INFORMATION AND COMMUNICATION TECHNOLOGIES IMPROVING EFFICIENCIES

Fully Refereed Paper

Multidisciplinary Collaboration using Agent-based Virtual Worlds

Mike Rosenman
Kathryn Merrick

Mary Lou Maher
University of Sydney, Australia
mary@arch.usyd.edu.au

Adel Ahmed
Robert Shen
Owen Macindoe
David Marchant
Kanyarat Nampremprree

ABSTRACT

Design projects in the Architecture, Engineering and Construction (AEC) domain involve collaboration among a number of design disciplines, usually in separate locations. With the increase in CAD usage in design offices, there has been an increase in the interest in collaboration using the electronic medium, both synchronously and asynchronously. This paper puts forward an environment which provides real-time multi-user collaboration in a 3-D virtual world for designers in different locations. This virtual world collaborative environment allows for the different design disciplines to model their view of a building as different representations. A 3-D virtual world is chosen as the environment since it provides real-time multi-user collaboration through 3-D visualisations and walkthroughs as well as multi-user immersion. An extended proprietary virtual world system is used to provide a more complete collaborative environment. Relationships between the objects in the different models are seen as central to the maintenance of consistency and control over possible actions. Agent technology is used to create, manage and display the different views of a design and to create and manage the relationships between these views. This project concentrates on synchronous collaboration for conceptual design.

Keywords: design collaboration, multidisciplinary design, virtual worlds, agents

1.0 INTRODUCTION

Large design projects, such as those in the Architecture, Engineering and Construction (AEC) domain, involve collaboration between designers from many different design disciplines in varying locations. Existing tools for developing and documenting designs of buildings (and other artefacts) tend to focus on supporting a single user from a single discipline and this is inadequate. Collaboration among different participants in the design of a building involves the ability of the different participants to work on their part of the project using their own particular ways of working yet being able to communicate with the other participants to implement the overall design of the building. The creation of different discipline models and the creation of relationships between the objects in the different models as central to the maintenance of consistency between the models are put forward as essential for a collaborative environment. Collaboration involves both synchronous and asynchronous communication.

A collaborative design environment requires real-time multi-user collaboration by designers in different physical locations. This environment should provide 3D visualisation, walkthroughs and rendering to allow communication of the various views of the design as modelled by the different disciplines. This is of special importance at the conceptual stage of the design since much of the early collaborative decision-making is carried out at this stage. A virtual world environment based on an underlying object-oriented representation of the design is put forward here as a required environment for synchronous collaboration in the design of buildings. This is in contrast to the decision made by Lee et al. (2003) to use a commercial CAD system for visualisation. One of the main advantages of virtual world environments is that it allows users to be immersed in the environment, allowing for real-time walkthroughs and collaboration (Savioja et al., 2002; Conti et al., 2003). Moreover, CAD models contain a great deal of detail which makes real-time interaction extremely difficult.

This paper introduces DesignWorld, a prototype system for enabling collaboration between designers from different disciplines who may be in different physical locations. DesignWorld, shown in Figure 1, consists of a 3D virtual world augmented with a number of web-based communication and design tools. Unlike previous approaches which use a single shared data model (Wong and Sriram, 1993; Krishnamurthy and Law, 1997), DesignWorld, uses agent technology to maintain different views of a single design in order to support multidisciplinary collaboration. This architecture enables DesignWorld to address the issues of multiple representations of objects, versioning, ownership and relationships between objects from different disciplines. DesignWorld is targeted towards the conceptual stage of design where concepts are general and still fluid.

2.0 3D VIRTUAL WORLDS

A virtual world is a distributed, virtual space where people can interact with other people, objects or computer controlled agents using an avatar. DesignWorld uses the Second Life (www.secondlife.com) virtual environment as the platform for design and collaboration. While virtual worlds such as Second Life offer tools for creating and modifying virtual buildings and other artefacts, they do not offer features for managing multiple representations, versions or relationships necessary for multidisciplinary design. DesignWorld addresses this issue by augmenting Second Life with web-based tools and using agents to create views and relationships and manage versions on behalf of designers. DesignWorld is an improved version of the CRC Collaborative Designer (CCD) prototype (Rosenman et al., 2005). CCD was implemented using the Active Worlds (www.activeworlds.com) virtual world platform. The new version, implemented in Second

Life, provides facilities for modelling objects in the world and additional programming capability for associating agent models and an external data model with objects in the world.

