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Title: **Development of an Integrated Information Resource Base for 4D/VR Construction Process Simulation & Visualisation**

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Abstract: *The objective of this paper is to report on the development of an integrated database to act as an information resource base for 4D/VR construction process simulation and visualisation. A comprehensive database was designed, implemented and populated with the School of Health Construction Project (An eight million pounds, three-storey development at the University of Teesside campus). The database is composed of a core database of building components which, in turn, is integrated with a CAD package (AutoCAD 2000), a project management package (MS Project) and graphical user interfaces.*

The core database was designed using the unified classification for the construction industry (Uniclass). One of the benefits of using the Uniclass method, apart from providing standards for structuring building information, is that it provides a media for integrating PBS (Product Breakdown Structure) with WBS (Work Breakdown Structure). This is an important aspect for delivering a meaningful 4D model. Integrated interfaces between MS Access Database, AutoCAD Drawings and MS Project Schedules were developed and implemented. Furthermore, the British Standards of layering convention (BS 1192-5) was adapted and implemented. The database was populated automatically with detailed product data directly from 2D or 3D drawings, schedules of work and resources of the School of Health Project. This paper is also addressing object definition, structuring the data, and establishing the relationships and dependencies within the data set, the WBS and building objects as well as modelling the building in 3D in order to capture the essential space- and time-critical attributes of tasks. Practical application of database throughout the construction process has been highlighted and discussed. A proposal for incorporating IFC model is also discussed.

Keywords: *Integrated database, 4D simulation, Virtual Reality.*

Introduction

The objective of this paper is to report on the development of an integrated database to act as an information resource base for 4D/VR construction process simulation and visualisation. This development is a part of a substantial research project, The Virtual Construction Site: A Decision Support System for Construction Planning (The VIRCON project). The aim of the VIRCON project is to develop tools, which can add greater intelligence to the construction planning process. There are two principal lines of development:

- To build on work on *4D planning* where the process is visualised by building the 3D product model through time according to the critical path network.
- To build on work on the spatial configuration of the constructed product by applying those analytic principles to space use on site during construction – what we have dubbed *critical space analysis* (CSA).

In order to achieve the above, a comprehensive database was designed, implemented and populated with the School of Health Construction Project (An eight million pounds, three-storey development at the

University of Teesside campus). The database, the main deliverables of the VIRCON project, is being used as the basis for the development of 4D/VR and Critical Space Analysis models (North et al., 2001). The VIRCON database is composed of a core database of building components which, in turn, is integrated with a CAD package (AutoCAD 2000), a project management package (MS Project) and graphical user interfaces.

The core database was designed using a unified classification for the construction industry (Uniclass). Uniclass is a new classification scheme for the construction industry and follows the international work set out by ISO Technical report 14177 (CPIC, 1997). One of the benefits of using the Uniclass, apart from providing standards for structuring building information, is that it provides a media for integrating PBS (Product Breakdown Structure) with WBS (Work Breakdown Structure). This is an important aspect for delivering a meaningful 4D model. The remainder of the paper discusses the concept, development and population of the database.

Database Concept and Structure

Construction data and information of the project were captured from many sources including main contractor, sub-contractors, and engineering team. Interviews and brain storming sessions were followed to identify missing information and strategies for the project information. Substantial efforts were exerted to restructure and compile the data. A well-structured database was finally established and populated.

