Integrating CAD and 3D Virtual Worlds Using Agents and EDM

DING Lan[1], LIEW PakSan[2], MAHER Mary Lou[2], GERO John S[2] and DROGEMULLER Robin[1]
[1] *CMIT, Commonwealth Scientific and Industrial Research Organisation*
[2] *Key Centre of Design Computing and Cognition, University of Sydney*

Keywords: Virtual Worlds, Agents, EDM database, IFCs, CAD

Abstract: This paper develops an overall architecture for integrating CAD and virtual worlds. The advantages of having access to the building model in a virtual world include the collaborative nature of the world. The EDM database as an object-oriented database is developed to establish a common object-oriented representation of building model, which can be accessed by both CAD systems and virtual worlds. The integration between CAD systems and an EDM database is implemented through the use of Industry Foundation Classes (IFCs) as an intermediate data model and the communication between the database and virtual worlds is developed through agents.

1 INTRODUCTION

While CAD systems are used extensively for the design and documentation of a building, they do not easily support collaboration with multi-user real time walkthrough and rendering. There are commercially available object-oriented 3D virtual worlds that allow individuals connected to the world server to walk around and in the design as avatars, for example Active Worlds[1]. The use of such worlds in architecture has been demonstrated (Maher and Simoff, 2000), but the design representation in the virtual world remains a separate representation to the CAD model. While the underlying representation of the design in both CAD and 3D worlds may be object-oriented, the decomposition into objects and the format are not compatible. This paper explores an object-oriented database approach to the integration of CAD systems and virtual worlds. Issues involve: (1) the translation of the representation/format of building data from CAD systems to a common object-oriented representation; (2) the translation of the objects and reconstruction of the building model in a 3D virtual world and (3) the development of multi-agent models to support the communication between the object-oriented database and virtual

[1] http://www.activeworlds.com

worlds.

1.1 From CAD to Virtual Worlds

With the increasing use of network communication, traditional CAD applications have shifted towards the development of networked design environments, real time interaction and high quality multi-user collaboration. Visualizing design concepts, representing alternative ideas, viewing various resulting performances and negotiating problem solutions in real time have become possible. 3D virtual worlds such as Active Worlds and Microsoft Virtual Worlds can provide a 3D virtual collaborative environment, however, most of their applications are in the games industry and online education and none has been implemented for the AEC industry. Integrating CAD systems with 3D virtual worlds enables us to establish an integrated collaborative design environment. Some benefits are presented as follows.

- V*isualisation of building model*

  Improving the value of shifting traditional 2D graphical representation towards real time walkthrough and rendering.

- *Representation of multi-dimension design space*

  Possibility to have multi-dimension design spaces by adding new components or linking with various application packages.

- *Providing real time interactions*

  Providing real time interactions between the designer and the building model, designer and designer or among building objects, enabling the exploration of alternative ideas and design plans produced in a real design process.

- *Providing multi-user real time collaboration for problem solutions*

  Allowing project manager, designer and client who may be located in different places to share project information, view design performances and negotiate problem solutions in real time.

- *Linking with a broad range of information and accessing various databases or different domain application models through a network*

  A virtual building may be linked with related information such as culture, history, environment and geography through the web when necessary. It also has the potential of linking with different databases and domain application models for the establishment of virtual multi-projects.

Although these advantages exist, there are some difficulties remaining to be solved:

- transferring a CAD model into a virtual building model with the addition of behaviour features.

- allowing virtual building objects transferred from CAD to be modified in the virtual environment.
- providing domain specific views of building objects and supporting real time design collaboration.

The approach described in this paper allows for a seamless transfer of model information from CAD to a virtual world by representing geometric and behaviour information in a shared object representation. The shared object representation is not a new idea. Existing work on the development of the integrated building model to support the sharing of information include Jeng and Eastman (1998); Marir et al. (1998); Eastman (1999) and Whyte et al. (2000). Efforts involve the establishment of standard models to provide a common interpretation of objects, the development of the integrated database for the representation and sharing of model information, the new database schema architecture in an integrated environment to provide multiple design views and to support design collaboration, etc. Our approach constructs the shared object representation for CAD and virtual worlds using the EDM (www.epmtech.jotne.com) database and uses agents to monitor and facilitate the use and modification of the building model in CAD, virtual worlds, and potentially other applications.

