Using Agents for Mining Maintenance Data while interacting in 3D Object-oriented Virtual Environments

Report No. [2001-002-B + report no. 4]

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1. SUMMARY

This report demonstrates the development of: (a) object-oriented representation to provide 3D interactive environment using data provided by Woods Bagot; (b) establishing basis of agent technology for mining building maintenance data, and (C) 3D interaction in virtual environments using object-oriented representation. Applying data mining over industry maintenance database has been demonstrated in the previous report.

2. 3D OBJECT-ORIENTED REPRESENTATION OF BUILDINGS

3D building models are useful across the entire spectrum of architecture, engineering and construction (AEC) practices. Architects and their clients use 3D building models to observe and evaluate building designs before construction, while there is still a chance to make substantial changes at a reasonable cost. Engineers use 3D building models for energy, lighting, acoustics and fire simulations. The results of these simulations give valuable insight into building useability and safety. Professionals in the construction industry utilise 3D models to estimate costs and to plan cost-effective construction sequences. This process often leads to the early discovery of design conflicts that would otherwise result in expensive construction mistakes. Even for an existing building, it is often desirable to have a 3D model to facilitate analysis of the energy properties of the building or to predict how a potential fire might spread or to study potential changes to the building, or to identify possible uses of existing building spaces (Lewis and Sequin, 1998).

2.1 The role of 3D CAD models in design and construction

An understanding of the ways in which 3D CAD modelling techniques can be used to support and reflect design thinking can lead to the development of a greater integration in the building design and construction industry. Since the inception of CAD, computers appear to have played a vital role in the practice of architecture, engineering and their allied professions. This is, however, merely an illusion. It did not happen simply because most designers in practice were not formally trained to use the computer as a productivity tool, and they were therefore unfamiliar with its capabilities. In fact, there are many designers who still develop conceptual sketches for a project, then pass these sketches on to draftsperson who create 2D design development and construction drawings with little integration, if any, with other consultants.

The primary purpose of a 3D CAD model needs to be established at an early stage in a project. 3D CAD modelling can be used in structural, lighting, acoustic, thermal, acoustic, bio-climatic and spatial analysis. There is still a common misconception that CAD systems are just drafting tools for use in the post-design stages of work rather than having a much richer role to play during designing and construction. 3D CAD models can help to resolve ambiguities, provide linkages to design data and present computerised visualisation. Discovering design conflicts and inconsistencies early is far less costly than repairing design and construction mistakes in buildings as cost increases exponentially at every stage from conceptual design to construction as shown in Figure 2.1. 3D CAD modelling allows for such inconsistencies to be discovered before construction and therefore for better design and construction decisions to be made in the very early stages of the design and construction phase.

2.2 Interoperability and data sharing of 3D CAD models

Interoperability has one important meaning: it is the capability of devices from different manufacturers to communicate and work together. This meaning has great benefits that cannot be realised without establishing rules of standardisation and compatibility among different sectors in the building and manufacturing industry. The lack of true interoperability is arguably the single largest software problem facing today's manufacturers. It can cause time-to-market delays, bottlenecks, errors, lost data, quality problems, and extensive reworking of parts. This problem also impedes the cost-effective outsourcing of design and production in global manufacturing.

There are currently a variety of software packages available designed to facilitate interoperability between the products of various manufacturers and suppliers. They assist in converting and viewing CAD formats; translating between many different CAD/CAM (computer aided manufacturing) formats; and modifying and sharing objects. Moreover, there are Application Service Providers (ASPs) for the translation and adaptation of 3D solid models, enabling rapid sharing of 3D engineering data across design and manufacturing firms, and their clientele, regardless of their installed CAD systems (Reffat, 2002).

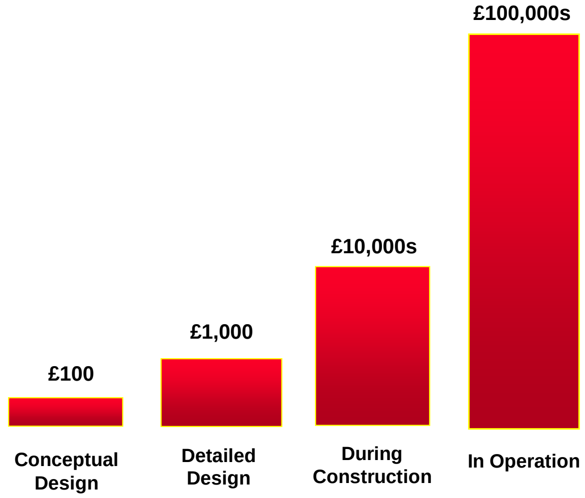

Figure 2.1 Exponential increase in repairing design and construction mistakes from conceptual design to construction operation.

2.3 Using 3D CAD modelling as a means of useful knowledge sharing

Building design is a process that has often been considered as an activity carried out only by architects and engineers. They are co-designers in proposing the end product of a building form, materials, supporting structure and environmental control services. However, while these co-designers share the same task, that is designing a specific building, they tend to think largely about concepts with regard to their own particular interest in the evolving building solution. Their co-designing work is in the form of knowledge contribution from each of them based on their particular experience. Their method of working together will therefore be in the form of knowledge sharing in order to evolve a commonly agreed building solution. Knowledge sharing among co-designers occurs when they allow for the exchange of design information that presents their individual knowledge and contribution usually in the form of inputs and outputs. (Cornick, 1996). Example of the knowledge shared among the co-designers include: shapes, proportions, arrangements, and materials of building elements brought together in an overall building form, structural and services elements and enclosures with regard to their structural stability, and size, shape and arrangement of building services.

The development of a 3D CAD model has the essential role of supporting knowledge sharing among co-designers. One set of designers conceives the overall form and how all its parts would fit and work together; other designers then conceive how all the system parts can be engineered as an overall assembly. The degree of realism that can be created in the 3D CAD model and the ease by which 3D views can be generated are essential in knowledge sharing. This is a much richer notion than a simple demonstration of the material, finish and form of building objects (Reffat, 2002).

2.4 An object oriented approach to 3D CAD modelling

The representation of building objects is not limited to the graphical information that illustrates only the structure of these objects. There are various other types of non-graphical information that are not less important than the structural representation of these objects. Non-graphical information includes functional, behavioural and semantic properties. Each building object is created to perform certain functions. These functions should produce the required set of behaviours. An integrated view of both graphical and non-graphical information can be looked at as functional, behavioural and structural scheme of object representation. Structure is what the object is, function is what it does, and behaviour is how it does it. Furthermore, the purpose of creating this object or building element is “what for”. The structure of an object exhibits behaviour; behaviour affects function; and function enables purpose (Rosenman and Gero, 1998). For instance, the structure of a hydraulic elevator includes piston and oil column, its functions are to contain loads and move them vertically, its behaviours are to push loads up and hold them by compression and its purpose involves transferring people and goods from one storey to the other. This is a simplified description of the non-graphical information related to an object or a building element The non-graphical information is not limited only to the description and properties of the object but can also include the relationships of this object to other objects in the building..

