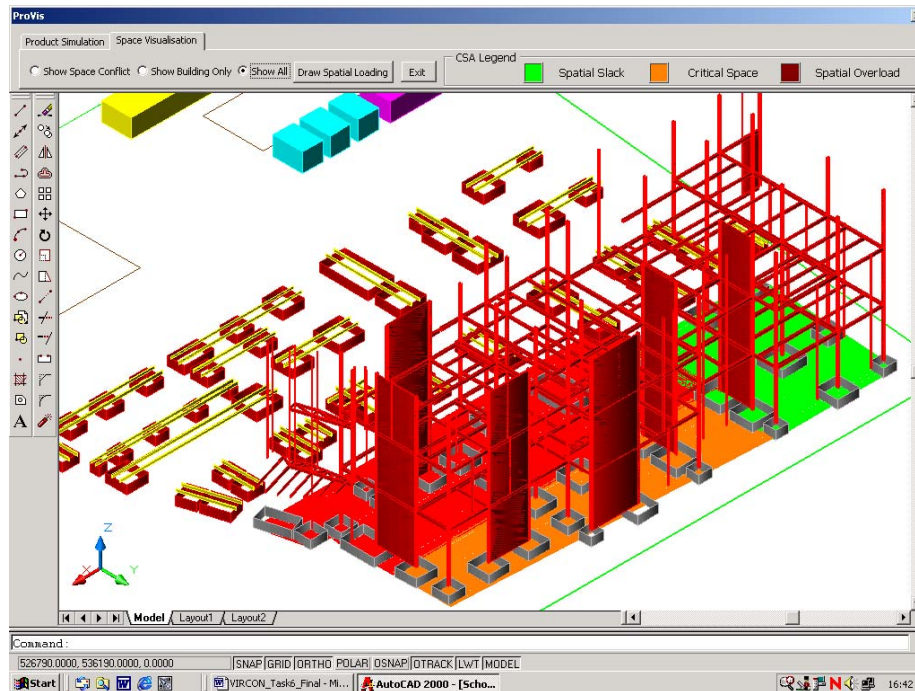


Figure 3.4: Critical Space Analysis (CSA) results

3.3 External Construction Visualisation with Time

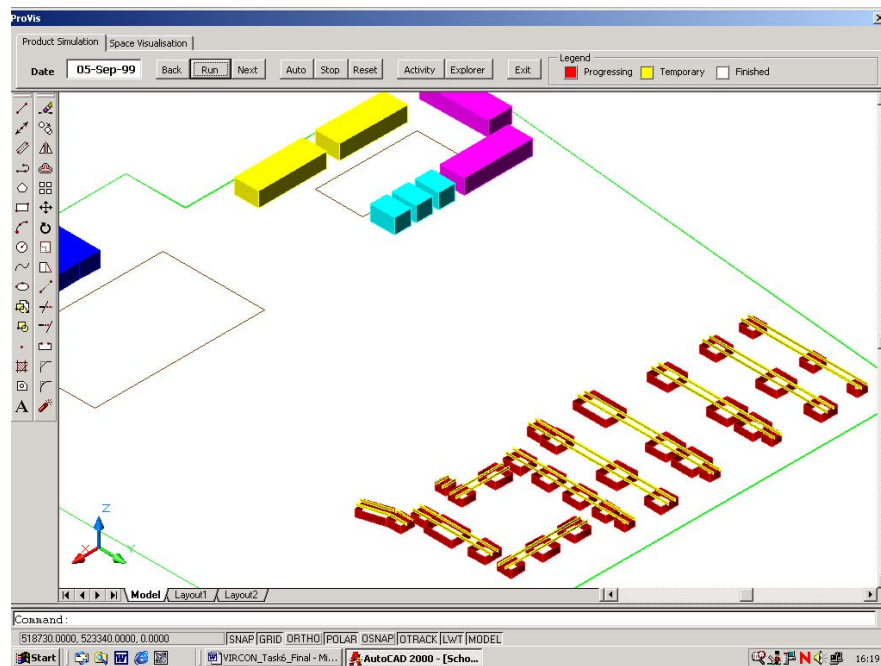
Up to now, about 30 construction 3D products have been prepared in 4D model, which contain the main structural components and temporary construction facilities of the Centuria Building. The total construction duration is 116 working days from August 1999 to February 2000. Parallel to this, the 4D visualisation of the mechanical and electrical systems of the same building is being tackled by a joint research group at the University of Wolverhampton.

The construction visualisation of the Centuria Building has been developed on the platform of personal computers using Windows 98. Although there are no requirements on the hardware to run the program, the recommended CPU speed and installed memory are not less than Pentium 266 and 64 MB, respectively.

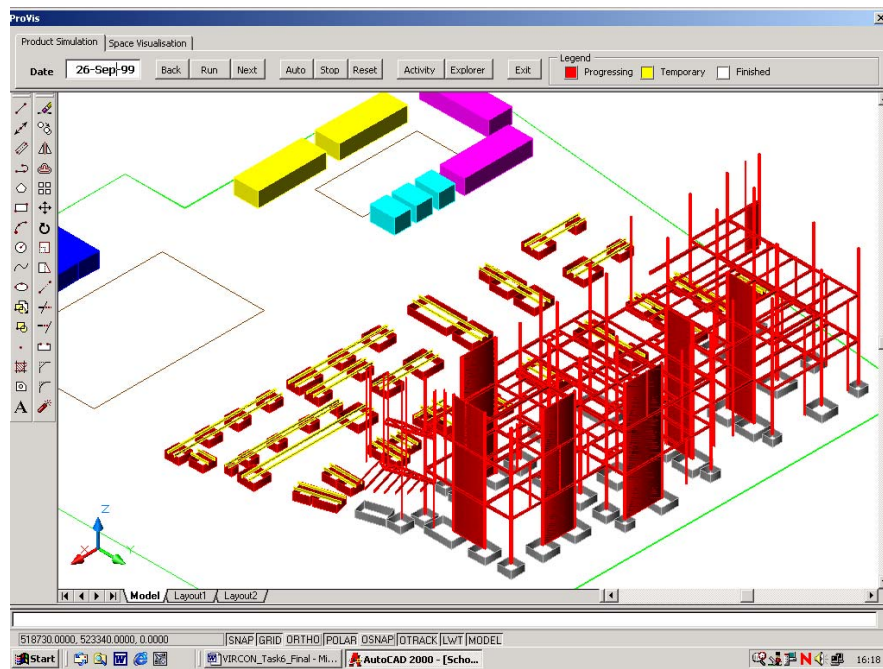
A series of screen captures (Figures 3.5 to 3.11) of the visualisation process are presented here to show the dynamic construction situations of the Centuria Building in various dates.

As the visualisation simulation was carried out in the unit of week, the displayed construction situation is the possibly achieving stage during the calendar week of the monitor day according to the project schedule. Figure 3.5 shows the foundation construction on 05/09/1999. Figure 3.6 shows the construction situation of columns on 26/09/1999. Figure 3.7 shows the construction situation of floors and wall on 05/11/1999. Figure 3.8 shows the construction situation of lower trusses of the roof on 12/11/1999. Figure 3.9 shows the construction situation of the upper trusses of the roof on 26/11/1999. Figure 3.10 shows the construction situation of purlins of the roof on 14/01/2000. Figure 3.11 shows the whole Centuria Building after structural construction on 16/02/2000.

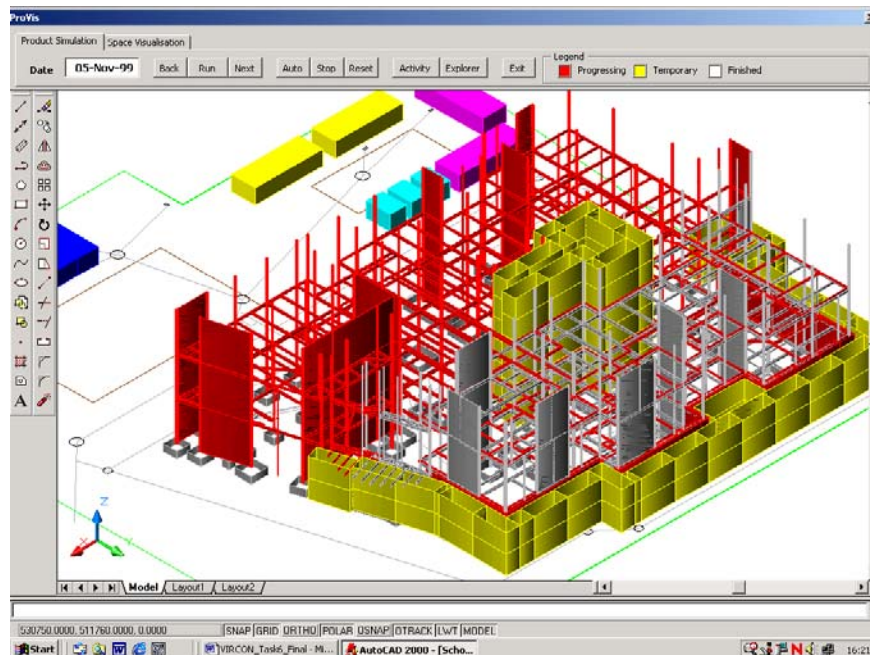
Figure 3.12 is an example to show the visualisation of the construction situation of the Centuria Building using the DDDoolz4.0 VR explorer. The users are able to virtually walk through the building to visualise the construction site with the navigation of the program.