1.2 IFCs and EDM Database

IFCs (IAI, 2000) provide an object-oriented representation for the life-cycle information in the AEC industry and have been linked to some CAD systems since they play an important role in data exchange. For example, ArchiCAD and Autodesks' Architectural Desktop now have the capability to import and export IFC data. We use ArchiCAD as an example CAD system, to link a CAD model with IFCs to support expanding behaviour data. The Express Data Manager Developer (EDM, 2002) database is an object-oriented database which supports modelling, application development and database management. It uses EXPRESS as a data description language to define the representation of a model. The EDM database has the following capabilities: (1) definition of object mappings between schema, which supports model conversion and merging; (2) definition of "business objects", which supports domain specific views of a model and (3) definition of rules, which supports intelligent behaviours of objects. This paper uses an EDM database as a central database and integrates it with CAD through IFCs.

1.3 Agent-based Virtual Worlds

Agent-based virtual worlds have been proposed and developed by Maher and Gero (2002). A 3D virtual world can be modelled as a society of agents in which each object in the world has agency, that is, a capability for autonomous behaviour. This added capability allows virtual objects to sense the environment, reason about their goals and make modifications to the environment. In an agent-based virtual world, a particular behaviour may be triggered by changes in the data about the virtual world and an action is carried out through the agent's ability to reason about itself in the world. For example, when an additional object is added to a repository of objects, an agent within the society senses that there is new information not present previously and creates the appropriate objects within the virtual world.

In this paper, the agent-based virtual worlds are developed for the integration of EDM database and virtual worlds.

2 DEVELOPMENT OF EDM DATABASE FOR THE ESTABLISHMENT OF A CENTRAL MODEL

2.1 CAD-IFCs Model

IFCs are a representation of information for architecture, engineering, construction and facility management projects. The IFC object descriptions deal with not only full 3D geometry but also relationships, process, material, cost and other behaviour data. Integrating a CAD model with IFCs enables the accurate geometric representation to be integrated with structural and behaviour elements and facilitates linking with external applications, Figure 1.

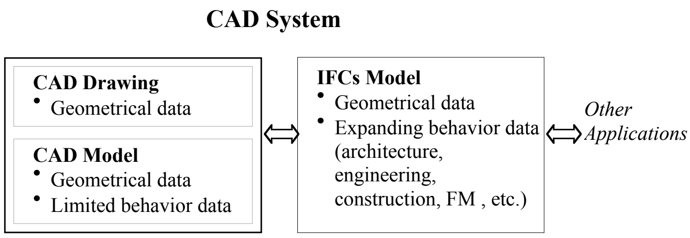

Figure 1 An illustration of the CAD-IFCs model.

IFCs allow the definition of views of the objects contained in a model, e.g. views for architectural design, HVAC design, cost estimation, fire safety design, etc.. IFCs also provide a hierarchical description of objects, properties and relationships. This provides an understandable structure for complex data about buildings. An illustration of the functionality of IFCs (IAI, 2001) is presented in Figure 2.

Although IFCs are still being developed, and therefore do not yet provide full support for transferring a CAD model to an EDM database, this project uses the standard IFCs where they are defined and uses proxy objects to cover information that is not yet directly defined in the IFC model. This project focuses on the structure of the EDM database and the agent model for monitoring and facilitating transfer to and from the virtual world.