Being able to exchange non-graphical information in building projects using the computer is quite useful. A general approach has been developed by employing computer techniques that were first applied in the field of artificial intelligence (AI). In this approach objects have attributes, one of which is their geometry, which can be viewed by CAD systems, databases that contain non-geometric attribute descriptions of objects and data-structures that follow agreed standards and format. Integrated software systems would assist in describing the geometry of architectural form, the geometry of the structural frame, the structural calculations of the frame, and the work sequence and time duration of construction. Using the AI approach, when the architectural form (graphical information) is changed the other three systems (graphical and non-graphical) automatically change to suit the new form. The importance of this approach lies on the capability of computer systems to recognise the graphically represented objects as real objects with attributes rather than just geometrical forms. Object-oriented databases incorporated within CAD systems allow such a facility to be utilised. Object-oriented technologies also facilitate collaborative design.

CAD systems are now becoming increasingly object- based and web-based systems are moving in a similar direction. Recent trends in CAD systems development (Szalapaj, 2001) show attempts to integrate GIS (geographic information systems) with facilities management. This type of development involves making connections between graphical and non-graphical information, and object-oriented environments for supporting such integration are increasingly being used. The integration of graphical and non-graphical information is of paramount importance in achieving the best results in planning and co-ordinating building systems.

Object-oriented computer-aided design is an important new development in the architecture and engineering professions. Traditional CAD systems were developed to mimic the processes of hand drafting and overlay graphics. A traditional CAD drawing has little more intelligence than a hand drafted paper document. Object-oriented computer-aided design represents the next generation of CAD applications predicated on the concepts of object-oriented design that has been used successfully in the software industry to build much larger, more complex applications than were ever possible using older design methods. It is only recently that object-oriented design has been applied as a way to conceptualise and communicate design solutions.

2.5 Object-oriented representation to provide 3D interactive environment using data provided by Woods Bagot

The research team has coordinated with Woods Bagot (an Industry Partner in this project), to model the selected building (Building no. 10, Royal Prince Alfred Hospital, Sydney) into object-oriented 3D CAD. Woods Bagot has kindly contributed by modelling Building no. 10 using ArchiCAD, an object oriented CAD modelling system. One floor only has been modelled as a prototype for this project. Some captions of this 3D model are shown in Figures 2.2, 2.3 and 2.4.

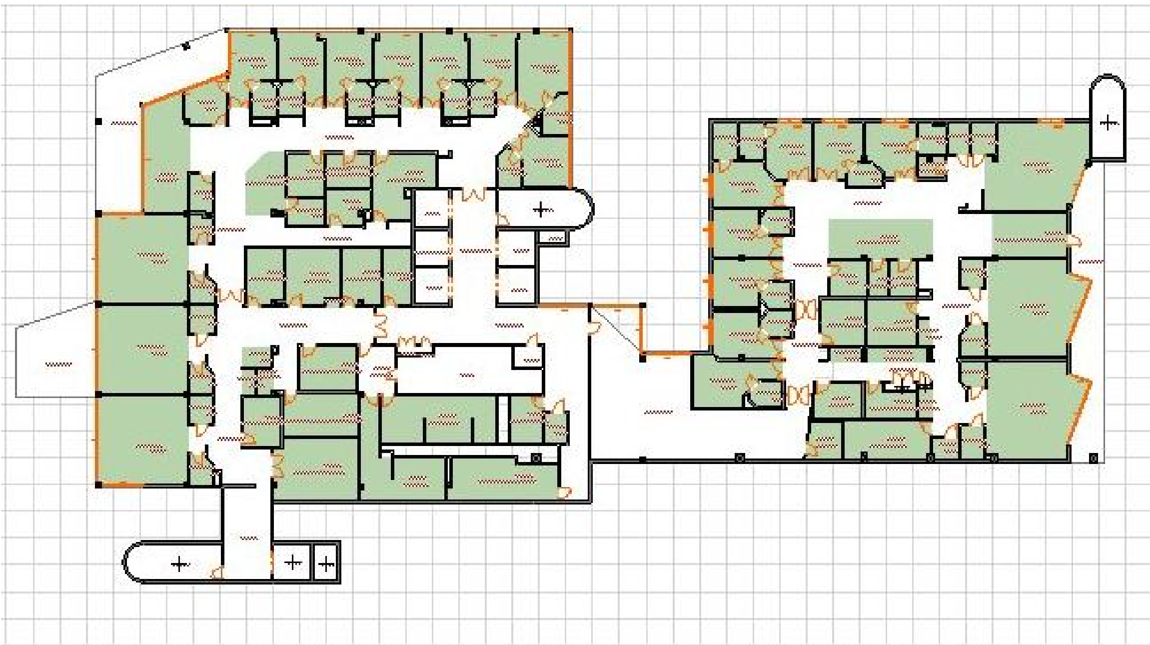

Figure 2.2 Top view of typical floor of Building no. 10, Royal Prince Alfred Hospital, Sydney.

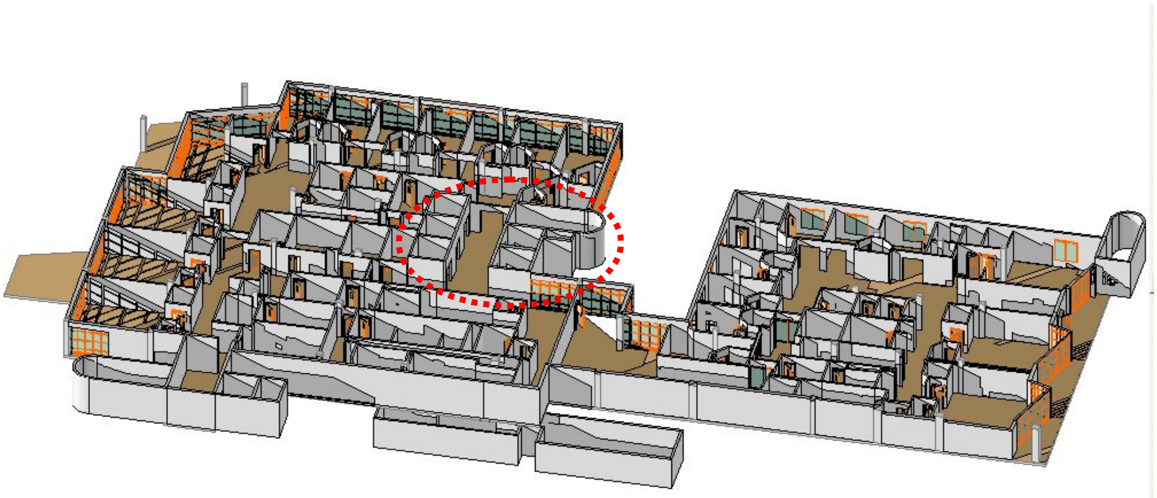

Figure 2.3 3D view of typical floor of Building no. 10, Royal Prince Alfred Hospital, Sydney.