Database Concept

The database was developed based on the ∀relational database concept∀ and implemented using MS Access 2000. The rationale for opting to relational database rather than object-oriented one can be discussed. Underwood et al. (2000) indicated that a relational database (flat structure) is more suited for product data compared with OODBMSs. Furthermore, relational databases are more widely used in industry than OODBMSs and posses a Structured Query Language (SQL) that enables complex searches to be carried out. According to Barry (1996), the many-to-many relationships, in fact, can be created in the relational schema. This is possible by introducing an *intersection entity* or, in other words, separating or *normalising* the data into many tables and using *join* to combine those data. It is indicated that the technique of *join* can affect the performance of the RDBMSs. This performance problem occurs because multiple tables with some matching key information are being accessed to combine data from all the tables by matching that key information. The more tables needed, the more joins are needed, and the slower the process becomes. Based on Silberschatz et al. (1997), a new alternative in developing *object-relational databases* is currently available and has been adapted in this VIRCON project. The object-relational data models enables extension from the relational data model by providing a richer type system including object orientation, and adding structures to relational query languages, such as SQL to deal with the added data types. Incorporating SQL query language in the MS Access allows *nested relations* to be created and eliminates necessity of having all attributes in *atomic* domains. A domain is atomic if elements of the domain are considered to be indivisible units.

As the prime objective of developing the database is to experiment with time critical and space critical tasks and to use the database as an information hub for the School of Health, SQL and API (Application Programming Interface) are fit for the purpose at this stage of development. It is the intention of the research team to keep the option open on the development.

Database Structure and Access Physical Class Diagram

Preliminarily, building elements and components were being identified, classified and structured using the standard classification method (Uniclass). Figure 1 shows an outline structure of the integrated database. Based on the preliminary class diagram, MS Access has been used to deliver the physical diagram at the implementation stage. As shown in Figure 2, Project and Building tables are treated as the centre hub joining variety of product tables on the left-hand side with associated-process on the right-hand side. It is vital to notice that embedding the Uniclass code system in the database structure allows representation of classes and inheritances hence overcomes one of the limitation of relational database against object-oriented database.

