DEVELOPMENT OF AN INTEGRATED INFORMATION RESOURCE BASE FOR 4D/VR CONSTRUCTION PROCESSES SIMULATION

Nashwan Dawood, Eknarin Sriprasert, Zaki Mallasi and Brian Hobbs

Centre for Construction Innovation Research
School of Science and Technology
University of Teesside, Middlesbrough, TS1 3BA
Tel: +44 (0)1642 342405, e-mail: N.N.Dawood@tees.ac.uk

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.
A comprehensive database was designed, implemented and populated with the School of Health Construction Project (A six million pounds, three story development at the university of Teesside campus) as part of VIRCON. The database is composed of a core database of building components which is in turn, integrated with a CAD package (AUTOCAD 2000), a Project Management Package (MS Project) and Graphical User Interfaces.
The core database was designed using 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 with detailed 2D drawings (whole building and M&E), 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.

KEYWORDS

Integrated database, 3D modelling, 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. This development is 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 by using fundamental and inexpensive software packages, 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 (A six million pounds, three story development at the University of Teesside campus). The database which is the main deliverables of the VIRCON project, is being used as the base for the development of 4D/VR and Critical Space Analysis models (North, et al 2001) and the experimental work of the VIRCON project. The VIRCON database is composed of a core database of building components which are in turn, integrated with a CAD package (AutoCAD 2000), a Project Management Package (MS Project) and Graphical User Interfaces.

The core database was designed using (Uniclass). Uniclass is a new classification scheme for the construction industry and follows the international work set out by ISO Technical report 14177. One of the benefits of using the Uniclass method, a part 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 the 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 progressively populated.

Database Concept

The database was developed based on the ✂relational database concept✂ and implemented using MS Access 97. The rationale for opting to relational database rather than object-oriented one are:

- To speed-up the development process and produce VIRCON tools fairly early in the research project.
- Wide diffusion.
- To standardise on the use of MS and propriety software and to ease the problem of integration between different software applications.
- 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.

- Support of data manipulation (DML).
- 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.
- To an extent, there are two new languages that have been proposed to extend the relational model with powerful object-oriented features. These two languages are: (1) XSQL which is a research language, and (2) Illustra which is the commercial version of the Postgres database system, developed at the University of California at Berkeley. The extended type systems allow attributes of tuples to have complex types. Since object-relational database systems provide a convenient migration path for users of relational databases who wish to use object-oriented features, the VIRCON database can be further implemented, if needed, using this new option.

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 VBA (Visual Basic for Applications) are fit for purpose at this stage of development. It is the intention of the team to keep the option open on the development of Objects Models and indeed the overall database design and classification is based on objects modelling methodologies.

Database Structure

Preliminarily, building elements and components were being identified, classified and structured using ISO STEP. The main output of this task was the class diagram as shown in Figure 1. A typical class diagram model is composed of:

- Class objects' name and grouping, attributes and methods (development of Product Breakdown Structure, PBS);
- Inheritance and aggregated relationships between and among the classes and objects.
- Using UML notations.