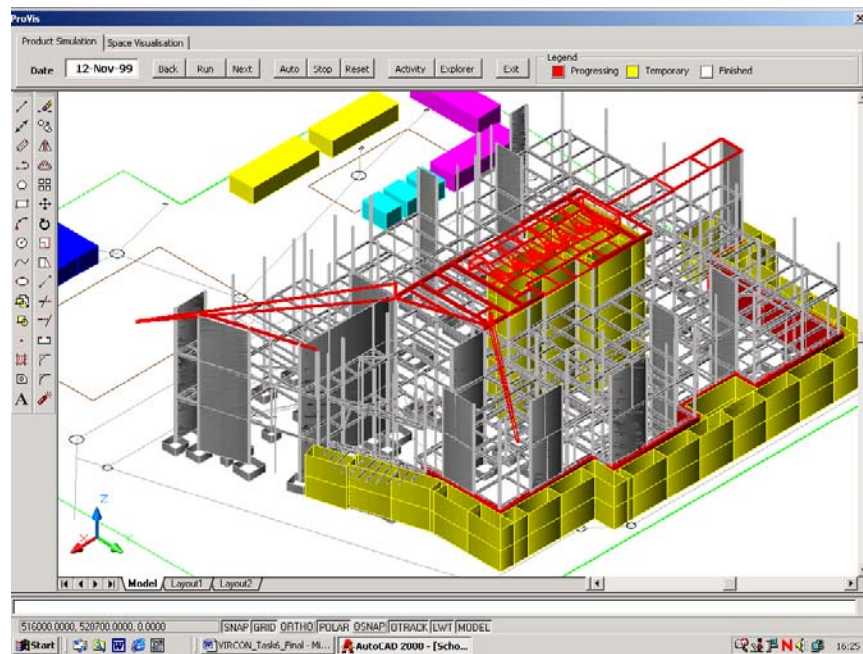
**Figure 3.5: 4D Visualisation for Constructing Centuria Building
(Foundation Construction on 05/09/1999)**



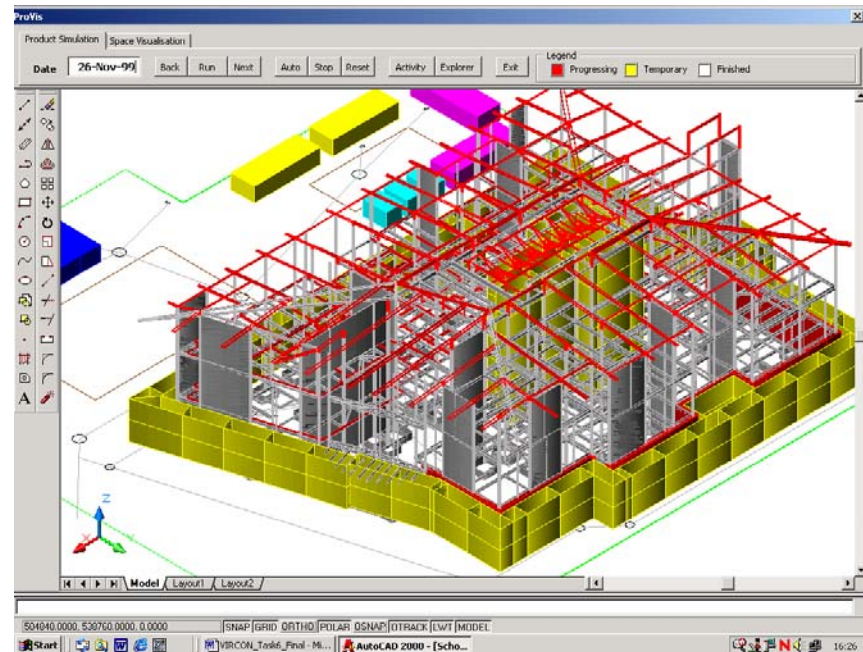
**Figure 3.6: 4D Visualisation for Constructing Centuria Building
(Construction Situation of Columns on 26/09/1999)**



**Figure 3.7: 4D Visualisation for Constructing Centuria Building
(Construction Situation of Floors and Walls on 05/11/1999)**



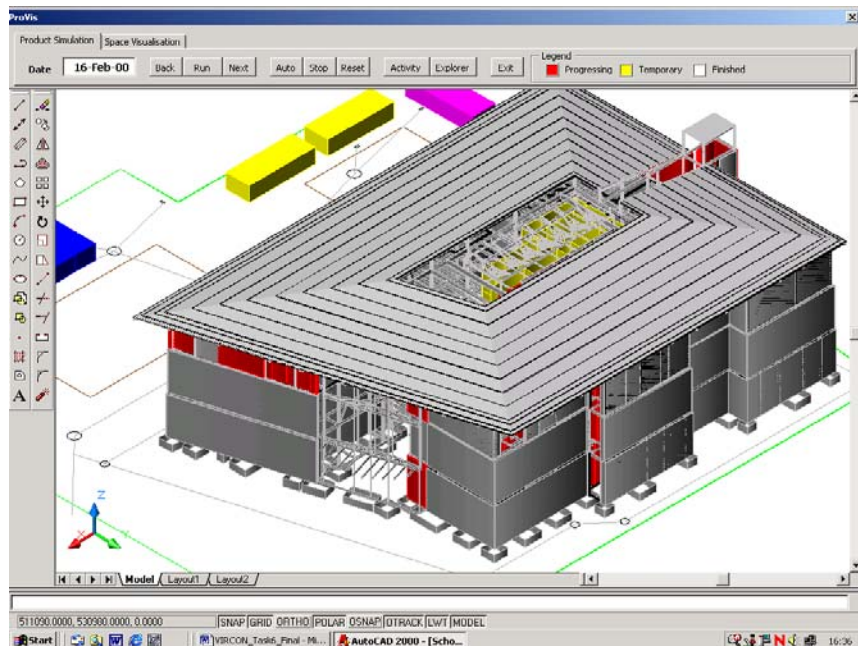
**Figure 3.8: 4D Visualisation for Constructing Centuria Building
(Construction Situation of Lower Trusses of the Roof on 12/11/1999)**



**Figure 3.9: 4D Visualisation for Constructing Centuria Building
(Construction Situation of Upper Trusses of the Roof on 26/11/1999)**



**Figure 3.10: 4D Visualisation for Constructing Centuria Building
(Construction Situation of Purlins of the Roof on 14/01/2000)**



**Figure 3.11: 4D Visualisation for Constructing Centuria Building
(Whole Building after Structural Construction on 16/02/2000)**

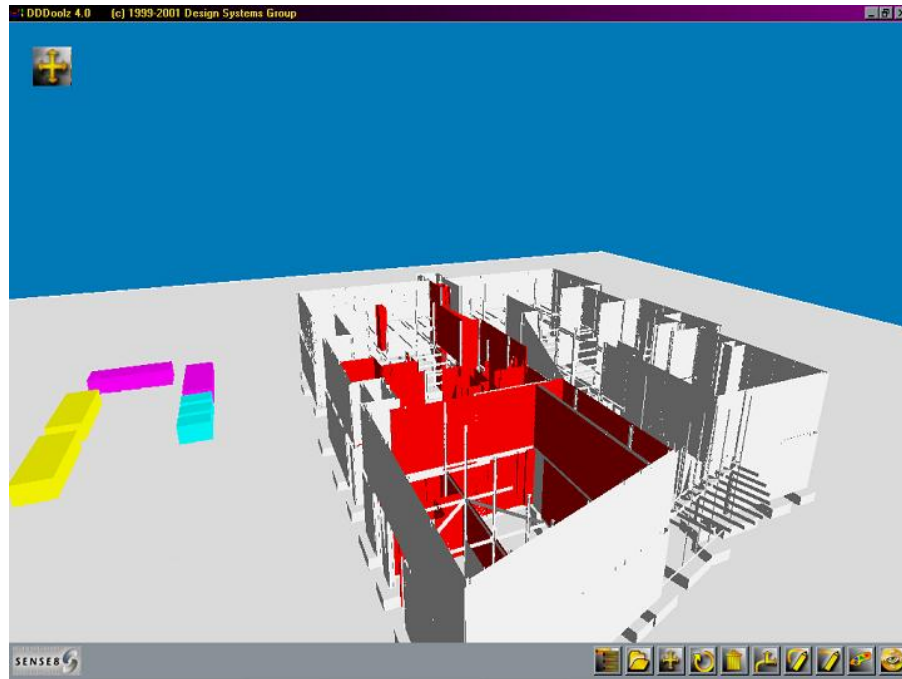


Figure 3.12: 4D Visualisation for Constructing the Centuria Building (VR Explorer)

3.4 Internal Construction Visualisation with Time

The VIRCON 4D visualisation approach also allows users to view the construction work in progress from any location by using the Dynamic View command in AutoCAD 2000. Figures 3.13 to 3.15 demonstrate internal views in different periods to show roof work progress. As shown in figure 3.13, the lower part of the atrium truss is highlighted in red to show that work execution is in progress. Figure 3.14 displays the beginning for assembling the upper part roof and therefore it is highlighted with red. The lower part roof activity is highlighted with white to show end of activity. In figure 3.15, the roof purlins activity is progressing and is highlighted with red. Additionally, the roof sheeting activity starts and is visualised in red.