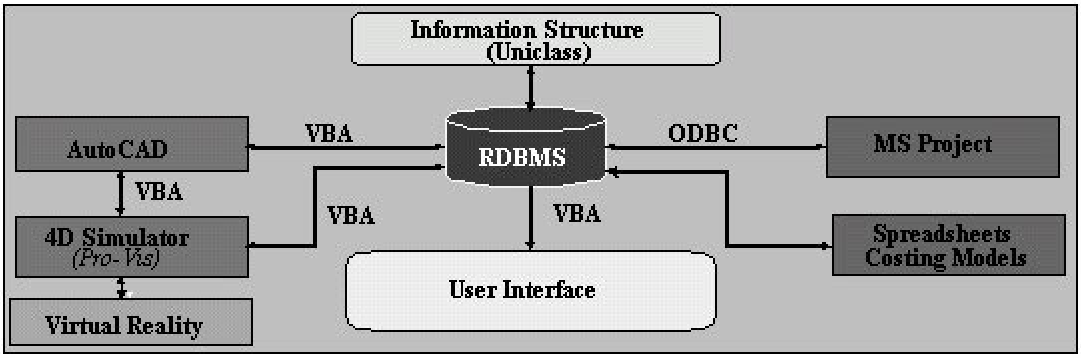

Figure-1: Outline structure of the integrated database

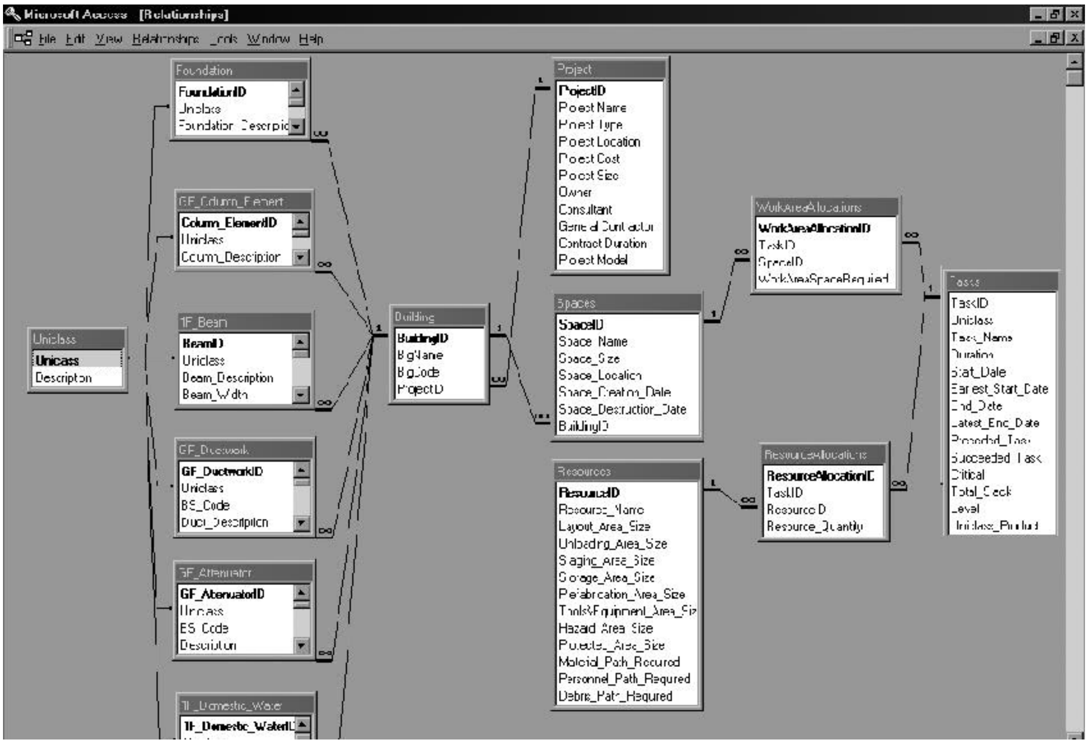

Figure-2: Access Physical Diagram

Uniclass Structure and Implementation

Uniclass is a new classification scheme for the construction industry, the full name of which is “Unified Classification for the Construction Industry”. The Construction Industry Project Information Committee

(CPIC), representing the four major sponsor organisations (the Construction Confederation, the Royal Institute of British Architects, the Royal Institution of Chartered Surveyors and the Chartered Institution of Building Services Engineers), and the Department of the Environment Construction Sponsorship Directorate were responsible for commissioning and steering the project, which was developed by NBS (National Building Specification) Services on behalf of CPIC.

Implementation of Uniclass in the VIRCON Database

According to Kang and Paulson (2000) there may be two methods to apply the Uniclass in building projects. One is the partial classification for specific subjects, such as a work section or an element in a WBS, and the other is the integrated information classification through the life cycle of a project. The four facets, including D, F, G, and J, (from facilities to work sections) can be used for physical objects representing work items in a building project thus facilitates integration of Product Breakdown Structure (PBS) and Work Breakdown Structure (WBS). If the application is expanded into the information generated from the life cycle of a project, the facets of [L, M, P] and [A, B, C, N, Q] are useful for classifying construction aids or materials. Since the VIRCON project focuses in planning stage of a building project, only facet D, F, G, and J are implemented.

The classification items in each facet can be used with the link to the other facets higher than their levels (see figure 3). For example, the code of [D72111 – G26 – F134:G261:G311 - JG10] means structural steel framing works [JG10] of ground floor column [F134:G261:G311] for superstructure frame [G26] in a school of health building facilities [D72111]. The classification items define work gradually according as the items are linked to other facets. Thus, facet J consists of the most detailed operations on which the works are undertaken with resources on construction sites. Finally, D, F, G, and J facets can apply to represent the physical objects according to the work being completed through a project. Figure 3 shows an example of an integrated PBS and WBS of the School of Health project. It is important to note that: 1- the codes in the first and second levels i.e. [D72111 – G26] represent summary levels; 2- the codes in the third level i.e. [F134:G261:G311] – GF Column represent product, which are stored inside the Uniclass code library in the database; and 3- the codes in the fourth level i.e. [JG10] represent process.