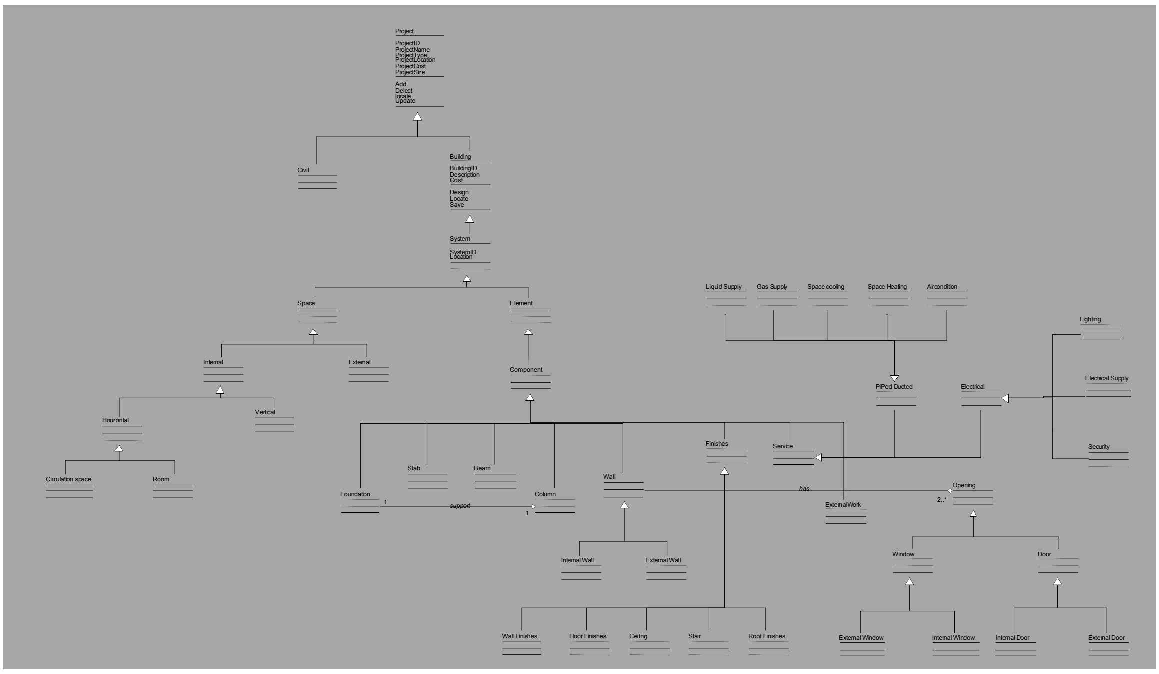

Figure 1: Class Diagram Employing Universal Modelling Language Notation

Access Physical Class Diagram

MS Access has been used to deliver the physical diagram at the implementation stage based on standard classification of product and space specification (North, 2001) on processes, space, and resources. 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.

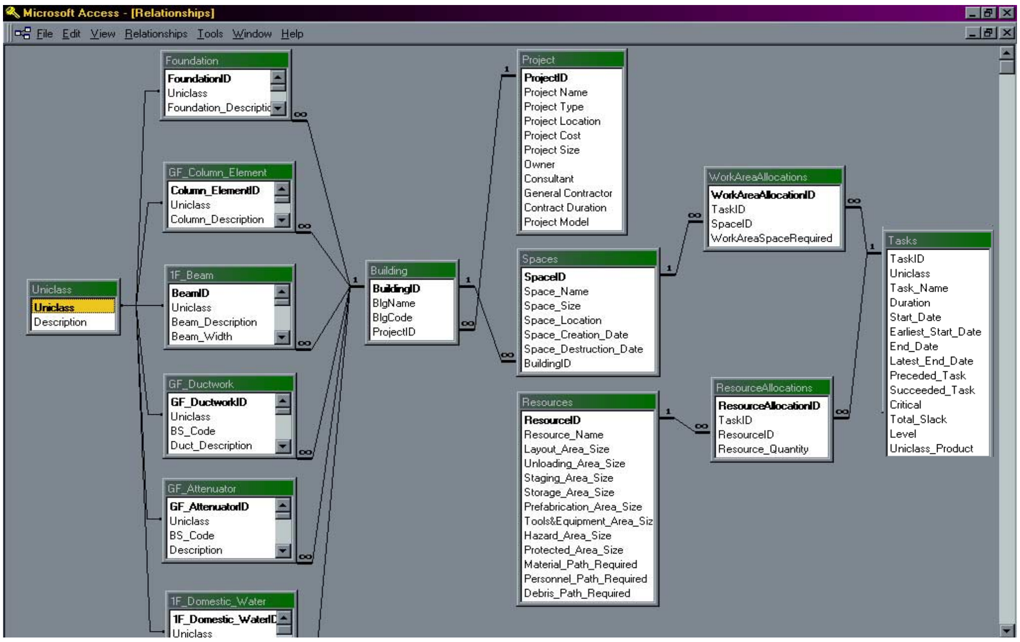

Figure 2: Access Physical Diagram

UNICLASS STRUCTURE AND IMPLEMINTATION

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.

Uniclass Code Structure

Uniclass follows the international framework set out in ISO Technical Report 14177 Classification of information in the construction industry July 1994. Uniclass offers a systematic scheme to structure and integrate product literature and project information. It incorporates: a) EPIC (Electronic Product Information Co-operation), a new system for structuring product data and product literature; and b) CAWS (Common Arrangement of Work Sections for building works), which became widely used through NBS, SMM7 (Standard Method of Measurement, seventh edition), and NES (National Engineering Specification). It is also intended to supersede CI/SfB, which was last revised in 1976.

Uniclass is structured with a faceted classification system such as CI/SfB rather than a hierarchical classification system such as Masterformat. However, often in classifying items in detail, the hierarchical system is partially used within a facet. The general structure of Uniclass facets is grouped into 15 main subjects, as shown in Table 1.