Figure 2.4 3D view of vertical transportation area (Lifts and stairs) at Building no. 10, Royal Prince Alfred Hospital, Sydney.

For this 3D CAD model to useful for interactivity in virtual environments (Active Worlds), it needs to be converted into an RWX format in order to view it and interact with its objects in Active Worlds. At the same time, the object in this 3D model should also exported to IFC Industry Foundation class) format in order to be accessible to the Express Data Manager to handle both graphical and non-graphical attributes of building objects. The elements exported from this 3D CAD model into the IFC format according are shown in Figure 2.5.

Mechanical and Electrical objects have not been included in this 3D CAD model at this stage of the project. Additional tasks will be included in the coming Quarter of this project to create these objects in the CAD system and convert them to both Active Worlds and IFC formats.

Elements	Quantity
IFC2DCOMPOSITECURVE	72
IFCAPPLICATION	1
IFCARBITRARYCLOSEDPROFILEDEF	1107
IFCAXIS2PLACEMENT2D	339
IFCAXIS2PLACEMENT3D	3310
IFCBOUNDINGBOX	1165
IFCBUILDING	1
IFCBUILDINGSTOREY	6
IFCCARTESIANPOINT	12761
IFCCIRCLE	21
IFCCOLUMN	104
IFCCOMPLEXPROPERTY	1425
IFCCOMPOSITECURVESEGMENT	106

IFCCONNECTIONCURVEGEOMETRY	866
IFCCONNECTIONSURFACEGEOMETRY	63
IFCCONVERSIONBASEDUNIT	1
IFCCURVEBOUNDEDPLANE	63
IFCDIMENSIONALEXPONENTS	1
IFCDIRECTION	1215
IFCDOOR	198
IFCDOORSTYLE	198
IFCEXTRUDEDAREASOLID	1425
IFCGEOMETRICREPRESENTATIONCONTEXT	2
IFCLINE	28
IFCLOCALPLACEMENT	1822
IFCMATERIAL	16
IFCMATERIALLAYER	2650
IFCMATERIALLAYERSET	932
IFCMATERIALLAYERSETUSAGE	932
IFCMEASUREWITHUNIT	1
IFCOPENINGELEMENT	260
IFCORGANIZATION	3
IFCOWNERHISTORY	650
IFCPERSON	2
IFCPERSONANDORGANIZATION	2
IFCPLANE	63
IFCPOLYLINE	3497
IFCPRODUCTDEFINITIONSHAPE	1425
IFCPROJECT	1
IFCPROPERTYSET	1425
IFCPROPERTYSINGLEVALUE	18680
IFCRECTANGLEPROFILEDEF	318
IFCRELAGGREGATES	4
IFCRELASSOCIATESMATERIAL	1036
IFCRELCONNECTSPATHELEMENTS	866

IFCRELCONTAINEDINSPATIALSTRUCTURE	2
IFCRELDEFINESBYPROPERTIES	1425
IFCRELDEFINESBYTYPE	260
IFCRELFILLSELEMENT	260
IFCRELSPACEBOUNDARY	63
IFCRELVOIDSELEMENT	260
IFCSHAPEREPRESENTATION	3520
IFCSITE	1
IFCSIUNIT	9
IFCSLAB	2
IFCSPACE	129
IFCTRIMMEDCURVE	49
IFCUNITASSIGNMENT	1
IFCVECTOR	28
IFCWALLSTANDARDCASE	930
IFCWINDOW	62
IFCWINDOWSTYLE	62

Figure 2.5 3D The elements exported from this 3D CAD model of 5 Building no. 10, Royal Prince Alfred Hospital, Sydney into the IFC format .

3. ESTABLISHING BASIS OF AGENT TECHNOLOGY FOR MINING BUILDING MAINTENANCE DATA N IN VIRTUAL ENVIRONMENTS

3.1 Conceptual Architecture of a Software Agent

A software agent is basically a complete software package that exhibits the characteristics of autonomy and goal-directed behaviours. A distinctive characteristic of an agent is its interactions with the environment. The sensor and effector of an agent are the main components that interface with the environment. Reasoning within the agent occurs according to information extracted (information pull) or propagated (information push) from the environment (Gero and Fujii 2000). The environment consists of other external systems or external agents that the current design agent is interacting with, 0.

When the agent is interacting with another computational system, information is either pulled or pushed into the agent through the sensor. Actions specified to the external computational system are performed through the effector according the goal of the agent, 0. When agents are interacting directly, messages are sent through the effector and received through the sensor. The actions produced by the effector are communication-based to facilitate interactions between agents, 0.

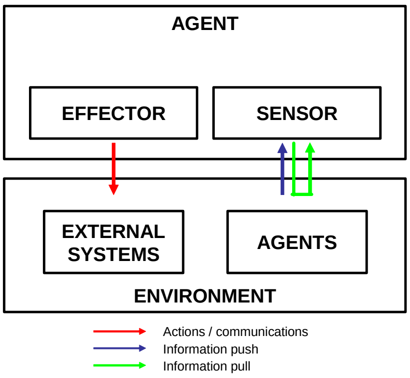

Figure 3.1 Interaction between an agent and its environment.

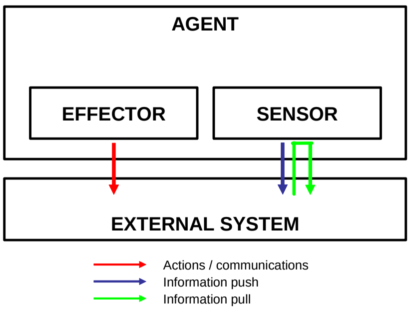

Figure 3.2 Interaction between an agent and an external computational system.

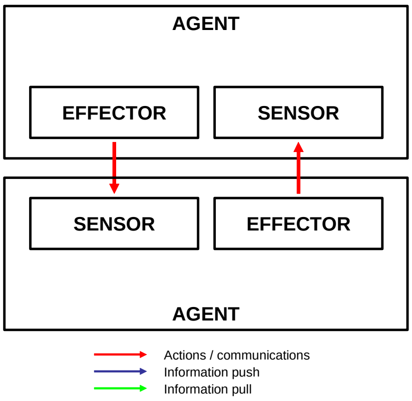

Figure 3.3 Agent-agent direct communications

3.2 Interface Agent

An interface agent is a specialised agent that has the sole purpose of connecting different computational systems, 0. The use of this agent has been demonstrated in a data sharing application as described in (Maher et al. 2003). In this application, an interface agent acts as a bridge connecting a virtual environment (Active Worlds) and a database (EXPRESS Data Manager). Functionalities performed by the interface agent includes: maintenance of data consistency between different systems and providing a unified interface to different systems through an agent paradigm.