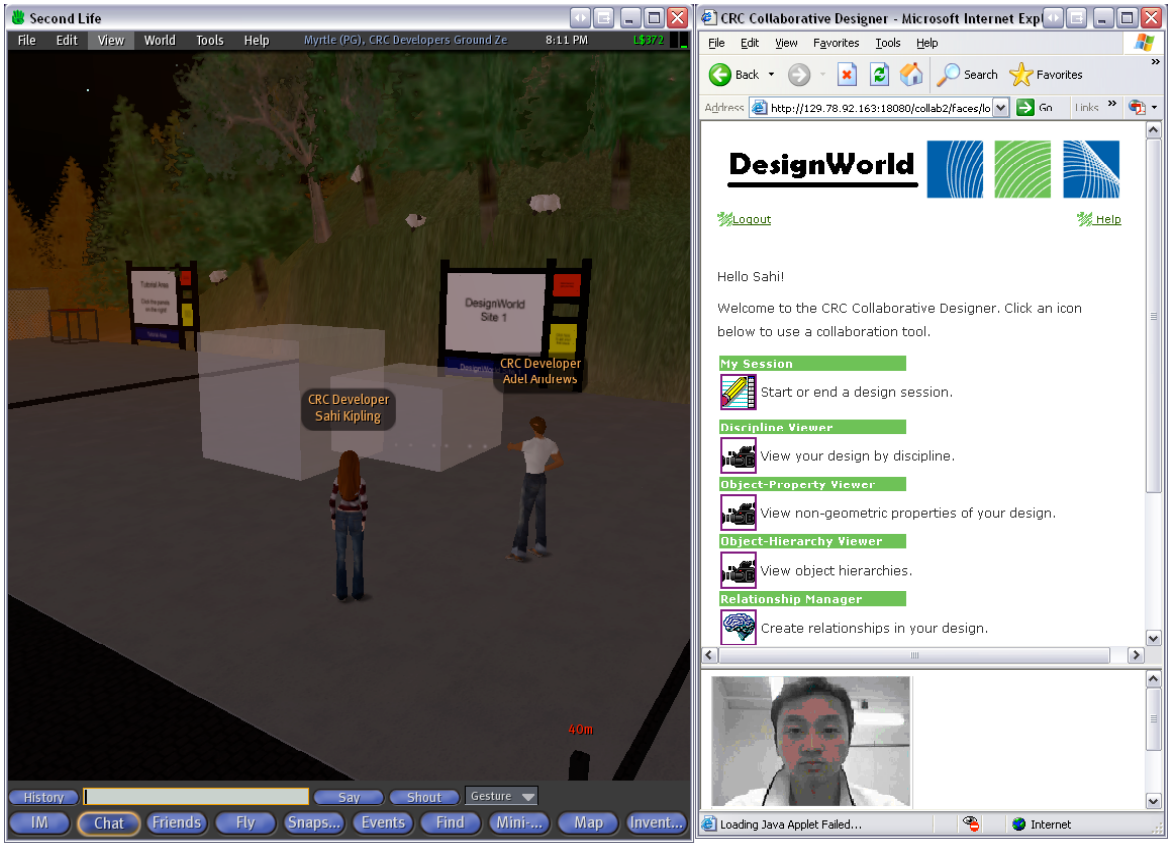

Figure 1. DesignWorld consists of a 3D virtual environment (left) augmented with web-based communication and design tools (right).

3.0 MULTIDISCIPLINARY MODELLING

Different disciplines have different views of a design object (building) according to their functional concerns and hence create different representations or models of that object to suit their purpose. For example, a building may be viewed as: a set of activities that take place in it; a set of spaces; a sculptural form; an environment modifier or shelter provider; a set of force resisting elements; or as a configuration of physical elements. Depending on the view taken, certain objects and their properties become relevant. For the architects, floors, walls, doors and windows, are associated with spatial and environmental functions, whereas structural engineers see the walls and floors as elements capable of bearing loads and resisting forces and moments. Hence, each will create a different model incorporating the objects and properties relevant to them. Both models must coexist since the two designers will have different uses for their models. According to Bucciarelli (2003) “There is one object of design, but different object worlds.” and “No participant has a ‘god’s eye view’ of the design.”