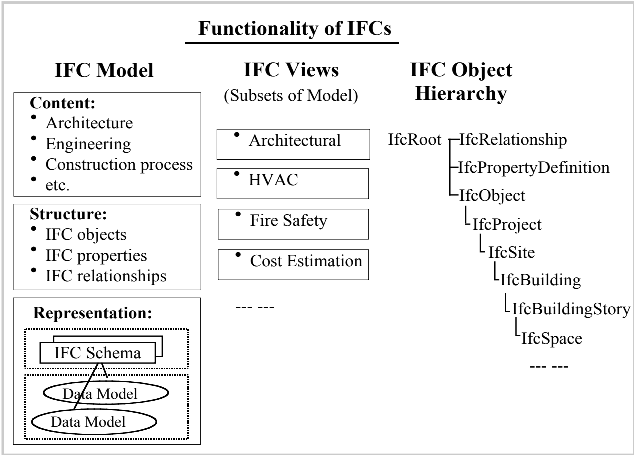

Figure 2 An illustration of the functionality of IFCs.

2.2 Construction of EDM Database

We develop the EDM database for storing the CAD-IFCs model to facilitate queries from other applications, such as virtual worlds. The construction of the EDM database includes defining a model schema, mapping schema, rule schema and query schema, Figure 3.

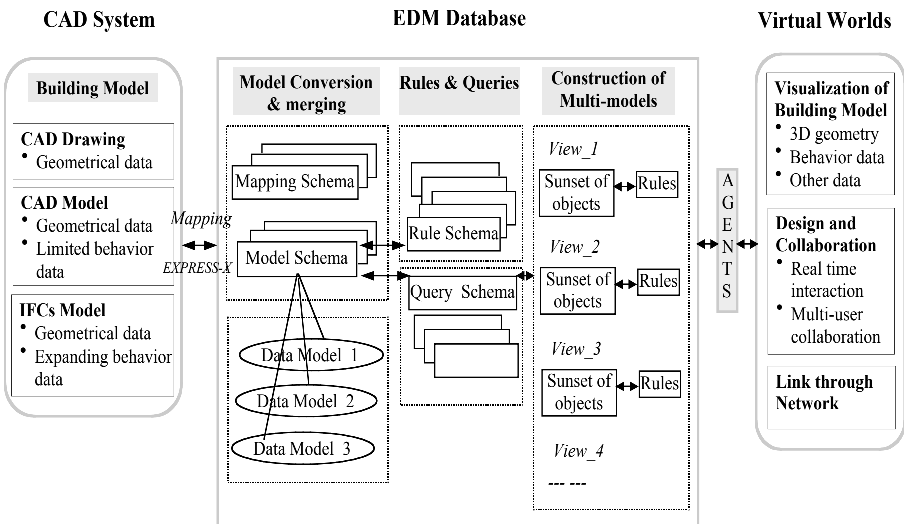

Figure 3 Construction of EDM database for the integration of CAD and virtual worlds.

The definition of a model schema consists of IFCs-based objects such as project, site, building, building story, space and building element, and object properties including shape, placement, material, cost and additional properties used in virtual worlds such as IsMoveable, RenderQuality, connection relationships and so on. The mapping schema can be established through EXPRESS_X. We develop a mapping schema to transfer the CAD-IFCs model into the EDM database.

The rule schema is used to add rules and constraints to a model schema. Various domain specific rules can be defined through the rule schema. For example, we can define a rule schema to describe the constraints to a circulation space against access by people with disability and define a rule schema to represent the rules against fire safety, Figure 4. The definition of rules and constraints within the EDM database supports the intelligent behaviours of objects.

```
RULE_SCHEMA Circulation_Space_Check for Model_Schema;

ENTITY RampFlight;
WHERE
  Width_and_gradients: Check_width_gradients (self);
 END_ENTITY;

FUNCTION Check_width_gradients (RampF:RampFlight): LOGICAL;
--- ---
END_FUNCTION;

RULE Handrail FOR (Stair, Ramp, Railing);
WHERE
  Handrail: Check_handrail ();
END_RULE;

FUNCTION Check_handrail (St: Stair; Ra: Ramp; Rail: Railing): LOGICAL;
--- ---
END_FUNCTION;

--- ---
END RULE_SCHEMA;
```

```
RULE_SCHEMA Fire_Safety_Check for Model_Schema;

ENTITY Wall;
WHERE
  FRL: Check_wall_FRL (self);
 END_ENTITY;

FUNCTION Check_ wall_FRL (Wa: Wall): LOGICAL;
--- ---
END_FUNCTION;

--- ---
END RULE_SCHEMA;
```

Figure 4 Examples of defining different domain rules to a model schema in EDM database.