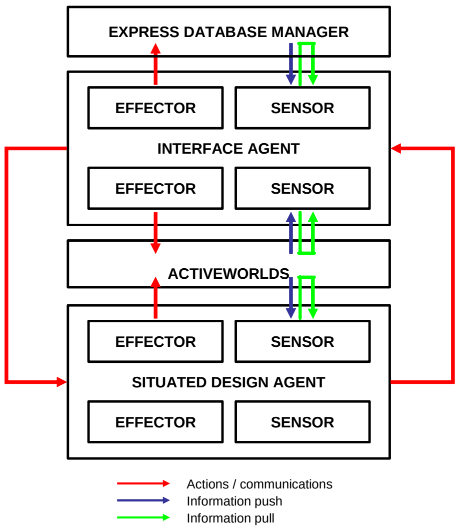

Figure 3.4 Interface agent interconnecting different computational systems (environments).

3.3 Conceptual Architecture

The proposed conceptual architecture for the life cycle analysis application is illustrated in Figure 3.5. This architecture is extended from 0. One function of the Maintenance Interface Agent is to connect data contained within the Maintenance Database with data contained within the EXPRESS Data Manager (EDM) Database via the virtual environment, Active Worlds. The Maintenance Agent performs data mining and life cycle analysis on the data in the Maintenance Database through the Maintenance Interface Agent. In subsequent development of the system, the Maintenance Agent communicates directly with a Situated Design Agent to assist designing by providing life cycle implications as feedbacks as different Mechanical and Electrical elements are used. A Situated Design Agent is basically a software agent that has the sole purpose of performing design actions. The behaviour of this agent is determined by the external state of the current environment, the internal state of the agent and the interactions between the agent and the environment (Liew and Gero 2002a, 2002b). This conceptual architecture will be instantiated into an implementation model.

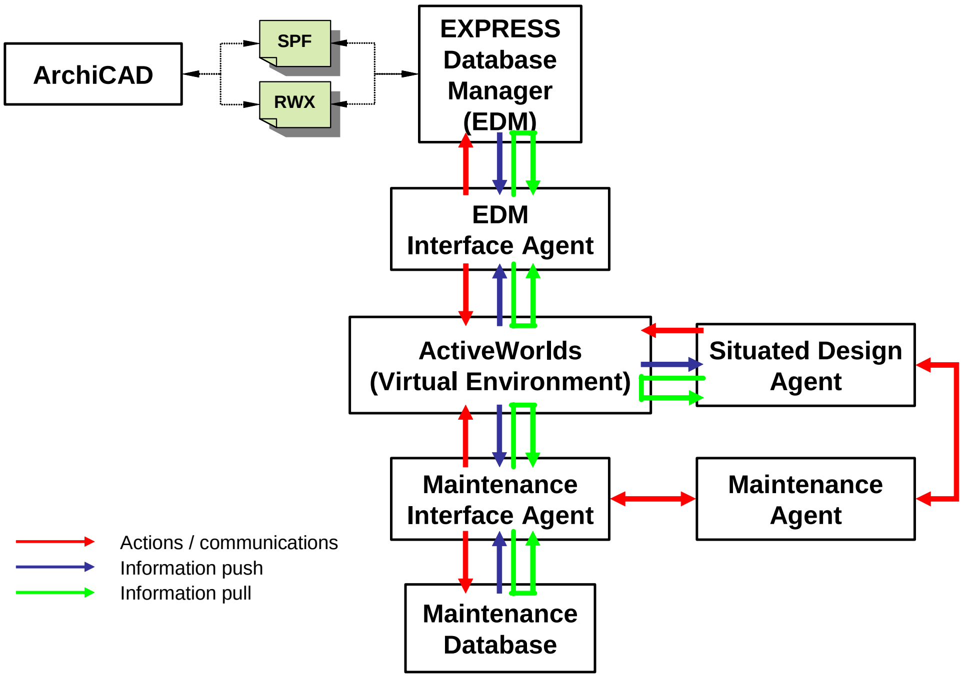

Figure 3.5 A conceptual architecture for life cycle analysis of building maintenance.

4. 3D INTERACTION IN VIRTUAL ENVIRONMENTS USING OBJECT-ORIENTED REPRESENTATION.

The following scenario is proposed during typical interactions between a user and the proposed system in the previous section.

- User select an object in Active Worlds;
- A window pops up to allow selection of EDM data related to object, life cycle or data mining information.

For the current implementation, only GUIs (Graphical User Interfaces) as supplied by WEKA are displayed. Within Active Worlds, only the following are displayed: walls, columns, slabs and different floors with simplified representations of mechanical and electrical objects. A complete list of mechanical and electrical objects is to be determined based on the richness of available maintenance data of Building no. 10, Royal Prince Alfred Hospital, Sydney. The following building asset types (batteries, air-conditioning units and valves) were considered in the demonstration of applying data mining over industry maintenance database in the previous report.

4.1 User Interface of Life Cycle Modelling

The following illustrates mock-up interfaces of the system to be developed. Descriptions of key user interfaces are described. The initial Graphical User Interface (GUI) is triggered when a user selects a building asset (Mechanical or electrical object) in Active Worlds, as shown in Figure 4.1.

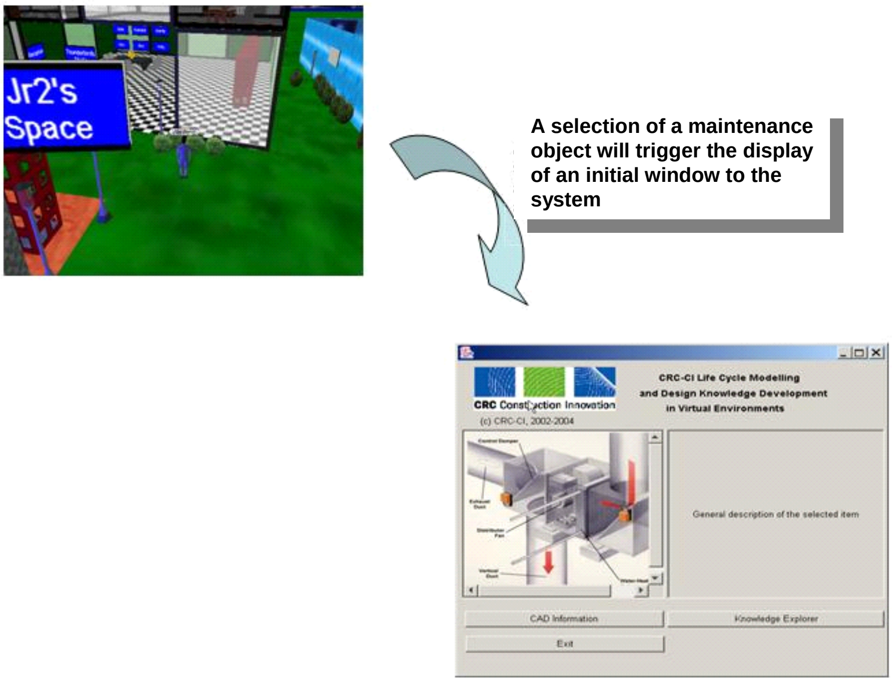

Figure 4.1 Triggering of the initial user interface to the LCM (Life Cycle Modelling) system.