Table 1. Structure of Uniclass Facets (CPIC, 1997)

Facets		
A – Form of information	F – Spaces	L – Construction products
B – Subject disciplines	G – Elements for buildings	M – Construction aids
C – Management	H – Elements for civil engineering works	N – Properties and characteristics
D – Facilities	J – Work sections for buildings	P – Materials
E – Construction entities	K – Work sections for civil engineering works	Q – UDC

A, B, and C facets in Table 1 are for general summaries concerning information form or management field. D, E, F, G, H, and K facets consist of facilities, spaces, elements, and operations for civil and architectural works. L, M, N, P, and Q facets are useful to classify information concerning construction products, materials, and attributes. The full list of attributes of each facet are available in CPIC, 1997.

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. 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 be applied to represent the physical objects according to the work being completed through a project. Fig. 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.

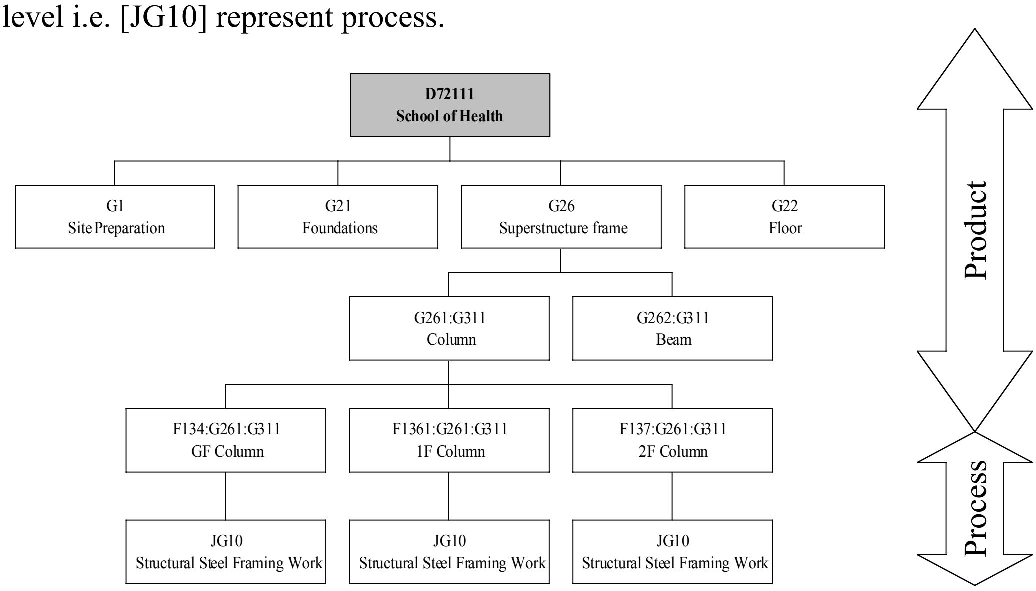

Figure 3: An Example of Integrated PBS and WBS of a Building Project

CONNECTING GRAPHICAL COMPONENTS (AUTOCAD 2000) WITH THE DATABASE

One of the main objectives of the project is to establish a dynamic connection between the database and graphical components in AutoCAD drawings of the construction project (refer to VIRCON database development process diagram). All related drawing information was obtained from VIRCON industrial partners including: main contractor, sub-contractors, and the engineering team. This section briefs the concepts behind establishing connectivity between AutoCAD and the database

British Standards Layering Convention

Roberts (1998) mentioned in the advanced GNVQ (General National Vocational Qualifications) that careful considerations should be taken whenever structuring the CAD model in layers. This is a central CAD principle that associates the ability to manipulate the model elements. Moreover, such a principle allows various project members to communicate and exchange CAD files in a more compatible way. Therefore, representation of drawing management through structuring the information in layers in accordance with the current British Standards (BS 1192-5) was established.

The British Standards committee advises that a project team should agree the layering and coding used for CAD files. A format with a specific concepts and categories should be used to eliminate the complexity when data are exchanged. It is also possible to use other specific codes only for specific purposes. Coding convention includes a mandatory field and an optional field as depicted in Figure 4. The mandatory field is given in an order of alphabetic and/or alphanumeric attributes as explained in the BS 1192-5. The optional field is given in the recommended character codes.