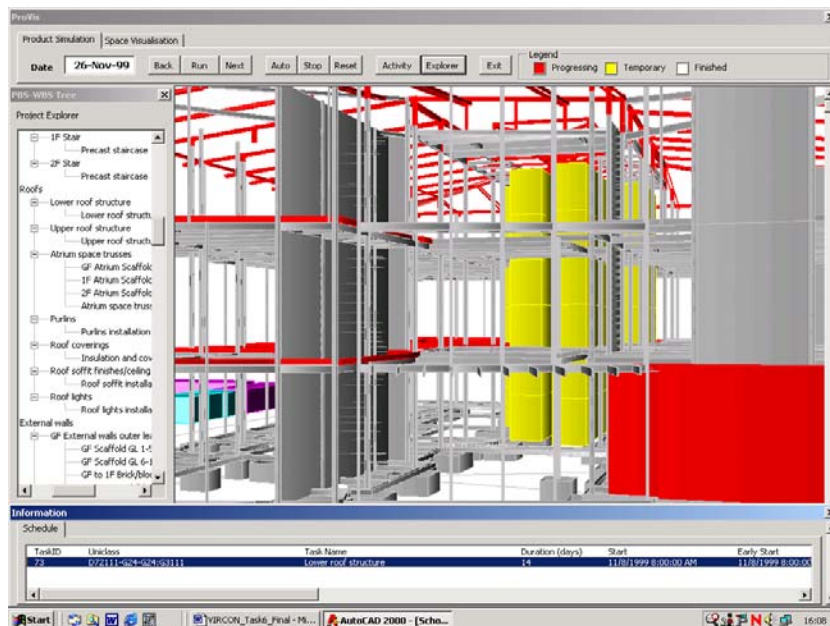


Figure 3.13: Lower Part Roof Activity starting on 26/11/1999

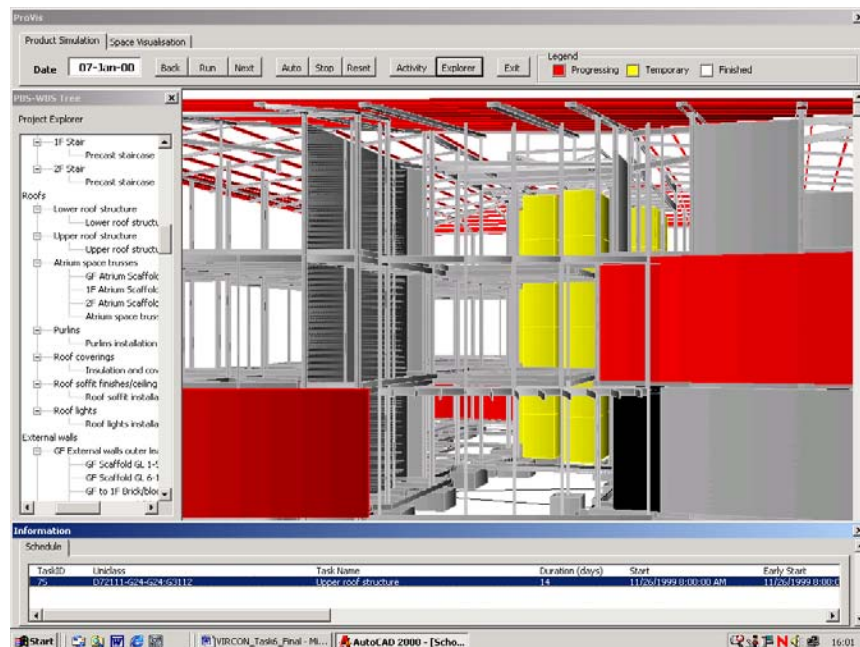


Figure 3.14: Upper Part Roof Activity starting on 07/01/2000

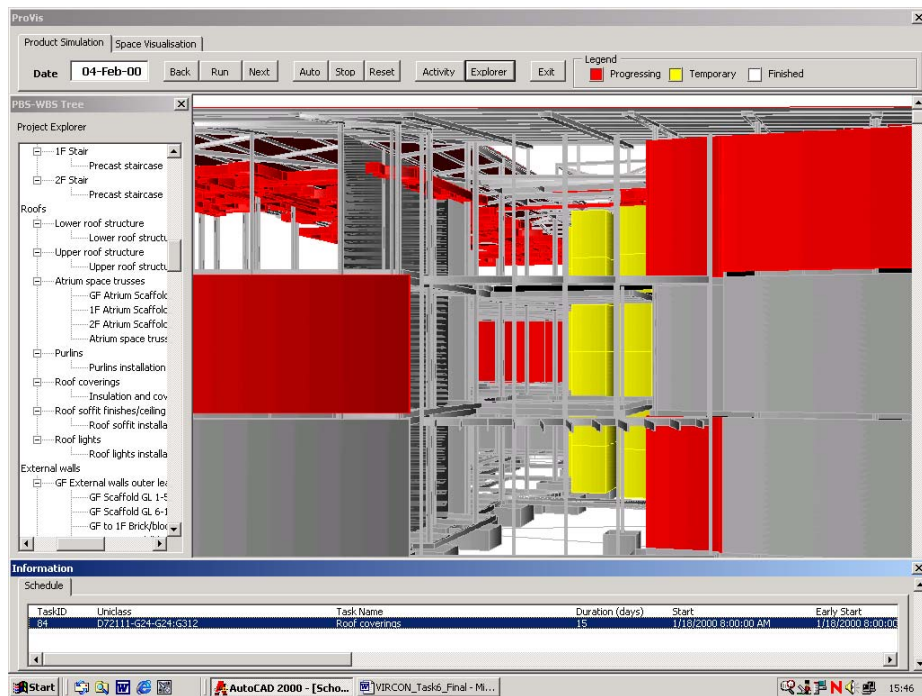


Figure 3.15: Roof Purlins and Sheeting Covering Activity starting on 04/02/2000

Chapter 4 Comparison of the ProVis/VIRCON with Other Research Prototypes

4.1 General

Still at present construction process planning typically means scheduling and schedules in Gantt chart format. This kind of a schedule is not a particularly good communication means for individuals having different background and being not necessarily familiar with formal scheduling outputs. Today, we must rely solely on the project participants' ability to interpret these rather abstract, discipline-specific models to form a mental picture of the corresponding construction approach. Even a good construction plan often gets misinterpreted by some of the participants, which can lead to inefficient processes accomplishing the wrong thing. To increase the quality of the process plans, better models and simulations of the construction process are needed. This is a one way to decrease the duration of the projects and same time keeping up the certainty that the schedule is realistic.

Since 1995, an emergence of 4D CAD (3D plus time) and VR (Virtual Reality) technologies has potentially enabled designers and builders to communicate the design and construction process visually, making the communication of design and construction decisions more comprehensive and faster.

Currently, not only the VIRCON research project conducted by University of Teesside, University of Wolverhampton, and UMIST, a number of researches in 4D CAD and VR applications in construction is being conducted by many universities and research institutes worldwide. Excluding commercial software development companies, these active universities and research institutes are Stanford University-USA, VTT-Finland, Salford and Strathclyde Universities-UK, and University of Sydney and Melbourne-Australia.

Each research project has developed its own methodology and technology attempting to deliver the most informative but the most feasible and economic 4D CAD and VR applications. Therefore, it is worth to compare and contrast these methodologies with the one developed in ProVis/VIRCON project. It is envisaged that advantages and disadvantages of ProVis/VIRCON methodology can be identified and thus provides lights for future improvement.

4.2 Comparison of 4D CAD/VR Features between ProVis/VIRCON and Other Research Prototypes

In this section, comparison of 4D CAD/VR features of ProVis/VIRCON is made with other 10 research prototypes that have been finished or being developed in the active universities and research institutes as mentioned earlier. An intense review of documents, published papers, web sites, and the prototypes of those projects was conducted. 50 main different features of the methodologies and technologies employed by these researches can be identified. These features then can be grouped into 12 groups including:

- 1) CAD Visualisation Environment
- 2) VR Visualisation Environment

- 3) Scheduling Software
- 4) Database
- 5) Standard Classification
- 6) Product-Process Linking
- 7) Product Visualisation
- 8) Process Visualisation
- 9) Space Visualisation
- 10) Associated Annotations
- 11) Model Test
- 12) Applications

The comparison results are presented in Table 4.1

4.2.1 Advantages of ProVis/VIRCON over Other Prototypes

Based on results presented in Table 4.1, advantages of ProVis/VIRCON over other prototypes can be discussed as follows:

- 1) In comparison with others, ProVis solely utilises available commercial software that widely accepted and used in the construction industry such as AutoCAD, MS Project, and MS Access for the visualisation development. The VR software such as DDDoolz 4.0 and VRML can also be downloaded from the Internet with no cost. As a result, this will promote widely acceptance and usage of ProVis in the industry.
- 2) The utilisation of a database as a central information resource base in the architecture of ProVis makes it possible and relatively easy to incorporate any kind of 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.
- 3) The first implementation of the Unified Classification for Construction Industry (Uniclass) in ProVis assists planners to systematically breakdown and organise the project schedule. The form of product-based Work Breakdown Structure forces planners to prepare schedules that have consistency in level of detail and also 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.
- 4) Since the ProVis has been self developed using Visual Basic Application (VBA) as an add-in AutoCAD, it is flexible to customise and improve the prototype in the future.
- 5) The ProVis has ability to generate textual-based annotations and reports of the 4D analysis. The annotations include list of progressing activities and critical activities. The reports include space occupation, space availability, and space conflicts location. This feature can enhance benefits and greatly help users to easily detect problems while navigating the model.

- 6) In ProVis, space requirements by workman, materials, equipment, and temporary works can be explicitly shown as CAD objects. The interference of the space can also be highlighted.
- 7) The space template assignor and/or AreaMan developed in the VIRCON project allow users/planners to interact and manually assign additional dynamic space objects such as resource paths, staging areas, and hazard areas to the CAD model. This feature can substantially improve the model to reflect the real scenario and generate better analysis outcomes.
- 8) 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. After that, the users can verify the updated schedule by visualising in ProVis and perhaps adjust the schedule based on their satisfaction.
- 9) The 4D model generated by the ProVis is from the real live project (Teesside School of Health Project). Therefore, it is justified that the ProVis can be used in any real complex projects.

4.2.2 Disadvantages of ProVis/VIRCON under Other Prototypes

Based on results presented in Table 4.1, disadvantages of ProVis/VIRCON under other prototypes can be discussed as follows:

- 1) The VIRCON database implemented in MS Access is currently non-IFC compliant. Justifications for this can be described as follows:
 - a) Input of the VIRCON database is the non-IFC complaint drawing based design generated in AutoCAD. Unlike model-based design where each component is represented as object i.e. foundation, beam, and column, each component in the AutoCAD is represented as fragmented geometrical shapes i.e. lines, polylines, and circles. However, it should be noted that the IFC complaint model based design has not been widely implemented in practices. The existing IFC complaint CAD software i.e. ArchiCAD 6.5 appears to support only the old version of IFC (Version 1.5.1) and has no database connectivity feature.
 - b) Apart from CAD software, no commercial IFC complaint software for other construction management functions (i.e. project planning and scheduling, cost estimating and control) is currently available.
 - c) Without the use of complicated and expensive object oriented database management software, it has been proven that the 4D model of the real project can be simulated smoothly. Each simulated progress status can also be exported to other CAD software using widely accepted data standard such as DXF format. Therefore, a main limitation of non-IFC complaint of the VIRCON database is solely inability to share data across non-CAD based software. This limitation is subject to whether or not IFC complaint non-CAD based software (planning and scheduling, cost estimating) will be available in the future.
- 2) The MS Access can't support multi-users and has low scalability. Fortunately, it is relatively easy to upsize the MS Access database to be a SQL server database using

upsizing wizard in the MS Access. Once the database is upsized to be the SQL Server, it will support multi-users and therefore suitable for implementation in the multi-organizational level. A web-publishing wizard in both MS Access and SQL server will allow authorised users to access the data from any corner in the world via the Internet.