The query schema is developed to construct domain specific views of a model. Each view presents a subset of objects of a model and has its own domain rules. The construction of a multiple view model in the EDM database reduces complexity in model translation and visualisation.

2.3 Buildings Models in Virtual Worlds

Virtual worlds such as Active Worlds and Microsoft Virtual Worlds are implemented using an object-oriented representation. Building objects can be viewed and manipulated in a multi-user environment through the development of virtual worlds. An example of the visualisation of IFCs-based building model (Drogemuller et al, 2001) using Microsoft Virtual Worlds is shown in Figure 5, where IFC-based building objects are converted into virtual building objects such as rooms/spaces, artifacts/elements, portals, etc. and their properties can be edited.

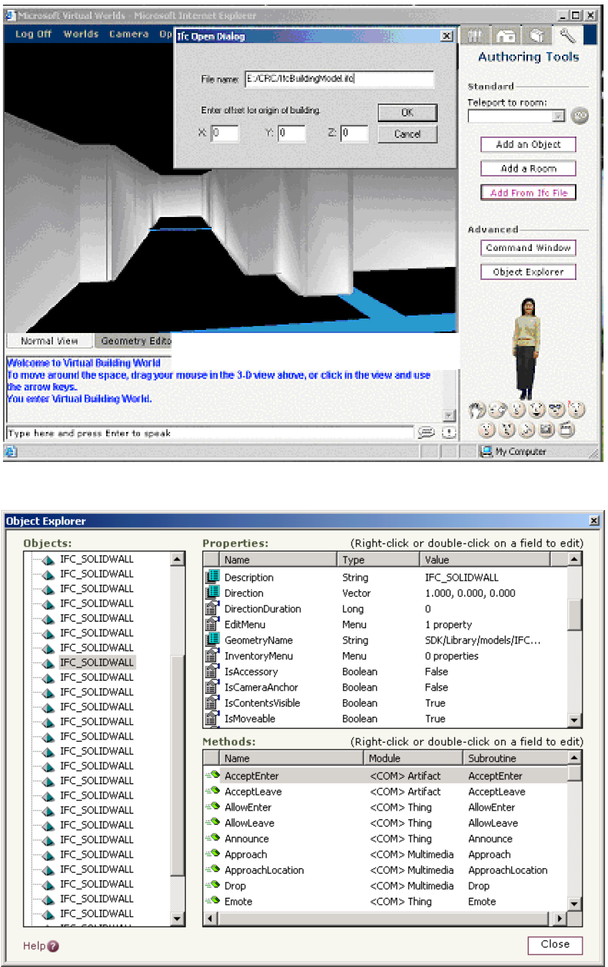

Figure 5 An example of the visualisation of IFCs-based building model in a virtual world (Drogemuller et al, 2001).

Our approach to integrating CAD and 3D virtual worlds uses the EDM database as a model for sharing building project data. The Active Worlds platform is developed for the visualisation of the building model while the intelligent behaviours of building objects are supported through the agents. The building objects in virtual worlds are interactive and operational and their properties are editable. The changes can be saved back to the EDM database and shared with CAD systems.

The multiple views of a design model in a virtual world are developed through the addition of new components that represent different design spaces. The multi-models in the EDM database can then be represented in the multiple design spaces where the coordination between different designs can be achieved through real time communication.

3 AN AGENT APPROACH TO DATA SHARING

A society of agents is developed to provide a multi-agent model that complements the information about a building in the EDM database and the virtual worlds (VW). As a society of agents, the individual agents not only include intelligent behaviours associated with the objects in the building, but also include a protocol for these objects to communicate and reason about the design and construction of the building, Figure 6.