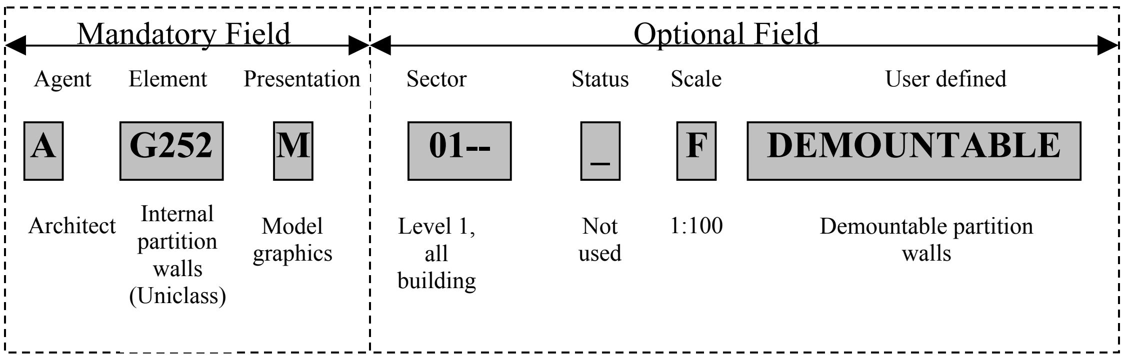

Figure 4: Example of Layer Coding using both Mandatory and Optional Fields

Dynamic Extraction of CAD Components to the Database

AutoCAD refers to all 2D/3D building components (architectural, mechanical, electrical…etc.) as 'objects' with specific properties. The preparation method for all CAD objects in the CAD drawings was to redraw them as closed 2D/3D polylines. For the purpose of obtaining spatial properties of a CAD component, it is advised to convert simple drawn lines in the CAD drawings into closed polylines. This is an AutoCAD technique so that each object will have a specific area. For example, each Universal column is drawn as a closed 2D polyline as illustrated in figure 5.

A VBA code was written for each layer in the AutoCAD drawing to enable the extraction of 'objects' properties and write them to the related table in the VIRCON database. For example, walls information drawn in the _A-G251-M-01---_F-INNERLEAF_ layer will be extracted to the _GF_External_Wall_InnerLeaf_ table of the VIRCON database. For simplicity, the VBA code records this following information:

- Area of each object, which represents the space occupied by a building product.
- Centre of the Bounding Box around an object e.g. (Centre_x, Centre_y, Centre_z) which in most cases is the centre of that object. The Bounding Box is illustrated in figure 5 where it shows the relationship between and object and its Bounding Box.

- The co-ordinates in x, y and z for the top right Point 1 (x,y,z) and the bottom left Point 2 (x,y,z) of that object bounding box.
- The length, width, depth and height of the object. This will work accurately if and only if the object is aligned horizontally and vertically to AutoCAD UCS (User Co-ordinate System) x, y, and z.

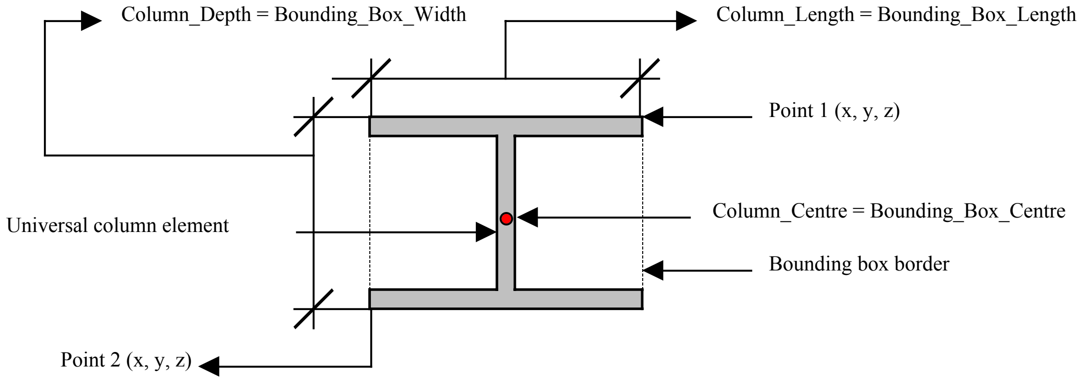

Figure 5: The Bounding Box relationship with a Universal column object

Finally, OLE DB technology (McFarlane, 2000) has been utilised in this development in order to apply connectivity to the database. Both OLE DB and ODBC are similar in terms of communicating between applications. However, OLE DB makes it easier for user interface and to work efficiently with a relational database. The external database can be managed within AutoCAD 2000 database connectivity new feature environment (DBCONNECT) through the OLE DB established connection.

SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

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 methodology to build and populate VIRCON database, and rational for opting to relational database was introduced and discussed. Figure 6 shows an overall processes of building and populating the database.
The research team is currently focusing on the development of 4D/VR modelling methodologies using the database as an information hub for the simulation processes.
A 4D prototype simulator is being developed using VBA. The simulator reads information from the VIRCON database and present 4D in AutoCAD2000 environment. For the simulation functionality, this system can simulate not only the completed products but also the status of work in progress. It can also perform spaces take-off and graphically present the occupied spaces (i.e. product area, temporary facilities area, and working areas) as well as free space in weekly or even daily basis. An efficient methodology to convert 3D CAD model to VR model is being explored. A free VR browser called ‘DDDoolz4’ developed at Eindhoven University (Eindhoven University of Technology, 2001) is found to be the most appropriate tool since it can directly import 3D CAD model from AutoCAD 2000 with an accepted polygon LOD (Level Of Detail). This approach therefore eliminates usage of other expensive software and potentially suits the VIRCON goals. Experiments are being conducted with School of Health and figures 7 shows a screen shots of the 4D simulation processes.

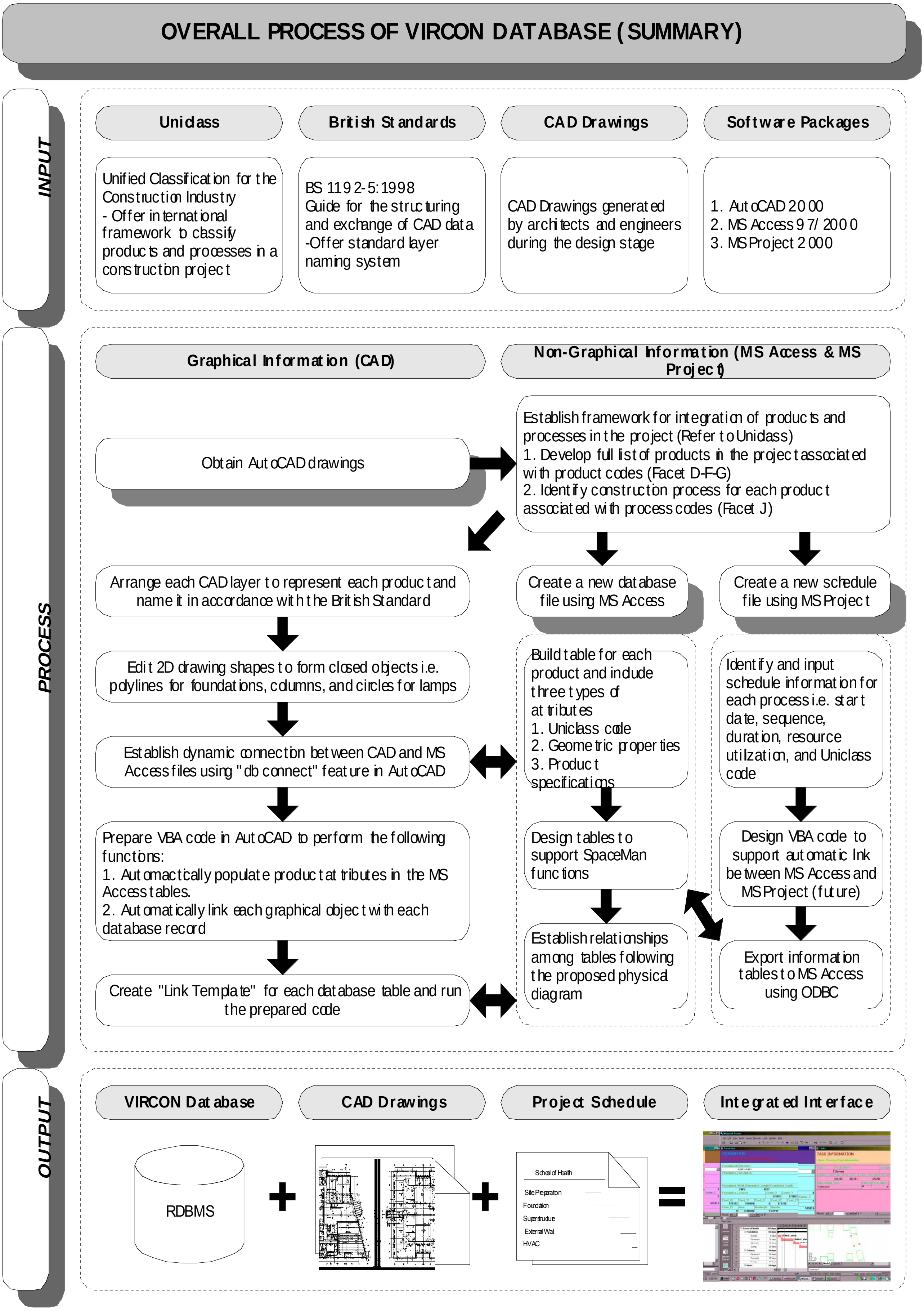

Figure 6: An overall summary of the database processes.