- 3) 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 should be concerned in future development.
- 4) In addition to interaction and assigning space objects in the CAD environment, future development should allow users to interact and assign space objects in the VR environment.

Table 4.1 Comparison of 4D CAD/VR features between VIRCON and other research prototypes

Main Features	Research Project												
	VIRCON (UT,UW,UCL, UMIST)		CIFE-Stanford			Salford		Salford, VTT	VTT	Strathclyde		Sydney	Melbo- urne
	ProVis	Wolv-4D- VRML	CIFE-4D CAD (98)	Feasibility Study (00)	4D SpaceGen (00)	Gallicon (01)	OSCON (01)	Diversity (01)	VIRIL (99)	VR site activity plan (99)	VR Planner (97)	VIRCON (01)	SSV (98)
CAD Visualisation Environment		N/A				N/A	N/A	N/A	N/A	N/A			N/A
1. AutoCAD (4D)	√		√										
2. AutoDesk WalkThrough												√	
3. Schedule Simulator-Bentley					√								
4. PlantSpace-Jacobus Technology				√									
VR Visualisation Environment													?
1. VRML (3D)	√				√		√	√					
2. VRML (4D)		√				√							
3. DDDoolz 4.0-Eindhoven	√												
4. SuperScape VRT									√	√	√	?	
5. SG Visualiser										√			
Schedule Software									?				?
1. MS Project	√	√				√		√					
2. Primavera P3				√	√					√	√	√	
3. CIFE-4D CAD			√										
3. CA-SuperProject							√						
Database			N/A	N/A	N/A				?	N/A			
1. MS Access	√	√											√
2. SQL Server/Oracle													√
3. OODBMS – ObjectStore						√	√	√				√	
4. Borland Dbase V3											√		
Standard Classification			N/A	N/A					?	N/A		N/A	N/A
1. Uniclass	√	√											
2. IFC					√	√	√	√					

Main Features	Research Project												
	VIRCON (UT,UW,UCL, UMIST)		CIFE-Stanford			Salford		Salford, VTT	VTT	Strathclyde		Sydney	Melbo- urne
	ProVis	Wolv-4D- VRML	CIFE-4D CAD (98)	Feasibility Study (00)	4D SpaceGen (00)	Gallicon (01)	OSCON (01)	Diversity (01)	VIRIL (99)	VR site activity plan (99)	VR Planner (97)	VIRCON (01)	SSV (98)
Product-Process Link						?							?
1. Uniclass approach (Product-based WBS)	√	√											
2. Manual grouping of CAD objects	√												
3. Product-Process manual linker				√				√	√	√		√	
4. Knowledge-based system			√							√	√		
5. Construction Method Modeler					√								
Product Visualisation						?	?	?	?	?		?	?
1. Show completed products at start or end date			√/?								√		
2. Show progressing products during activities periods (colouring)	√	√/?		√	√								
Process Visualisation			N/A	N/A		N/A	N/A	N/A	?		?	N/A	?
1. Show temporary works	√	√			√					√			
2. Show storage areas	√	√											
3. Show resource paths	√	√							√	√			
4. Show hazard areas	√	√											
5. Show process animations										√			
Space Visualisation		?	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1. Show space occupied by activities as objects	√				√								
2. Show space conflicts	√				√								
Associated Annotations				N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	?
1. Simple textual based messages	√	√											
2. Direct relates planning			Con-										

information to the visual depiction			cept										
Main Features	Research Project												
	VIRCON (UT,UW,UCL, UMIST)		CIFE-Stanford			Salford		Salford, VTT	VTT	Strathclyde		Sydney	Melbo- urne
	ProVis	Wolv-4D- VRML	CIFE-4D CAD (98)	Feasibility Study (00)	4D SpaceGen (00)	Gallicon (01)	OSCON (01)	Diversity (01)	VIRIL (99)	VR site activity plan (99)	VR Planner (97)	VIRCON (01)	SSV (98)
Model Test							N/A				N/A	N/A	?
1. Real live project	√	√		√		√		√	√	√			
2. Parts of real live project		√	√		√								
Applications													
1. Detection of consistency in level of detail of schedule	√	√	√	√	√	√		√				√	
2. Detection of omission of activities in schedule	√	√	√	√	√	√		√				√	
3. Detection of problems related to logic of schedule	√	√	√	√	√	√		√	√	√		√	
4. Detection of problems related to time-space conflict	√	√	√ manual	√ manual	√			√ future					
5. Detection of accessibility problems	√	√	√ manual	√ manual	√			√ future					
6. Training/Education												√	√
7. Optimisation of schedule to avoid time-space conflict problems	√	√											
8. Automatic schedule generation											√		
9. Integration of estimating, planning, and design						√	√						
10. Utilisation of space template assignor		√			√								
11. Interaction with virtual objects									√	√			
12. Multimedia information about process of constructing a building													√

Legend: √ - meet the criterion with supported documents √/? – meet the criterion but lack of supported documents N/A – Not available ? – No information

Chapter 5 Summary and Future Work

5.1 Summary

The objective of the report was to introduce and discuss the development of the ProVis prototype as a part of the VIRCON project. The report started with identifying the approach used to integrate products and processes for the visualisation purposes. To achieve the 4D visualisations, the VBA macros were developed and embedded in AutoCAD 2000. The 4D simulation and visualisations includes products, processes, and critical space visualisations.

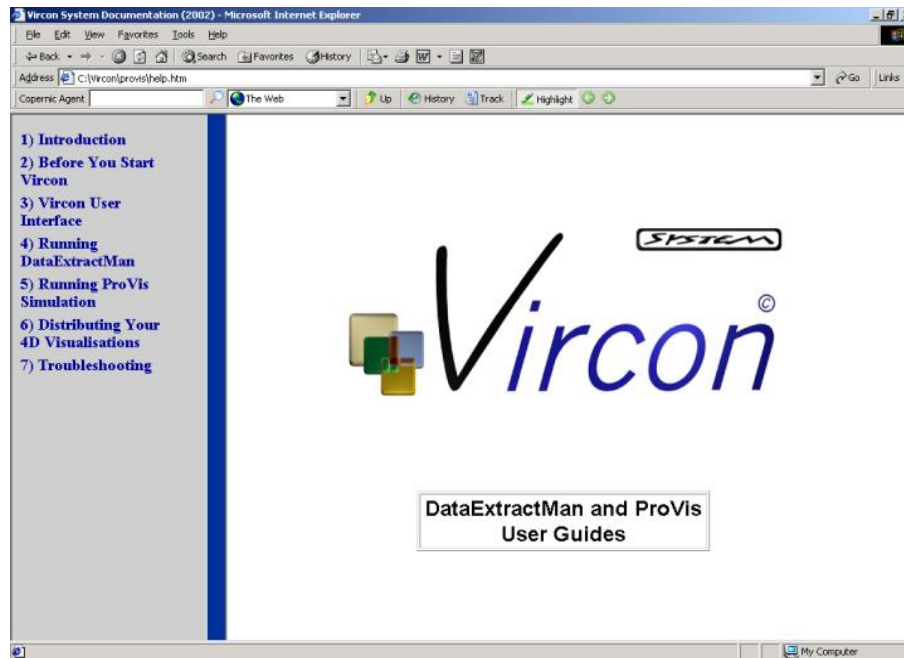
5.2 Future Work

- ❑ This version of the 4D simulator does not include all the resources associated with all activities. However, in the later stages, the research team will investigate ways of assigning standardises resources for the rest of project activities.
- ❑ The underlying VBA routines for visualising construction process can be enhanced in our future work and will be used in various levels to provide extra flexible support for identifying different types of spatial clashes. Of course, this will include the provision of other sets of algorithms and heuristics within the simulation model.
- ❑ It is expected that further spatial reasoning techniques will be developed to derive more useful information about the construction clashes.

Appendix A: ProVis Operation

A.1 General

The operation steps described here are prepared to guide the users when working with the ProVis prototype. Similarly, the 'Help' files are supplied automatically when installing the ProVis as part of the VIRCON system.



A.2.1 Introduction: welcome new user

Welcome to the ProVis User's Guide (Product Visualiser). This guide is specially written for users who are familiar with general concepts of AutoCAD 2000. This guide describes the main features of ProVis software, information on how to use ProVis, and the basic steps to produce successful visualisations for your construction project. You will find out that this guide easily helps you in the following:

- It contains easy step-by-step information so that you can achieve the best from running the ProVis software.
- You will find all related technical information for implementing, configuring and operating the ProVis as an add-on to your AutoCAD environment.
- This guide introduces the main features of ProVis user interface, configuration, set-up, and takes you through examples of how to run ProVis visualisations.
- This documentation explains how to share your 3D visualisation with other project team members.

A.2.2 Introduction: about ProVis software

The ProVis software is the output of an intensive effort and development from the University of Teesside research team - as part of the Virtual Construction Site (VIRCON). ProVis has evolved to enable the new generation of project planner to visualise construction operations through time in 4D (3D + time) according to the project schedule. The software implements integration methodology among MS Project 2000 scheduling software, the VIRCON MS Access database, and 3D models in AutoCAD 2000. ProVis access the VIRCON database and visualises the process of construction products on site. Users can examine the space needed at work face as well as the 3D product progress in time.

ProVis utilises the VIRCON database as the central information source for the 4D-CAD visualisation. The whole information about the resources and the construction operations start/end duration are fed into ProVis to achieve a typical scenario of how the work can be executed on site. In addition, ProVis visualises space-time conflicts after critical space is analysed by SpaceMan tool (time-space broker).

The integration of ProVis and the VIRCON database was developed through the utilisation of Visual Basic for Applications (VBA) programming language as an add-on to AutoCAD. The very simple and friendly user interface of ProVis achieves the following functionality:

- A methodology that automatically populate the project database with products information from the AutoCAD 3D model. This approach establishes a dynamic link between Work Breakdown Structure (WBS) and CPM with 2D/3D visualisation of the construction building.
- A 4D space visualisations in AutoCAD environment by accessing the integrated products and processes from the VIRCON database.
- ProVis utilises the analysis results from SpaceMan to visualise the critical spatial interference between construction activities in 4D.