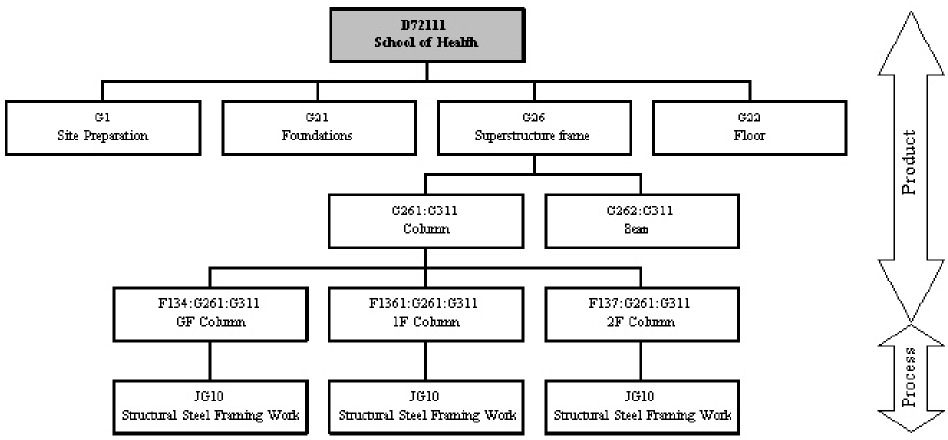

Figure-3: An Example of Product-based Work Breakdown Structure of a Building Project

Populating the VIRCON Database

This section intends to provide a detail process on how the construction product data (from the 2D CAD drawings) should be manipulated and populated to the VIRCON database. Incorporating with a systematic flowchart and an example of a Ground Floor Column, the process for populating product data is elaborated and discussed.

Process for Populating Product Data

1. 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.

2. The process map for populating the CAD drawings to the VIRCON database is shown in Figure 4. 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:

3. 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 (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.

4. 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.

5. 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 4.

6. 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.

7. Based on the Unified Classification for the Construction Industry (Uniclass) published by the Construction Project Information Committee (CPIC, 1997), a Uniclass code is assigned to 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.