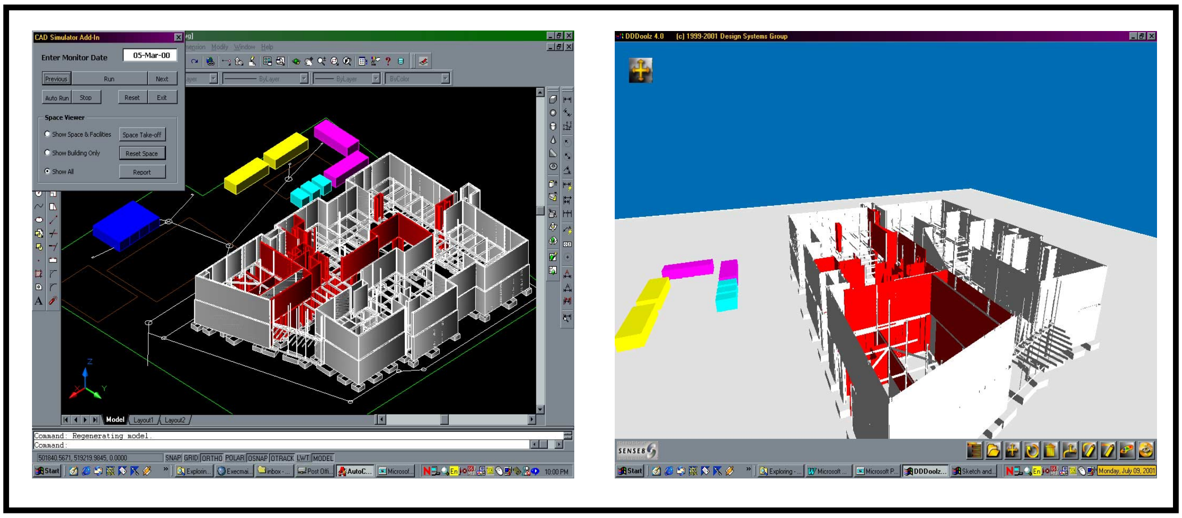

Figure 7: Screen shots of the 4D/VR simulation processes

Acknowledgement

The research team would like to acknowledge the support of EPSRC for this project and the contribution of the academic (UMIST,UCL and Wolverhampton) and the industrial partners.

REFERENCES

1. Barry, Douglas K. (1996). The object database handbook: how to select, implement, and use object-oriented databases. John Wiley & Sons, Inc.
2. 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.
3. Kang, L. S., and Paulson, B. C. (2000). "Information classification for civil engineering projects by uniclass." *J. Constr. Engrg. and Mgmt*., ASCE, 126(2), 158-167.
4. Silberschatz, A., Korth H. F., and Sudarshan S. (1997). *Database system concepts*. Third Edition, McGraw-Hill.
5. Underwood, J., Alshawi, M. A., Aouad, G., Child, T., and Faraj, I. Z. (2000). Enhancing building product libraries to enable the dynamic definition of design element specifications. *Engineering, Construction and Architectural Management*, Blackwell Science Ltd., 7, 4, 373-388.
6. Roberts, Keith (1998) Advanced GNVQ, CONSTRUCTION AND THE BUILT ENVIRONMENT, Addison Wesley Longman, England
7. BS 1192-5 Construction Drawing Practice (1998) Guide for the structuring and exchange of CAD data, BSI, ISBN 0 580 29514 1
8. McFarlane, Scott (2000) AutoCAD Database Connectivity (Autodesk's Programmer Series), Thomson Learning, Canada
9. Cox, Stanley and Hamilton, Alaine (1995) Architect's Job Book, Sixth Edition, RIBA Publications.
10. North, S (2001), SpaceMan: developing a Critical Space Analysis software prototype, Interal Report, The Bartlett School of Architecture, Building, Environmental Design and Planning, Faculty of the Built Environment, UCL.
11. Eindhoven University of Technology, http://www.ds.arch.tue.nl/Research/, last visited: 07/09/2001