A.2.3 Introduction: contacts information

- For general questions about ProVis software please contact *Prof. N. N. Dawood* at the University of Teesside.
- For technical support regarding any problems of installation, configuration and running ProVis software please contact any of the research team at University of Teesside.
 - *Ekharin Sriprasert*
 - *Zaki Mallasi*
- For other general enquires regarding VIRCON System, please contact *Steve North* or visit the *VIRCON* website for more resources.

A.3.1 Before You Start VIRCON: system requirements

ProVis runs on top of AutoCAD 2000 or later versions. MS Access 97/2000 is needed so that ProVis communicates with the VIRCON project database. Additional to this is the Visual Basic for Application that is shipped with AutoCAD 2000. Finally, you should make sure that your PC is provided with the latest ODBC drivers installed. The minimum basic hardware requirements is listed below:

- Processor: Intel processor 650 MHz or more.
- Operating System: Microsoft Windows 98x, NT
- RAM: 128 MB minimum.
- Hard Drive Free Space: 10 MB

A.3.2 Before You Start VIRCON: installation

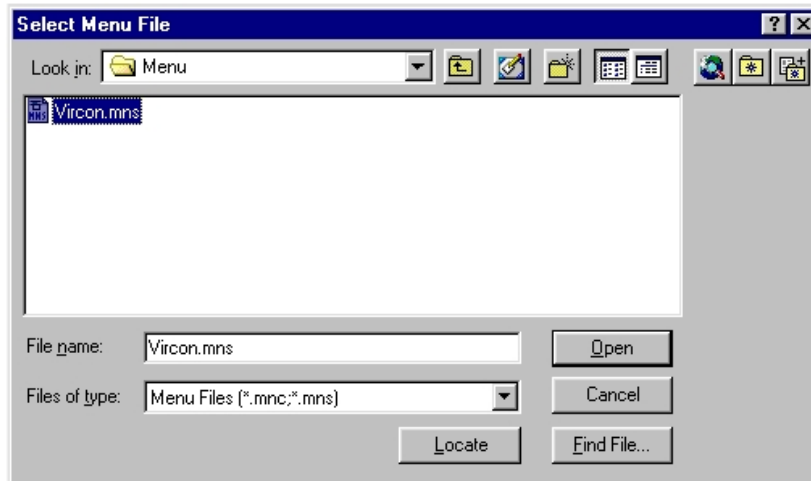
A.3.2.1 Files Checklist

The following table lists the files format and the description for each one that you will need before running the ProVis simulation.

File Name/Path	Description
VIRCON.mdb	The Microsoft Access database file for VIRCON
C:\VIRCON\DataExtractMan\DataExtractMan.dvb	The AutoCAD VBA file project that contains the DataExtractMan VBA macros
C:\VIRCON\ProVis\ProVis.dvb	The AutoCAD VBA file project that contains the ProVis VBA macros
C:\Program Files\ACAD2000\Data Links\VIRCON.udl	The AutoCAD 2000 linked data source file
C:\VIRCON\ProVis\Help\help.htm	The ProVis help file
C:\VIRCON\Menu\VIRCON.mns	The VIRCON menu file

A.3.2.2 Loading VIRCON Menu to AutoCAD Main Menu

Loading the special designed VIRCON menu to AutoCAD main menu can be done in easy steps. From AutoCAD *Command* line type '*menu*' and then press *Enter* key. The *Select Menu File* window opens so that you select the VIRCON.mns file from the correct path name. Click *Open* and the VIRCON menu is added next to the AutoCAD *Help* menu.

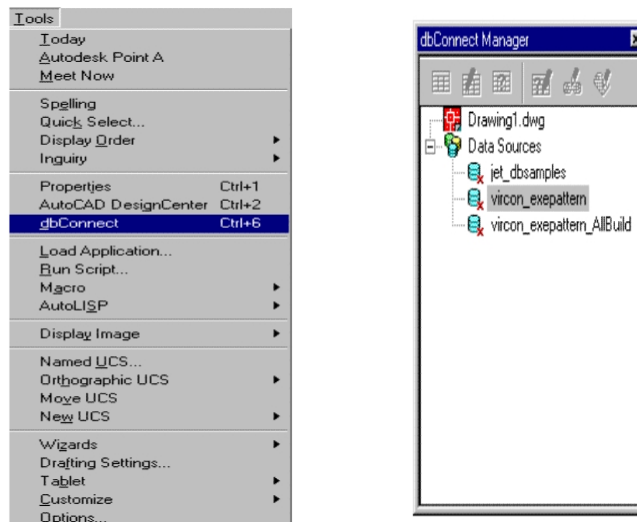


A.3.3 Before You Start VIRCON: database connection configuration

ODBC protocol is among the popular database connectivity protocols. It handles communication features between Microsoft Windows applications. In the case of ProVis, the user is required to set up a connection with the VIRCON database by using ODBC. Throughout this section, we will demonstrate to the user the required steps for establishing this connection.

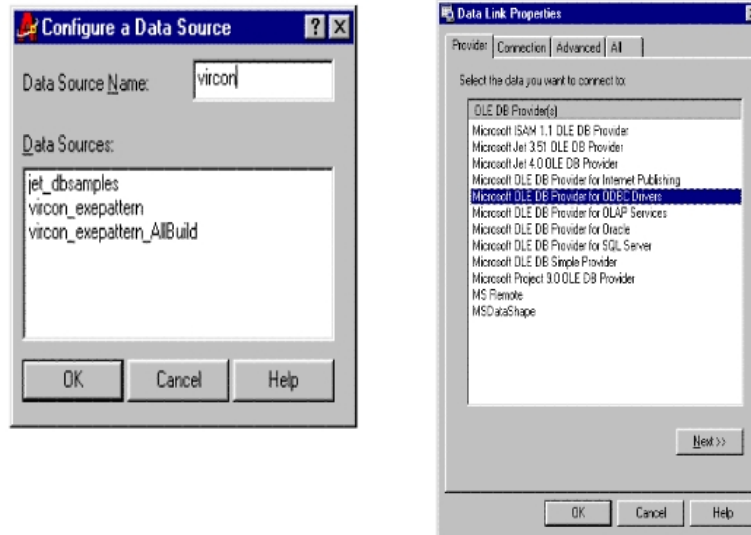
A.3.3.1 Establishing the database connection

Users can establish the database connection from within AutoCAD environment. From *Tools* pull down menu choose *dbConnect* and it will open the *dbConnect Manager* window.

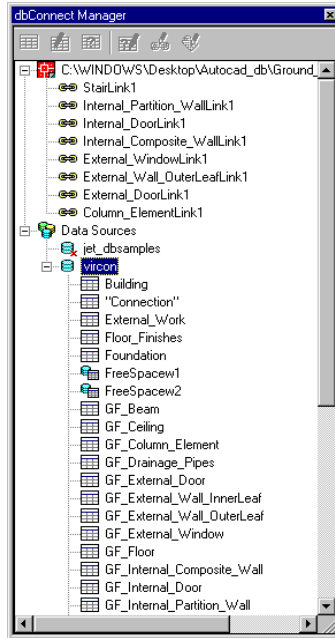


To establish the connection:

1. From the *Tools* menu select *dbConnect* and open the *dbConnect Manager* window.
2. Right-click the *Data Source* and choose *Configure Data Source*.
3. Type 'VIRCON' as the data source name and click *OK*. This opens the *Data Link Properties* dialog box. Then choose Microsoft Jet 3.5 OLE DB Provider.



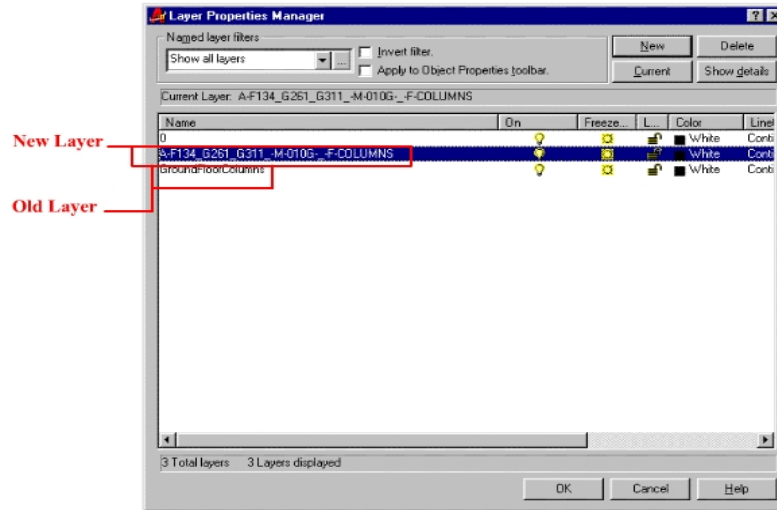
4. Click *Next*, and enter the mdb Access file in the path field.
5. Click *Test* connection.
6. Click *OK*.
7. Your *dbConnect Manager* window should contain 'VIRCON' in the Data Source list.



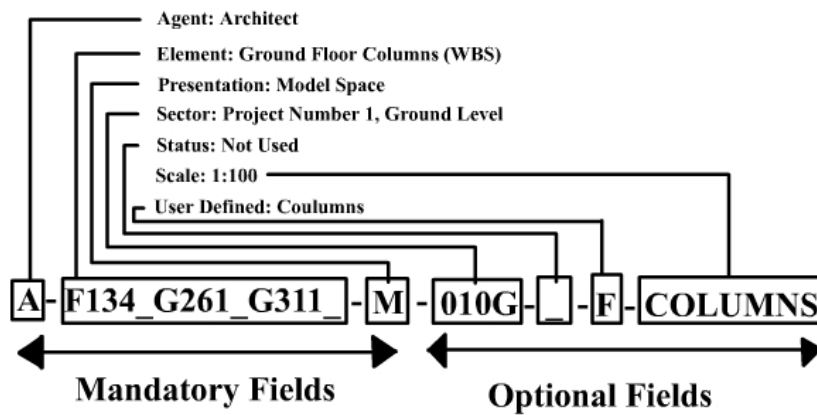
A.3.3.2 Setting AutoCAD workspace

There are several issues to consider before running the ProVis and visualise construction activities in 4D. The developed methodology for preparing the AutoCAD 3D model components is presented here. This section describes the necessary preparation steps for setting AutoCAD workspace before using ProVis. The example used here is the Ground Floor Columns. The details of each step is as follows:

1. Obtain all project CAD drawings such as: architectural, mechanical, electrical, structural or any other related information. It is a good housing style to keep a copy of the original CAD drawings saved in a separate folder on your computer.
2. From the pull down menu in AutoCAD go to *Format* then choose *Layer* to display the *Layer Property Manager* window. Here you will need to create a new layer for the ground floor columns and name it according to the British Standards (BS 1192-5). Notice that the Element field of BS layering contains the PBS product code based on the Unified Classification for the Construction Industry (Uniclass). Therefore, the code for ground floor column example should look like F134_G261_G311.