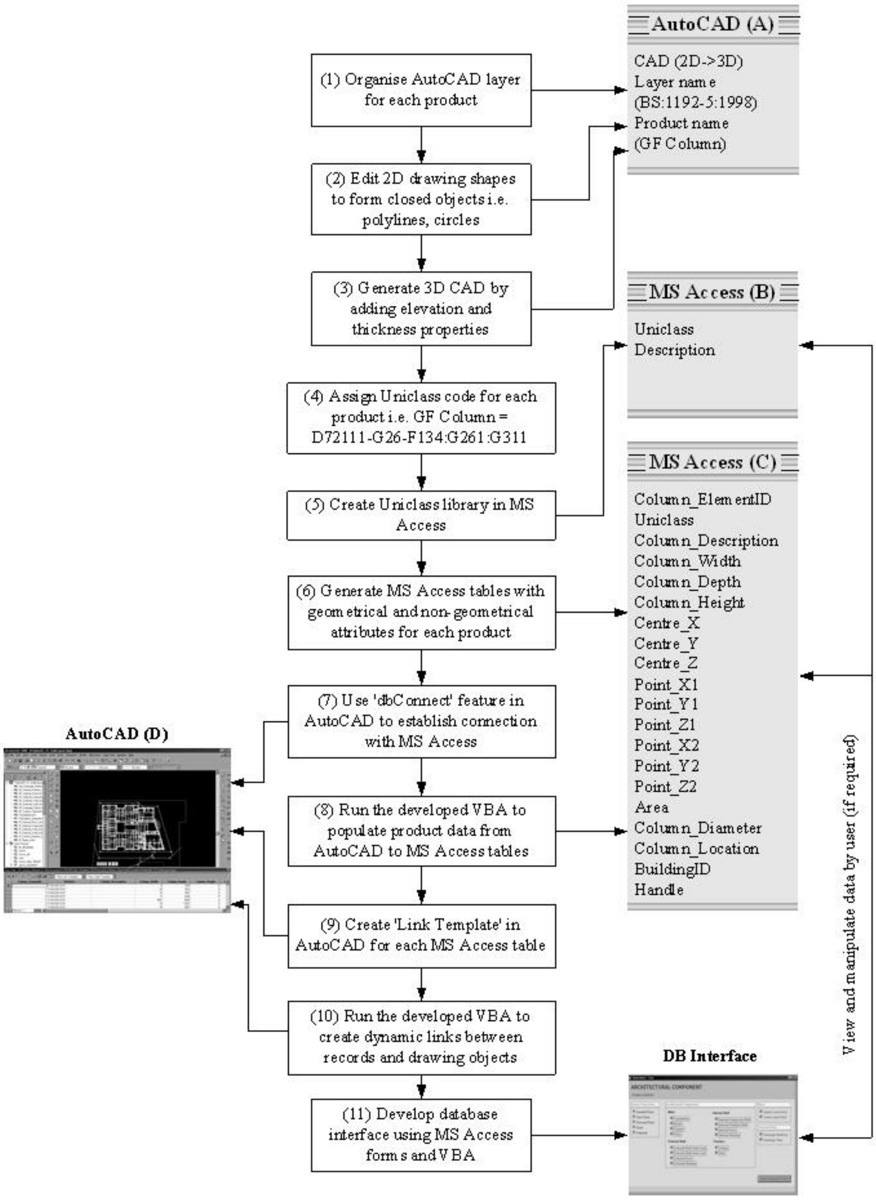

Figure-4: Process for Populating Product Data to the VIRCON Database
(An Example of Ground Floor Columns)

8. 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 4. The Uniclass library acts as a unique code in the relational database to identify MS Access tables that represent construction products.

9. 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 4". This represents spatial records for products in the database.

10. 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 AutoCAD help file and McFarlane (2000).

11. 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 4.

12. 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).

13. 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.

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 4 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, and critical space analysis.

Discussion on the Database Development

The database was developed with the main objectives of facilitating the optimisation processes of space configuration of the constructed products and 4D/VR visualisation. For this purpose the research team feels that these objective have been met. The VIRCON research team has also managed to develop VRML files of the construction site (mainly building products and heavy equipment) directly from the database (Heesom et al., 2002). This means that we can generate graphical images of the site without the use of any CAD system. The population of the database was based on real life industrial data. Apart from developing the database itself, the research developed guidelines for information and data management for the industry (in particular graphical data preparation which is prepared by Architects, etc.) so that populating the database will not be a burden on the industry, but rather part of the management process. All graphical data was based on 2D CAD drawings and the research team spent a substantial amount of time and effort to modify these drawings and therefore it was felt that if proper guide-lines were introduced, then there will be no need for modification when the database is populated. The other issue in the database development is 'IFC' compatibility and is currently being addressed. When the development started two years ago, the research team decided that developing/using a standard object library (IFCs) was not part of VIRCON requirement. No working software appeared to have been produced with IFC/ISO STEP. The project should not be chasing a moving target in some other research projects and there was a need to arrive at a relatively straightforward solution based on existing software. Furthermore, the industrial data was not 'IFC' compatible and it was felt that this will be the case in the industry for few years more. The team is watching closely 'IFC' and 'IFC model server' developments (cic.vtt.fi/ifcsvr) and will utilise outputs of such projects for the benefit of the VIRCON database. The idea is to store IFC model data in the VIRCON database system and to import and export IFC model and in doing so, the fields in the VIRCON database need to be enlarged. This is an ongoing development.

Conclusion

The objective of this paper is to report on the development of an integrated database to act as an information resource base for 4D/VR construction process simulation. A comprehensive database was introduced and discussed and rational for opting to relational database was introduced and discussed. Figure 4 shows an overall summary processes of the database. Currently, the research team is focusing on the development of 4D/VR modelling methodologies using the database as an information hub for the simulation processes. The visualisation process is discussed in a separate paper in this conference.

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