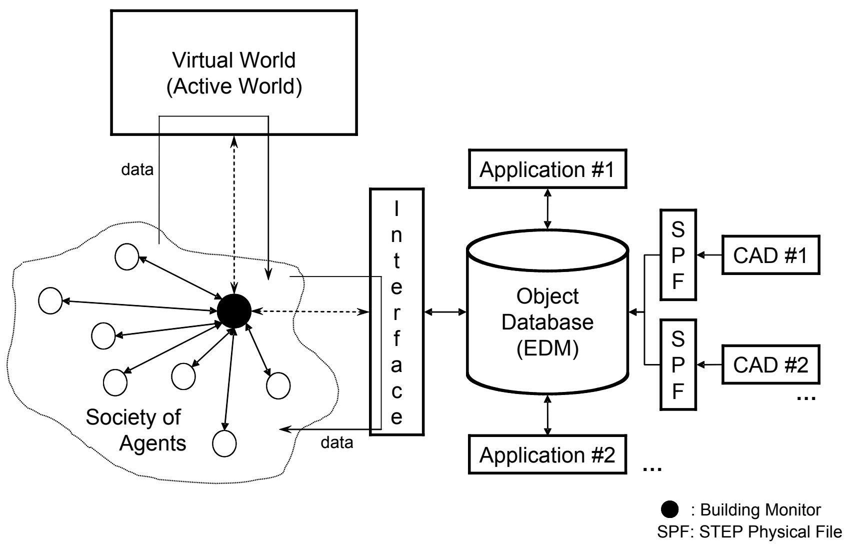

Figure 6 Communication between EDM database and virtual worlds through a society of agents.

Within the society, a "building-monitor" agent monitors the activity in the virtual worlds and the object database for new entries. When a new object is placed in either the database or the VW, the building-monitor agent creates a corresponding agent for that object. For example, when a new wall object is entered in the database, a wall agent is created by the monitor agent. This wall agent then monitors its associated VW object and database object. The society of agents is first initialised by stepping through all the objects within the database to form the initial set of agents. Each new agent created within the society instantiates its corresponding representation within the virtual worlds that forms another context for the agents.

Each new agent created within the society has a collection of sensors that allow it to detect relevant modifications made in the VW or the DB. The agent's sensors identify the relevant changes in the context (VW+DB) and record the sensor data in the agent's working memory. As a society of agents, each agent is also able to sense messages from other agents. The reasoning process of the agent follows the model of sensation, perception, conception, hypothesis, and action activation (Gero and Fujii, 2000) described below.

- Sensation transforms raw input from the Sensors into structures appropriate for reasoning and learning. The raw data can be obtained through the agent identifying the relevant data by monitoring the virtual world, the EDM database, or messages the agent receives from another agent.
- Perception transforms sense-data into percepts to be used for interpreting interactions or to be used as the units for constructing concepts. Percepts are grounded patterns of invariance over interactive experiences, and are constructed by clustering like patterns into equivalence classes so as to partition the sensory representation space. Perception is driven both by concepts and by the sense-data.
- Conception is a learning process that uses concepts to reinforce or modify the agent's beliefs and goals. Conception generalizes experience to provide a predictive ability for existing situations.
- Hypothesizing looks for mismatches between the current and desired situation, identifies which goals are relevant to the current state of the world and reasons about which goal should be achieved in order to reduce or eliminate that mismatch. An example of a goal is to place a new object in the virtual world to correspond to a new object in the EDM database.
- Action reasons about a sequence of operations on the world, which when executed, can achieve a specific goal. These operations are carried out by the Effectors which cause a direct change in the virtual world, the EDM database, or sends out a message to another agent.

There are two ways in which an agent decides to act:

- Data driven mode in which the sensor detects something in the context or a message from another agent that leads to the agent identifying a relevant goal to achieve;
- Goal driven mode in which an agent has a set of goals it is responsible for

achieving and directs a sensor to find information in the context that allows it to achieve that goal.