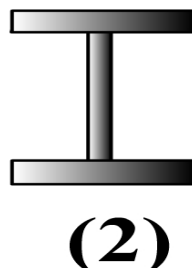
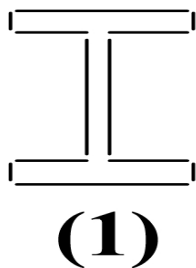


**Layer
Property
Manger
Window**



BS 1192-5

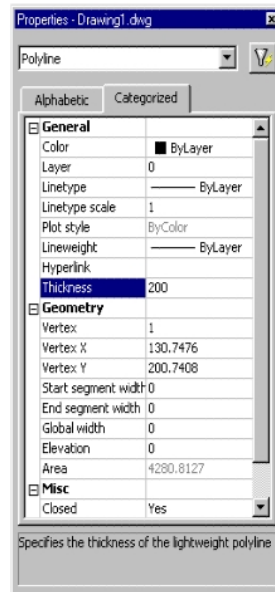
3. This step involves the editing of the existing 2D drawn shapes in the existing CAD layer and reproduces them in a new layer. In most CAD-drafting culture, the original CAD drawings are drawn using variety types of lines i.e. broken lines, curbs, blocks, the shapes of the drawings have to be edited to a set of closed objects using Polylines, lines and circles. For the ground floor columns example, the user should use Polylines (use '*pline*' AutoCAD command), as it will result in 2D closed shapes.



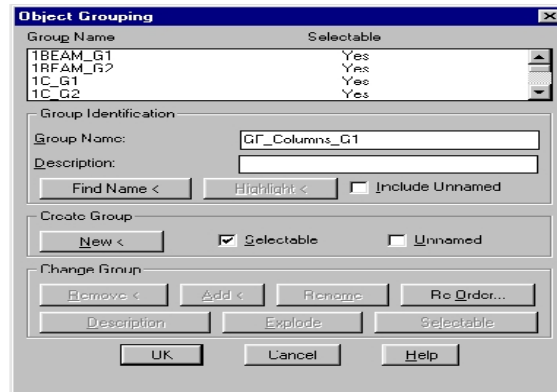
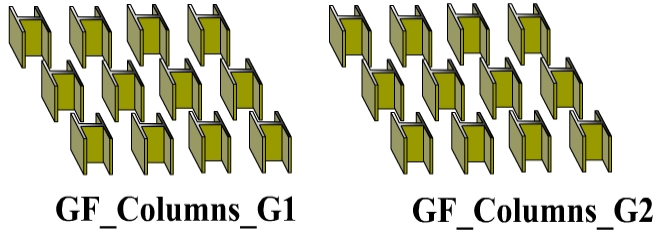
**1) Steel Column
drawn in separate
lines**

**2) Steel Column
drawn in Polyline**

4) To convert the previous 2D shapes into 3D you use the *Change Property* dialogue box in AutoCAD. The *Elevation* (i.e. projection value from zero ground level) and the *Thickness* values of each product are input which results in the new 3D shape.



5) Manual grouping of 3D CAD components within a layer is an appropriate technique for describing each construction activity, or phase/stage of work. For example, you can make two groups of ground floor columns and name them as GF_Columns_G1 and GF_Columns_G2 to match the programme of work. To group the components type 'group' in the AutoCAD command line and it will open the *Object Grouping* window. Enter the new group name in the *Group Name* field and then click *New* to select the 3D components.



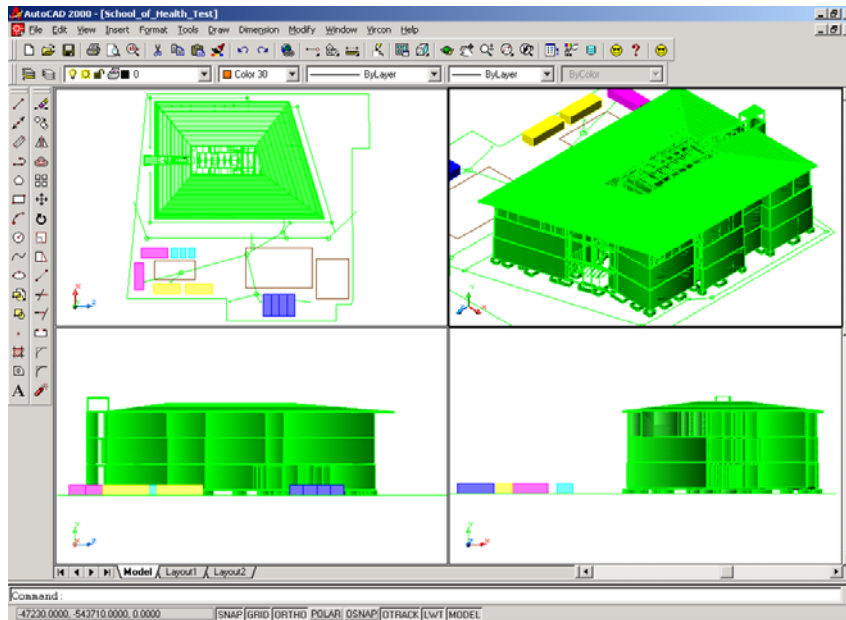
Grouping
objects in
AutoCAD

6) Open the *Tasks* table in the VIRCON database in order to update and link each 3D model groups with its processes in the project schedule. This is achieved by adding the group names previously created to the *Product_Group* column of the *Tasks* table. The full details to complete this step are available in the VIRCON database development manual.

Succeeded_Tax	Critical	Total_Stack	Level	Uniclass_Prod	Product_Group	Facility_Group
6SS+7d	-1	0	4	G11		
8SS	-1	0	3	G12		
19SS+6d,20,21	-1	0	4	G12		
14	-1	0	3	G13		
	-1	0	4	G14		
	0	1056000	3	G15		
	0	1056000	4	G15		
4SS+5d,16SS+	-1	0	3	G16		
	-1	0	4	G16		
	0	1032000	3	G17		
	0	1032000	4	G17		
	0	72000	2			
	0	72000	3	G21:G311		
23,30,33,36,39	0	72000	4	G21:G311	F_G1	
31,34,37,40,43	0	393600	4	G21:G311	F_G2	
	0	940800	4	G21:G311		
	0	892800	4	G21:G311		
22	0	892800	4	G21:G311		
	0	878400	4	G21:G311		
	0	772800	4	G21:G311		
52SS+5d	0	820800	4	G21:G311	GHARDCORE_G1	
53SS+5d	0	676800	4	G21:G311	GHARDCORE_G2	
	0	72000	2			
	0	724800	3	F134:G26:G31		
24SS+13d,26	0	820800	4	F134:G26:G31	GF_Columns_G1	
25SS+18d,27,4	0	676800	4	F134:G26:G31	GF_Columns_G2	
	0	72000	3	F13601:G261:G		
24SS+13d,26,5	0	72000	4	F13601:G261:G1C_G1		
25SS+18d,27,4	0	393600	4	F13601:G261:G1C_G2		

Tasks
table in
VIRCON
database

7) Adjust your AutoCAD display area to match your convenience. From the pull down menu click on *View* then choose *Viewports* to adjust the required number of views to view the 4D simulation.

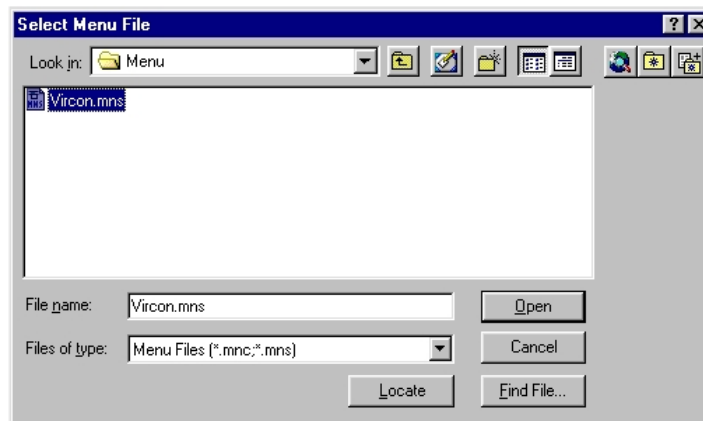


**Four
adjusted
viewport
in
AutoCAD
(top, 3D,
and two
side views)**

8) Finally, always remember to save your work before proceeding to running ProVis simulation.

A.4.1 ProVis User Interface: main menu

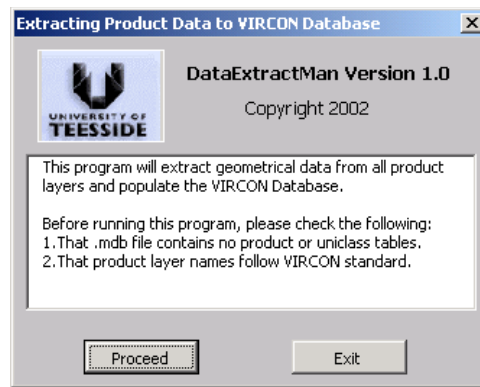
ProVis main menu sits across the top of AutoCAD window. This interface was mainly implemented in order for ProVis to look like an add-on AutoCAD.