A single model approach to representing a design object is insufficient for modelling the different views of the different disciplines (Rosenman and Gero, 1996). Each viewer may represent an object with different elements and different composition hierarchies. While architects may model walls on different floors as separate elements, the structural engineers may model only a single shear wall. Each discipline model must, however, be

consistent vis-a-vis the objects described. While Nederveen (1993), Pierra (1993) and Naja (1999) use the concept of common models to communicate between the discipline models, it is never quite clear who creates the common models and maintains the consistency between them and the discipline models. In this project, this consistency will be provided by interrelationships between the various objects in different disciplines modelled by explicit (bidirectional) links from one object to another. Figure 2 shows an example of this approach, with each discipline labelling its objects according to its need and corresponding objects associated with '*correspondsTo*' relationships. While this approach may have the disadvantage of replicating the same information, it saves the complexities of creating the common concepts and allows each discipline great flexibility in creating its model. The discipline models allow each discipline to work according to its own concepts and representations. The whole model may be seen as the union of the different models.

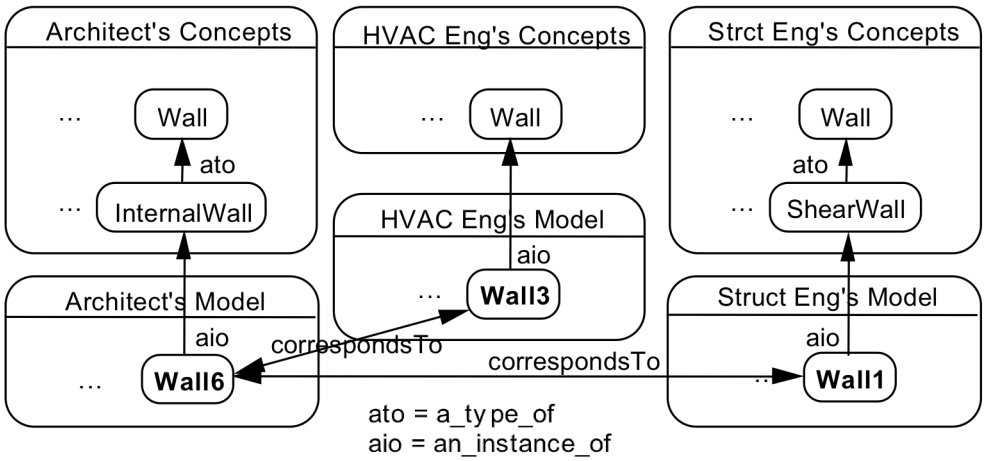

Figure 2. Discipline models and relationships

4.0 DESIGNWORLD

DesignWorld consists of three main components, the client browsers, the web applications and the external model, Figure 3.

4.1 Client Browsers

There are two client browsers, the Second Life browser and the Web browser which provide the extended capabilities to the Second Life virtual environment. Second Life provides the environment where the different designers meet and construct their models (through the associated modeller agent). The Web browser consists of the relationships browser and the extended communications facilities. The relationships browser allows for the creation of relationships between the different objects by any of the designers. The non-geometric property browser allows for the display of the non-geometric properties which cannot be displayed in the Second Life browser.

4.2 Web Applications

The web applications include the agent society, the webcam and audio facility which allow visual and aural communication and the GroupBoard sketch tool(www.groupboard.com) which allows for quick graphical communication of ideas.