Figure 4.2 illustrates the details of the initial GUI. This GUI provides a visual presentation of the selected mechanical and electrical elements and relevant textual descriptions. The CAD Information button provides the user with CAD related information as contained in the EDM database through a browser, as shown in Figure 4.3. The Knowledge Explorer buttons trigger the display of a WEKA Knowledge Explorer shown in Figure 4.4.

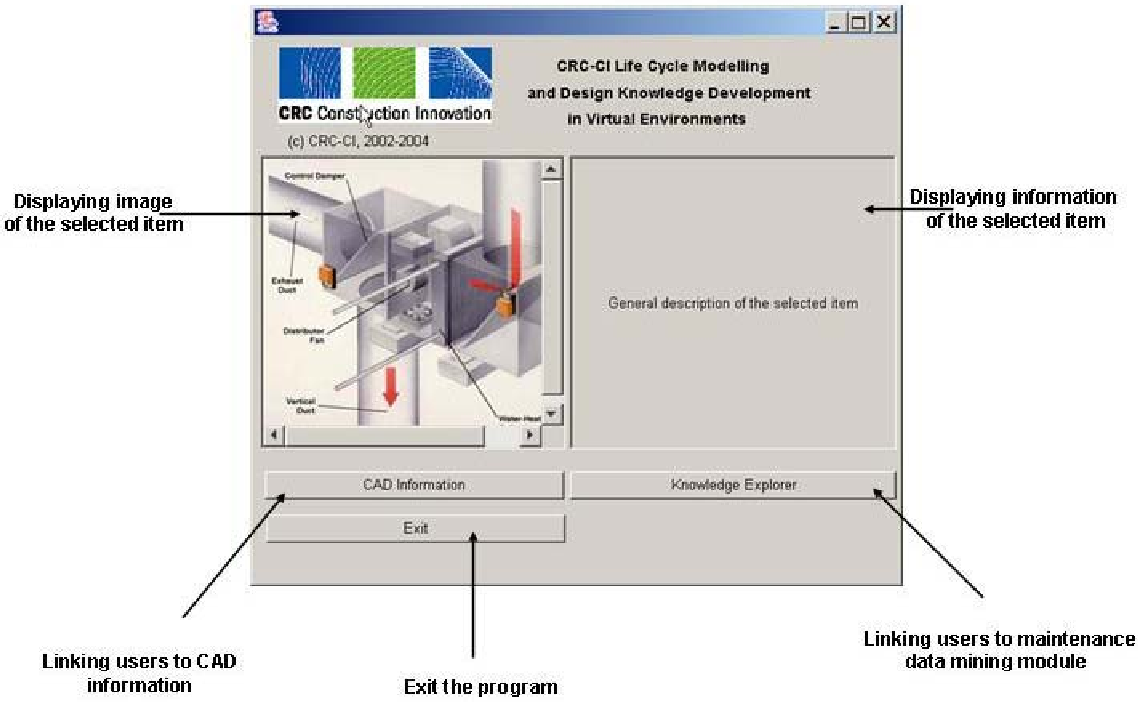

Figure 4.2 An initial window to the LCM system.

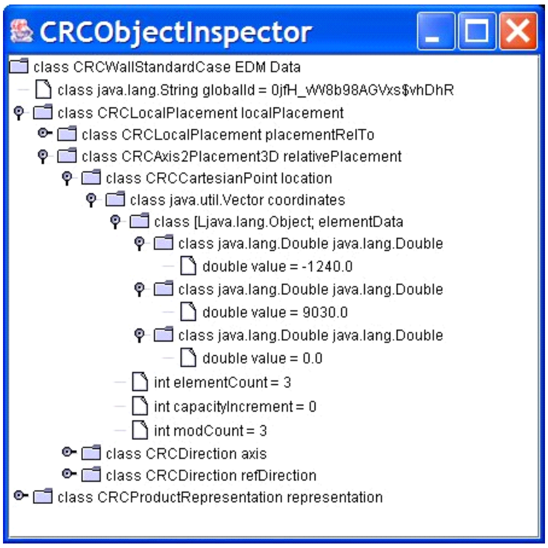

Figure 4.3 Browsing CAD information using Object Inspector.

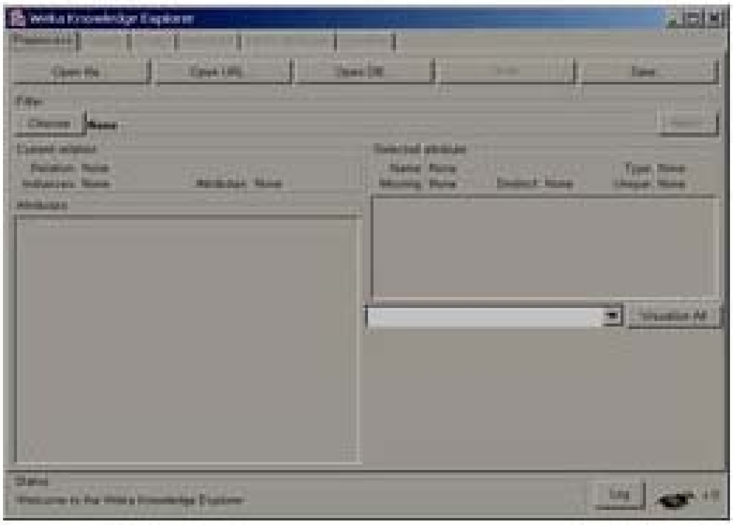

Figure 4.4 An interface of WEKA Knowledge Explorer.

From WEKA Knowledge Explorer, users are linked to a variety of data mining and visualisation tools that allows complex data cleaning and analysis through data pre-processing, critical attribute selection, classification, clustering and associative rules algorithm. Figure 4.5 illustrates the loading of a maintenance file into the WEKA Knowledge Explorer. When a user clicks on the Open file button, WEKA opens up a window for user to select the required maintenance file.