The two ProVis sub-menus are:

1. Run DataExtractMan: this sub-menu initialises the automatic population process of the VIRCON database. It is useful because it reads all 3D geometrical information of the product components in CAD layers and extracts their space properties to the product tables in the database. For each construction product, an MS Access table is created to record all geometrical data of all elements in a construction product. The information includes the width, length, depth, the Uniclass code, and the co-ordinates of the AutoCAD bounding box (including one centre and two points). This represents spatial records for products in the database.

An example name for a populated product table for the ground floors columns is PR_01_01_COLUMNS



2. Run ProVis: this sub-menu brings up the ProVis 4D Simulator window that provides the user with the 4D player. The ProVis 4D simulator is further discussed in the *4D Simulator Window* section.

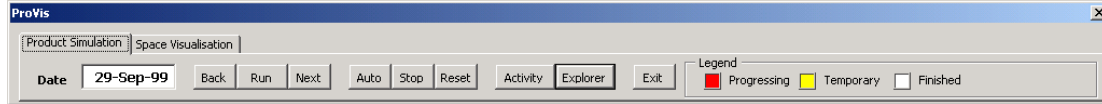
3. Help: this sub-menu launches the Internet browser to preview the DataExtracMan and

A.4.2 ProVis User Interface: 4D simulator window

The designed GUI components for ProVis 4D simulator are put together in VBA. The functionality of the GUI is to link the 3D CAD model components with the VIRCON database records and resources for the project activities. A window tabbed-system interface is used which provides the end-user with the major components. The three major parts are explained here:

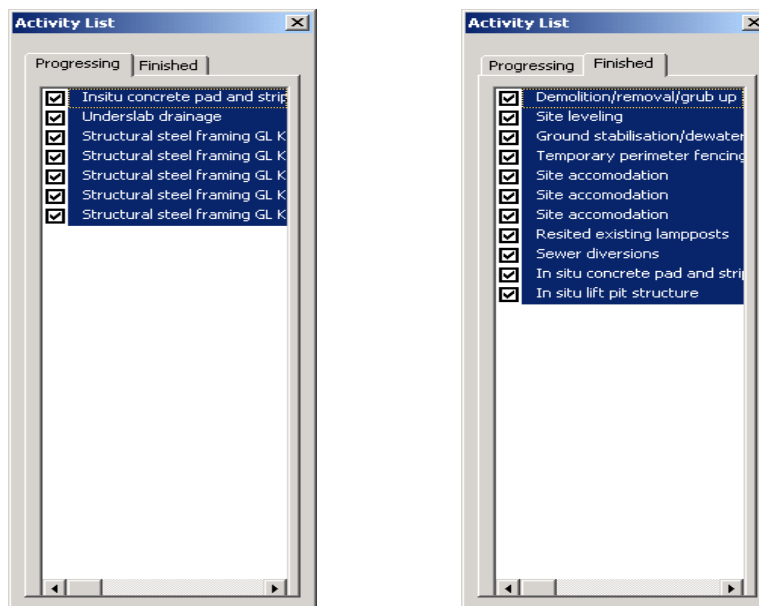
1- Product Simulation Tab: a snapshot of the Product Simulation tab main components is shown below. The user enters a specific monitor date for which the 4D simulation to start. Users are provided with 4D player buttons: next, previous, auto run, stop, and reset the simulation. The 4D environment loads the weekly 3D-CAD model when the user clicks on next, previous, and auto run buttons. The simulator displays the 3D geometry with its associated tasks and resources from VIRCON database by using Database Access Objects (DAO).

The *Legend* part explains the colouring conventions for activities in progress as a red colour, the finished activities as a white colour, and the temporary construction processes as a yellow colour.



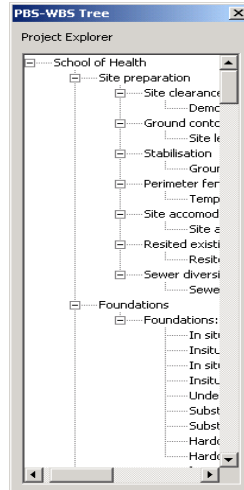
2- Activities Window: is brought to display when the user clicks the *Activity List* button in the *Product Simulation Tab*. The purpose of this window is to display the following:

- a- Display finished activities and whenever the user un-check on a specific activity it hides/show that activity.
- b- Also displays the unfinished activities (i.e. activities in progress).



3- PBS-WBS Tree Window: is brought to display when the user clicks the *Explorer* button in the *Product Simulation Tab*. The purpose of this window is to display the following:

- a- WBS of the construction project in a tree-view style.
- b- Displays finished activities and whenever the user clicks on an activity it opens the *Information window* showing the chosen activity's project information (e.g. start, end, duration, slack, etc.)

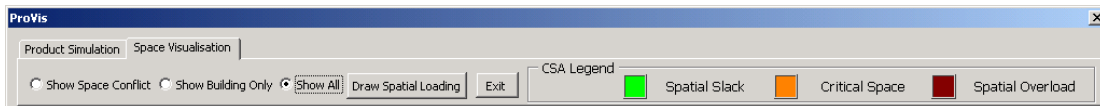


The screenshot shows an 'Information' window with a 'Schedule' tab. It contains a table with the following data:

TaskID	Uniclass	Task Name	Duration (days)	Start	Early Start
17	D72111-G21	Foundations	64	8/31/1999 8:00:00 AM	8/31/1999 8:00:00

2- Space Visualisation Tab: the space visualisation tab gives the user show/hide options for visualising the construction activities at a chosen date. There are three hide/show option radio buttons for viewing specific building components of the project 3D model. The first is *Show Space Conflicts* that in turn switches the Space Conflicts layer on, and hide the rest of the model. It should be noted here that this option should only be used after pressing the *Draw Space Conflicts* button. The second is the *Show Building Only* option button that displays only the major building 3D components. The third option is *Show All* allows the user to view the whole building model. The *Draw Space Conflicts* allows the user to draw space conflicts between the assigned construction activities after space is analysed in SpaceMan. Different types of space conflicts are drawn back on the 3D model in different AutoCAD colours.

The *Legend* part explains the colouring conventions for the space conflicts overloads. It indicates to the user the percentage of space available for continuing construction activities.



A.5.1 Running ProVis Simulator: manual run

The ProVis manual run allows the user with more control over the 4D simulation. The manual run controllers are the next, previous, run, and stop buttons.

Next Button: advances the simulation time by one week from the displayed monitor time.

Back Button: reverses the simulation time by one week from the displayed monitor time.

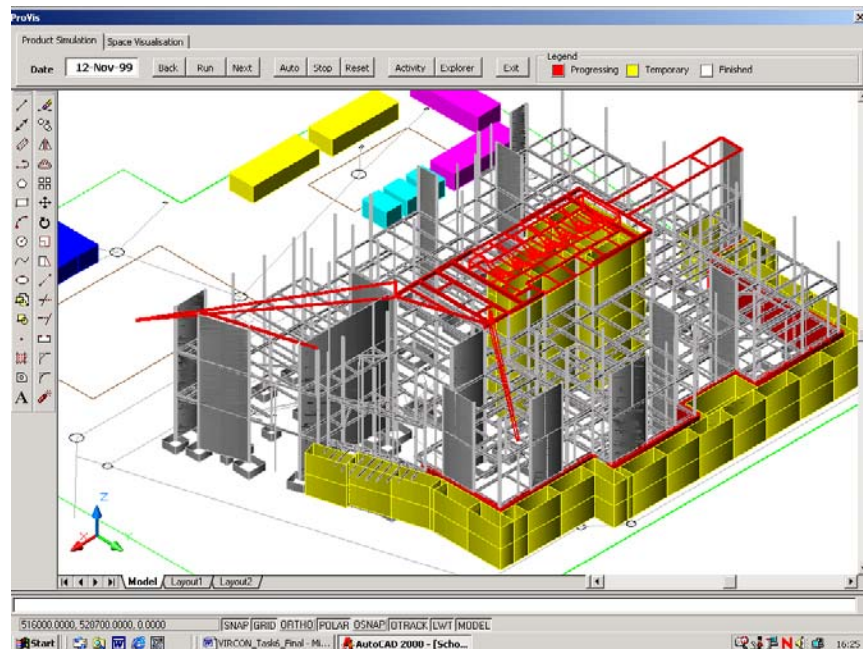
Stop Button: stops the simulation.

Run Button: runs the simulation. The user inputs any desired monitoring time and ProVis displays the construction progress at that time.

Reset Button: resets the simulation to the project starting date.

A.5.2 Running ProVis Simulator: auto run

In ProVis, press the auto run button to start the automatic run in 4D. The auto run advances the actual monitor time week by week till it reaches the finish date in the project schedule.



A.6.1 Distributing the 4D Visualisation: exporting the 3D model

You have several choices of file formats for exporting your 4D visualisations. The purpose of the export is solely to distribute and share your 4D visualisations results with your project members. It allows you to discuss the space visualisations results with your project team and perhaps recommend further modifications based on their views.

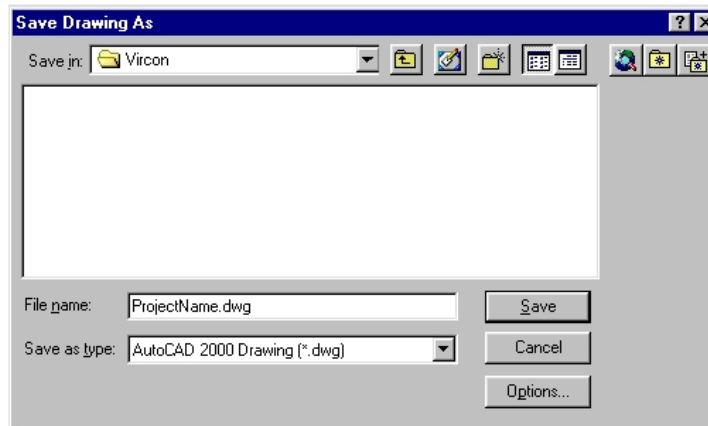
ProVis does not contain any exporting utilities to other standard file formats. However, the user can utilise the *Export* or *SaveAs* from AutoCAD *File* menu and select the specific file format to export. Additionally, there are many available 3D software that are supported with importing utilities for AutoCAD standard files.