4 DISCUSSION

The approach to integrating CAD and 3D virtual worlds using agents and the EDM database is being tested using a simple building model in ArchiCAD. ArchiCAD can export IFCs, but the classes need to be cleaned before inserting them into the EDM database. The agent model is being developed to recognise a wall in the EDM database and to create both a wall agent and a 3D wall object in the virtual world. Further developments will increase the scope of the types of objects in the EDM database and the functionality of the agents.

3D virtual worlds offer a range of behaviours beyond CAD models. The technological infrastructure of virtual worlds makes them more appropriate for web-based sharing of dynamic visual representations without the need to continuously move large files between users. Agents in virtual worlds provide for novel functionalities not directly available with CAD models. They have the capacity to modify the behaviours of components and models based on the context or on the needs of each viewer.

ACKNOWLEDGMENTS

This research is funded by the Cooperative Research Centre in Construction Innovation (CRC-CI) Australia and is based on CRC Program One and Program Four. Special thanks to David Marchant, Greg Smith, Steven Shaw and Cheryl McNamara for discussions during the development of this work.

REFERENCES

Ambrose, M., S. Tucker and R. Drogemuller. 2002. Exploring a building's life cycle energy through CAD. In *9th International Conference Durability of Building Materials and Components*, vol. 3. Australia: CSIRO.

Drogemuller, R., M. Ambrose and S. Tucker. 2002. Automated building life cycle energy assessment. In *Distributed Knowledge in Building*, *Proceedings of CIB W78*, vol. 2, eds. K. Agger, P. Christiansson and R. Howard, 185-192.

Drogemuller, R., S. Shaw and L. Ding. 2001. Implementation of virtual collaborative design worlds, *CSIRO MIT Project*. Australia: CSIRO.

Eastman, C. M. 1999. *Building Product Models: Computer Environments Supporting Design and Construction*, CRC Press.

Eastman, C. M. 1991. A data model analysis of modularity and extensibility in building databases, *Report No. 16*, CAD line.

EPM Technology. 2002. *EDMAssist4.5*, vols 1-5. Norway: EPM Technology.

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

Graphisoft. 2001. *ArchiCAD IFC Reference Guide, Version 1.0,* Graphisoft.

IAI. 2000. *IFC specifications*, www.iai-international.org.

IAI. 2001. *IFC 2x Model Implementation Guide,* IAI.

Jeng, T. S. and C. M. Eastman. 1998. A database architecture for design collaboration. In *Automation in Construction* (7) (1998), 475-483.

Kalay, Y. E. 1999. The future of CAAD: from computer-aided design to computer-aided collaboration. In *Computers in Building: Proceedings of the CAADFutures'99 Conference.* U.S.A.: Kluwer Academic Publishers.

Maher, M. L. and J. S. Gero. 2002. Agent models of virtual worlds. *ACADIA 2002: Thresholds.* CA: California State Polytechnic University, Pamona, pp 127-138.

Maher, M. L. and S. Simoff. 2000. Collaboratively designing within the design. *Proceedings of Co-Designing 2000*, 391-399. U.K.: Coventry University.

Maher, M. L., S. Simoff and A. Cicognani. 2000. *Understanding Virtual Design Studios*. London: Springer-Verlag.

Marir, F., G. Aouad and G. Cooper. 1998. OSCONCAD: A model-based system integrated with computer-based construction applications, *Itcon vol.3 (1998).*

Szewczyk, J. 2001. Engineering portals – networked collaborative architectural information management. In *19th eCAADe Conference Proceedings.* Finland: Helsinki.

Vellon, M., K. Marple, D. Mitchell and S. Drucker. 2000. *The Architecture of a Distributed Virtual Worlds System,* Microsoft Corporation.

Whyte, J., N. Bouchlaghem, A. Thorpe and R. McCaffer. 2000. From CAD to virtual reality: modelling approaches, data exchange and interactive 3D building design tools. In *Automation in Construction* (10) (2000), 43-55.

This is a copy of the paper: Ding, L, Liew, P, Maher, ML, Gero, JS and Drogemuller, R (2003) An EDM approach to the integration of CAD and 3D virtual worlds, *CAADFutures* (to appear)