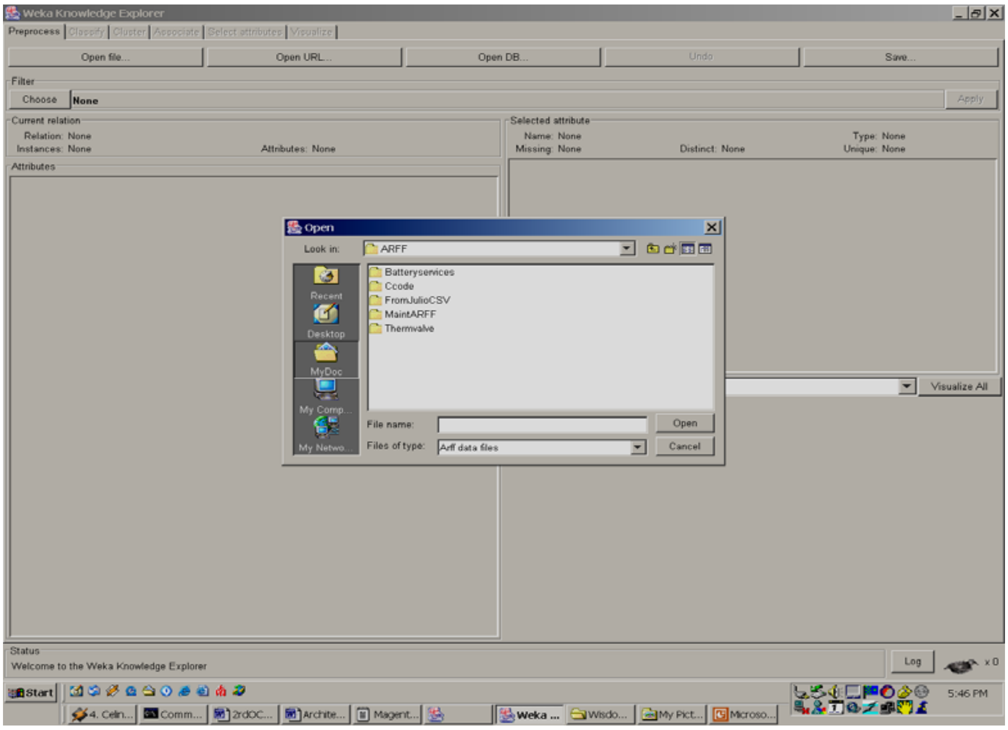

Figure 4.5 Loading a maintenance file to the LCM system.

4.2 Mining building maintenance data within virtual environments

Once the maintenance file is loaded, the user will have access to four panels: Pre-Processing Panel Classification Panel, Attributes Selection Panel, and Associative Rules Panel. The flow control between these panels is presented in Figure 4.6. The four panels are shown in the following Figures from 4.7 to 4.10 respectively.

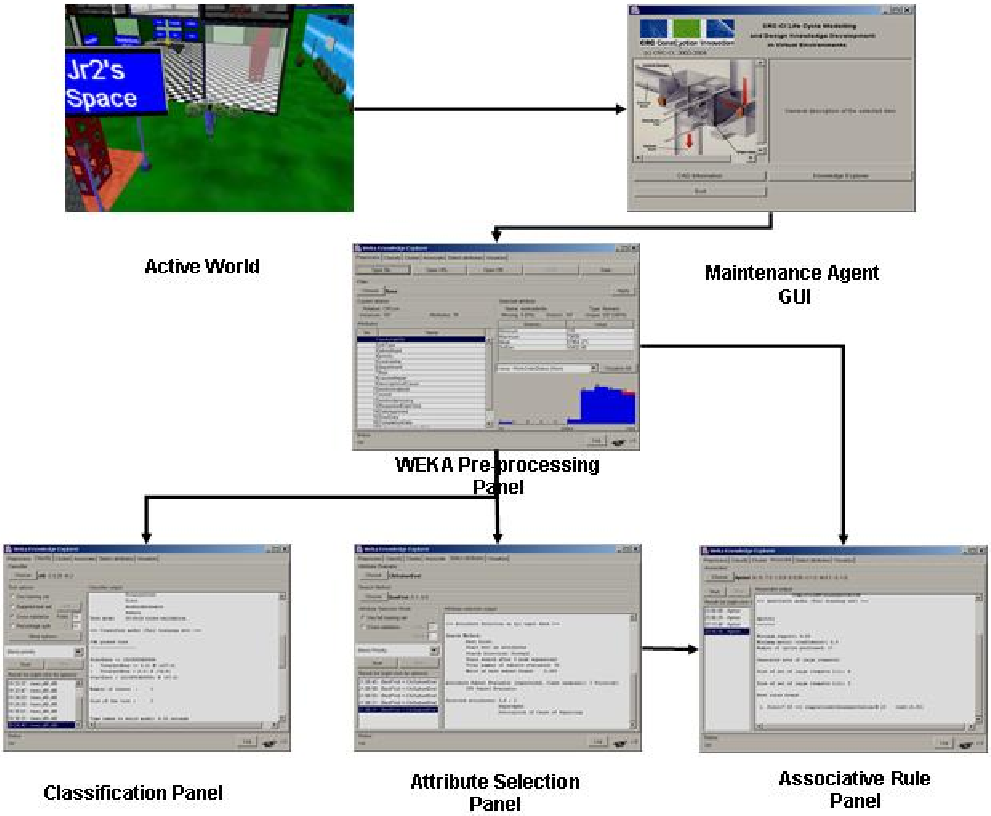

Figure 4.6 Flow control of mining building maintenance data within virtual environments (Active Worlds).

The pre-processing panel shown in Figure 4.7 provides the following functionalities for knowledge acquisition:

- Loading maintenance data file from the file system, through the internet, or from a database system;
- Pre-processing of the initial data through a filtering algorithm to remove irrelevant attributes; and
- Describing maintenance data in terms of statistical methods or visualization tool (stacked histograms).

Through an initial analysis of the maintenance data of air handling unit, thermostatic valve, and battery unit, many useful rules were obtained through a stacked histogram provided in this panel. The descriptions of these rules are available in previous report (Preliminary Result from Data Mining).