This section will give you a general description about the standard exporting file formats.

A.6.2 Distributing the 4D Visualisation: CAD exports

AutoCAD 2000 allows you to export DWG and DXF file formats to share the ProVis simulation with your engineering team. The following are the basic steps required to export your construction project 4D model to other CAD applications:

1. Click *File > SaveAs* from the AutoCAD pull down menu.
2. On the *Save Drawing As* window, select either *DWG* or *DXF* (AutoCAD R12/LT2 DXF is preferred).
3. After specifying the correct path name, type the preferable file name in the *File name* field.
4. Click *Save*.



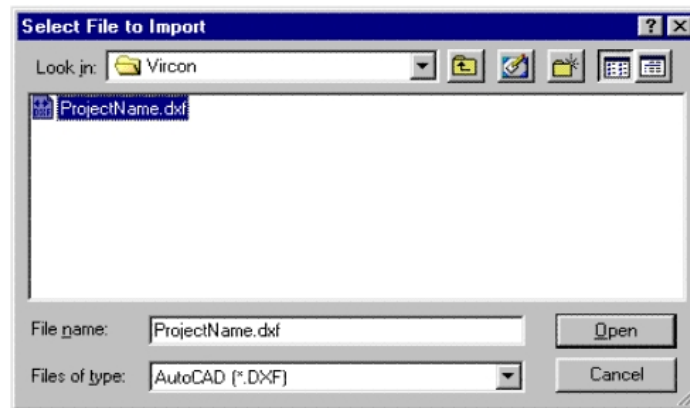
A.6.3 Distributing the 4D Visualisation: desktop VR export

Virtual Reality (VR) desktop is what brings 4D visualisations to real sense. AutoCAD 2000 lacks the integration tools for producing complex VR worlds. As a solution, the user could use the available third party 3D applications/add-on as the VR environment editor. The following explains two examples of visualising the 4D in desktop VR.

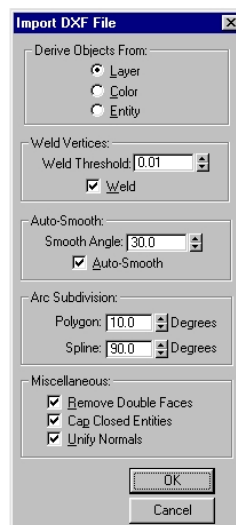
A) VRML (WRL) Files: You could use VRML files (Virtual Reality Modelling Language) for viewing your visualisations on your normal desktop or for distributing the 3D worlds over the web. Here, we are going to explore the basic steps to produce VRML worlds using 3D Studio MAX 3.1 from KINETIX.

1. In AutoCAD *SaveAs* window, save your project file as DXF file.
2. Launch 3D Studio MAX 3.
3. In 3D Studio MAX pull down menu, click *File > Import* to open the *Select File to Import* window.
4. Change the import *Files of type* to DXF.

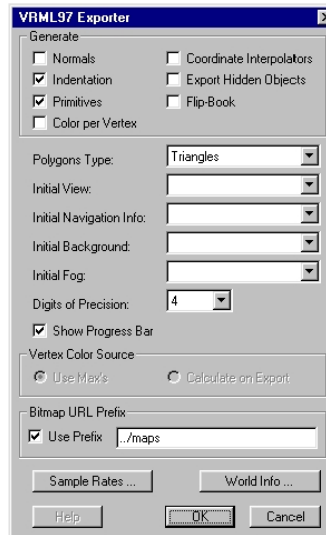
5. Select the *ProjectName.dxf* file and click *Open*.



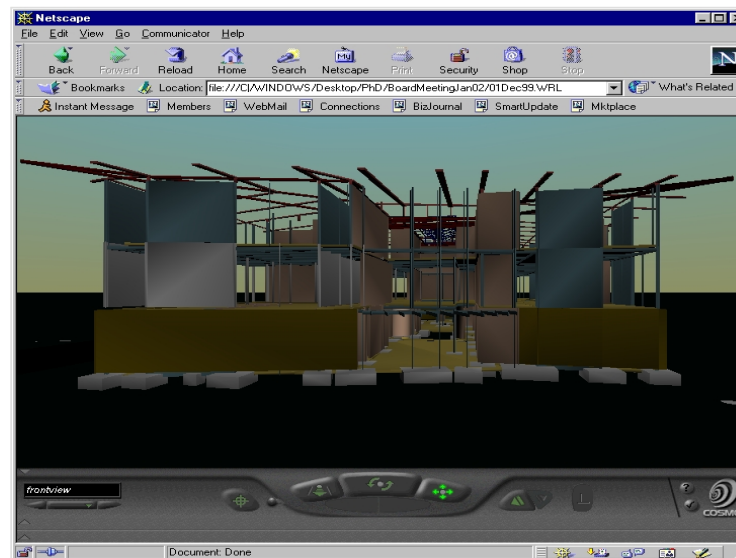
6. In the *Import DXF File* window check the *Layer* option of the *Derive Objects From* item. Click *OK*.



7. After adding lights and setting cameras in 3D Studio MAX, click the *Export* from the *File* menu to export as VRML (WRL) file format.
8. Keep the standard settings as they are in the *VRML97 Exporter* window and click *OK*.



9. The final VRML file can be viewed in any VRML browsers such as *Cosmo Player* that runs on Netscape Internet browser



B) DDDoolz4.0 Files: To carry out another type of visualisation in the VR environment, a VR explorer titled as DDDoolz4.0 was developed by Eindhoven University of Technology. This allows a direct conversion from CAD to VR through basic 3D file transfer. A 3D AutoCAD file is imported to the VR explorer as a 3D studio file (3ds). The user can experience a smooth navigation through the VR model. The DDDoolz4.0 is a free *download* from the Internet.

A.7 Troubleshooting

This section helps you when you are facing problems running ProVis software. The majority of error messages that could show on your screen are due to the possible following reasons:

1. Sometimes the 3D components do not appear when running the 4D simulation: If this happens, then make sure you have specified the correct *GroupName* in the Tasks table of the database.
2. Sometimes the 3D components stay stand still during the simulation and do not disappear:
 - It means that the 3D components were grouped and the *GroupName* were not included in the Tasks table
 - It could be because you have misspelled the *GroupName* either in the CAD drawing or when you entered them in the Tasks table
3. If you populate the database and some objects space information (e.g. a square column) do not appear in the specified product table then:
 - Check that you have drawn that object as closed Polylines, lines and circles
 - Make sure that the shapes were created in the correct layer name (e.g. ground floor columns layer) corresponding to the specific activity.
4. The populated product tables in the database are named strangely not according to the naming convention described in the user's guide:
 - It is because the related layer had been misspelled when naming that layer. Check the layer name spelling!
 - Make sure that the shapes were created in the correct layer name (e.g. ground floor columns layer) corresponding to the specific activity.
5. The manual/auto runs do not work and you could not view the 4D simulation:
 - If the database error message appears, it means that your data link source file is not configured.
 - Reconfigure the ODBC connection from within AutoCAD.

If you are still facing other problems with ProVis software, please contact one of our *support* members and email your question to us. We will be happy to assist in any way.

References

Adjei-Kumi, T. (1997). "The development of an intelligent system for visual simulation of construction projects." Ph.D. Thesis, Strathclyde University.

Akinci, B., Fischer, M., Kunz, J., and Levitt, R. (2000). "Automated generation of work spaces required by construction activities." Working Paper #58. CIFE, Stanford University.

Aouad, G., Child, T., Marir, F., Brandon, P. (1997). "Open systems for construction (OSCON) Draft industrial report. Internal Paper, Buhu Research Centre, University of Salford.

Aouad, G., Sun, M., Bakis, M., and Swan, W. (2001). "Final report on Integrated Information Exchange Towards an Industry-wide Process Improvement with Particular Emphasis on Water and housing Industry Projects." University of Salford, UK.

BS 1192-5 Construction Drawing Practice (1998). Guide for the structuring and exchange of CAD data, British Standard Institute.

Construction Project Information Committee (CPIC). (1997). "Uniclass (Unified Classification for the Construction Industry). Marshall Crawford, John Cann, and Ruth O'Leary, eds., Royal Institute of British Architects Publications, London.

Dawood, N., Sriprasert, E., and Mallasi, Z. (2001). "VIRCON project: data capture and database development." Task 2: VIRCON Technical Report, University of Teesside, Middlesbrough, UK.

Eindhoven University of Technology (2001). <http://www.ds.arch.tue.nl/Research/>, last visited: 07/09/2001.

Fernando, T., Kahkonen, K., Leinonen, J., Murray, N., and Tawfik, H. (2001). "Facilitation of collaborative communication for building construction with virtual reality technology." Proceedings of the Conference AVRII and CONVR 2001, 4th-5th of October 2001, Chalmers, Gothenburg, Sweden, pp. 81-91.

Finkelstein, J. (1998). "4D multimedia datascapes: The SSV program." Proceedings of the IEEE Symposium on Information Visualization, pp. 280-285.

Heesom, D. and Mahdjoubi, L. (2001). "Visualisation development: specialist trades, mechanical and electrical and groundwork's operations." Task 7: VIRCON Interim Report, University of Wolverhampton.

Jaafari, A., Manivong, K. K., and Chaaya, M. (2001). "VIRCON: interactive system for teaching construction management." Journal of Construction Engineering and Management, pp. 66-75.

Kahkonen, K. and Leinonen, J. (1999). "Applications of virtual reality for building construction delivery –VIRIL." Technical Research Centre of Finland-VTT. <http://www.vtt.fi/indexe.htm>, last visited: 01/11/2000.

Koo, B. and Fischer, M. (2000). "Feasibility study of 4D CAD in commercial construction." Journal of Construction Engineering and Management, pp. 251-260.

McKinney, K., Fischer, M. (1998). "Generating, evaluating and visualizing construction schedules with CAD tools." Automation in Construction, pp. 433-447.

North, S. (2001). "SpaceMan: developing a critical space analysis software prototype." Task 5: VIRCON Technical Report, University College London, London.

Retik, A. and Shapira, A. (1999). "VR-based planning of construction site activities." Automation in Construction, pp. 671-680.