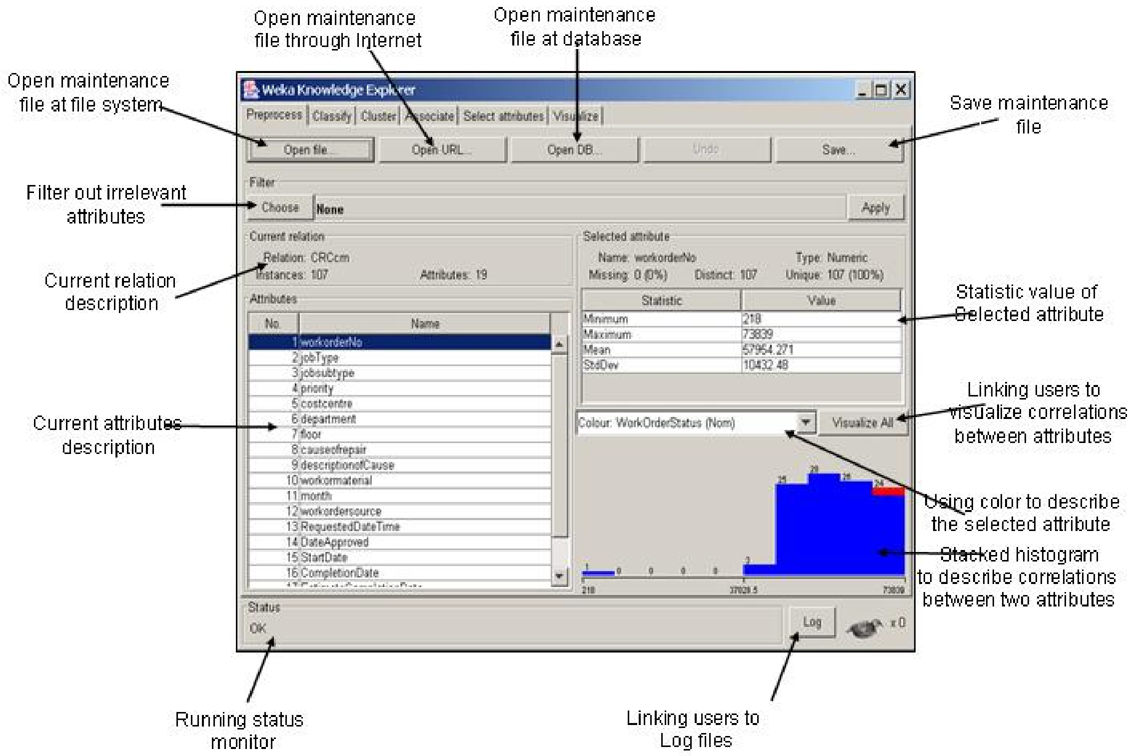

Figure 4.7 Pre-processing panel

The classification panel shown in Figure 4.8 provides the users with various classifiers to search for rules. Users can construct specific decision trees based on different targets to support planning. To use this panel a user needs to:

- choose the classification algorithm through Choose button;
- select the required test options through the radio buttons;
- select the classification target; and
- start the classification by clicking the Start button.

After comparing the results of several classifiers, the C4.5 decision tree classifier is selected as it was found to be suitable for the currently available maintenance data and a meaningful tree can be constructed.

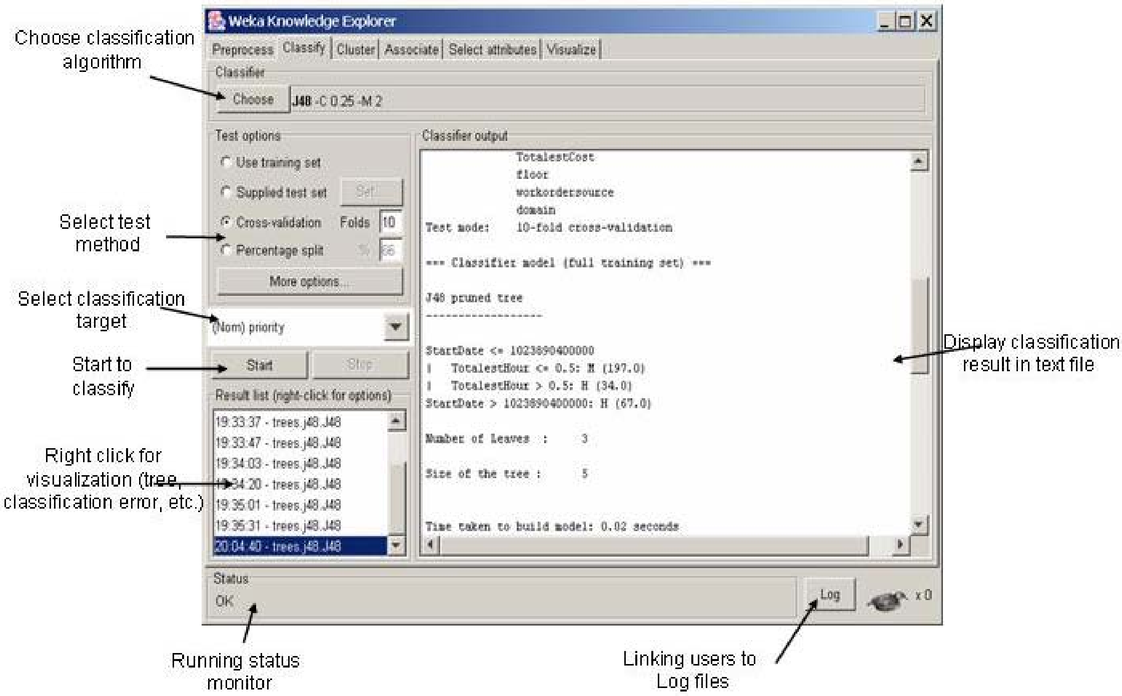

Figure 4.8 Classification panel

The general processes for selecting correlated attributes groups through the attribute selection panel shown in Figure 4.9 include:

- choosing the Select attributes panel;
- selecting the attribute evaluator and search method;
- choosing the test method (selection mode);
- selecting the attribute target against which the other attributes are related; and
- clicking the Start button to group correlated attributes.

The function of select attributes in this panel is similar to filter in the pre-processing panel. Both remove unrelated attributes. However, the focus in the attribute selection panel is on selecting strong correlated attributes groups. After the selection of these attributes, associative rule algorithms are used to correlate attributes into groups.

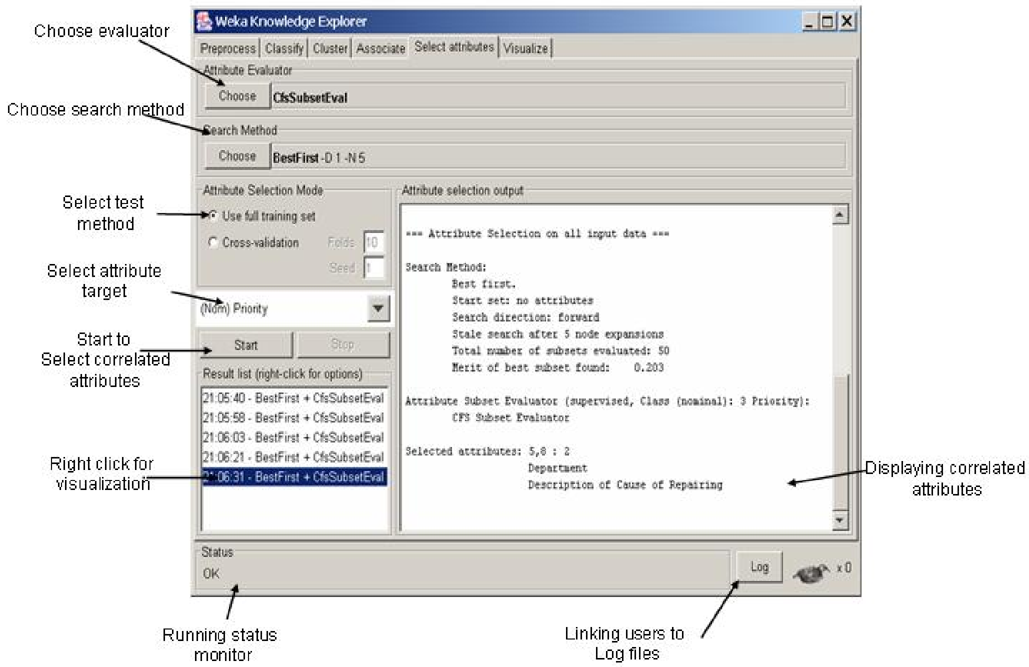

Figure 4.9 Attribute selection panel

The associative rule panel shown in Figure 4.10 provides a display of the rules generated. An example of rules generated from mining air handling unit is shown.

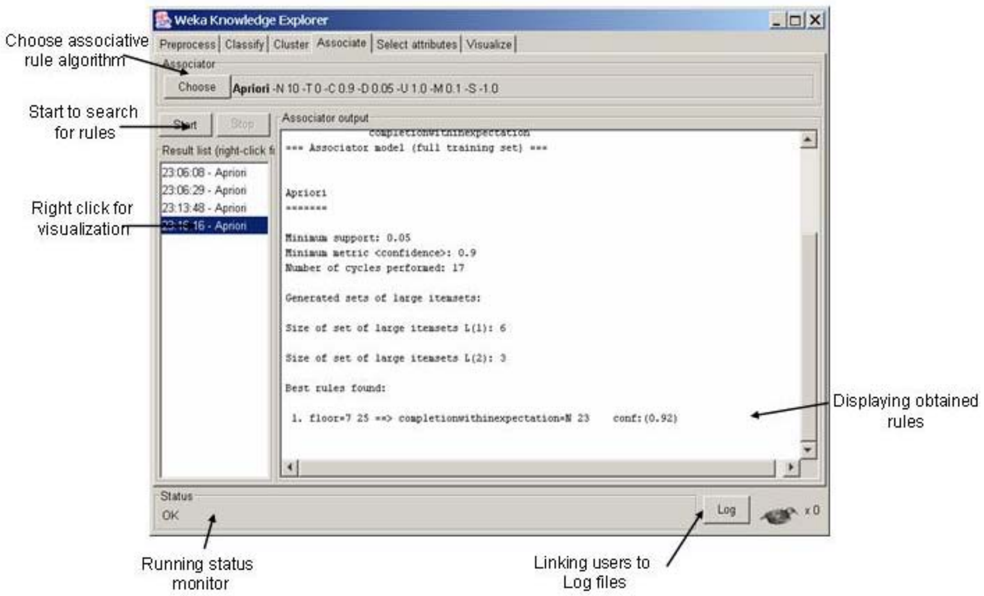

Figure 4.10 An associative rule panel.

5. CONCLUSION

Virtual environments of building models offer the opportunity for the user to navigate through the model, to manipulate and to interact with its objects. Integrating facilities databases with interactive 3D virtual environments of building models and data mining techniques will lead to the development of a visual modelling tool for the simulation and projection of the financial and physical impact of maintenance, refurbishment and major replacement and extension of a building and its components over its live cycle.

Data mining techniques are tools that allow building and facility manager to identify valid and useful patterns of knowledge from large amount of building data. The development of data mining agents of facilities and building maintenance data in a 3D virtual environment will provide useful information for improving the design, maintenance and management of building facilities and guiding future decisions.

In this project, so far, applying various data mining techniques on building maintenance data has been demonstrated. Patterns, correlations and useful rules within existing building maintenance data were discovered and addressed in the previous report.

In this report, 3D object–oriented model of the selected building no. 10 at Royal Prince Alfred Hospital is developed. The industry foundation classes of the selected building are exported from the 3D object-oriented model to accommodate graphical and non-graphical attributes. A framework of agents system within 3D virtual environments (Active Worlds) is established. The user interface of the agents system for mining building maintenance data within interactive 3D virtual environment has been designed and elaborated.

The deliverables in the coming quarter (due on 31 March 2004) include (a) developing software agents for data mining prosed in section 3.3 of this report; (b) linking knowledge development as a result of data mining with model in virtual environment of building no.10 at Royal Prince Alfred Hospital, Sydney shown in section 2.5 of this report. Building objects including mechanical and electrical objects will be converted to RWX and IFC format in order to be viewed and manipulated at virtual environments (Active Worlds) and linked to EDM (Express Data Manger) of maintenance data; and (c) populating maintenance database with selected data of the same building, maintenance data of three asset types were demonstrated in the previous report.

6. REFERENCES

Cornick, T.: 1996, *Computer-Integrated Building Design,* E & FN Spon, London.

Gero, JS and Fujii, H: 2000, A computational framework for concept formation in a situated design agent, *in Knowledge-Based Systems* 13(6): 361-368.

Lewis, R. and Sequin, C.: 1998, Generation of 3D building models from 2D architectural plans. *Computer-Aided Design*, 30 (10), 765-79.

Liew, PS and Gero, JS: 2002a, An implementation model of constructive memory for a situated design agent, *in* JS Gero and F Brazier (eds.), *Agents in Design 2002,* Key Centre of Design Computing and Cognition, University of Sydney, Australia, pp. 257-276.

Liew, PS and Gero, JS: 2002b, A memory system for a situated design agent based on constructive memory, *in* A Eshaq, et al. (eds.), *CAADRIA2002,* Prentice Hall, New York, pp. 199-206.

Maher, ML, Liew, PS and Gero, JS: 2003, An agent approach to data sharing in virtual worlds and CAD, *in* R Amor (ed.), *Construction IT Bridging the Distance, CIB Report 284*, pp. 204-213.

Reffat, R.: 2002, Three-dimensional CAD Models: Integrating Design and Construction, *in* R. Best and G. de Valence (eds), *Innovation in Design and Construction: Building in Value*, Butterworth Heinemann, Oxford, pp. 291-305.

Rosenman, M.A. and Gero, J.S.: 1998, Purpose and function in design. *Design Studies*, 19 (2), 161-186.

Szalapaj, P.: 2001, *CAD Principles for Architectural Design*, Architectural Press, Oxford.