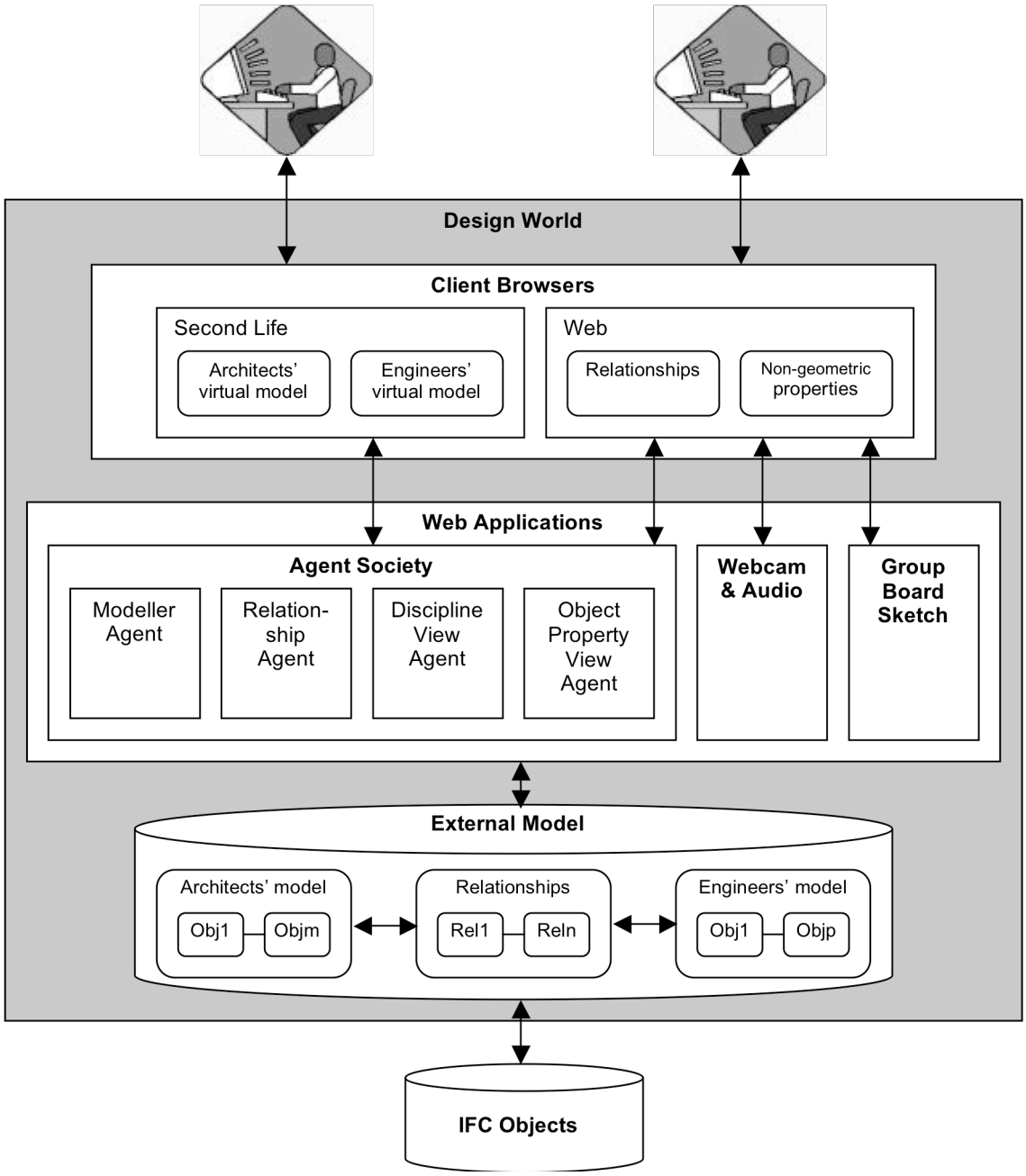

Figure 3. DesignWorld Architecture

4.2.1 The Agent Society

Agents are systems which can sense their environment using sensors, reason about their sensory input and affect their environment using effectors. DesignWorld agents perform tasks such as view creation and version management on behalf of designers. Designers wishing to perform a design action communicate their request to an agent, using one of the web-based design tools. After sensing a request, the agent uses a reflexive reasoning process to carry out the action for the user (Maher and Gero, 2002). DesignWorld agents can create different views of a design, manage relationships and store versions of the

design.

The agents in DesignWorld extend the platform of a virtual world by maintaining a model of designed structures in an SQL database in addition to the model maintained by the virtual world server. The use of an external model makes it possible to store information about design projects other than the spatial and rendering properties of individual objects stored on the virtual world server. The DesignWorld external model contains project information for a group of objects, and for each object there is discipline, versioning and relationship information. The external model is compatible with Industry Foundation Classes (IFCs) (IAI, 2000) providing the potential for models to be uploaded from IFC compatible applications such as ArchiCad for use in collaborative sessions.

The agents in DesignWorld keep track of the objects created by each discipline in order to maintain information relevant to the different functional concerns of designers from different disciplines. A selection of viewing tools enables designers to view the components relevant to them. The agent society is comprised of the four agents, the modeller agent, the relationships agent, the discipline view agent and the object property view agent.

4.2.1.1 Modeller Agent

The modeller agent creates and modifies the external model from the object creation and modification in Second Life. The modeller agent receives a message from the Web browser containing a request from a user for a particular design to be modelled and retrieves information from the external model to associate non-geometric information with every object in the current Second Life environment. The modeller agent also effects the external model as changes are made in the model in Second Life.

4.2.1.2 Relationships Agent

The relationships agent allows the designers to create and view the associations between different objects. Currently, the relationships which are supported are: *correspondsTo*, *decomposes* and *bounds*. The correspondsTo relationship allows the association of objects in different discipline models so as to say that they are the same object but may have different non-geometric and non-physical properties. For example a wall in the architect's model may be the same as a wall in the structural engineer's model. The wall has the same shape, dimensions and materials but its function for the architect may be to provide privacy to a space whereas its function for the structural engineer may be to support a slab. The decomposes relationship provides an association between a complex object and its components. This may also exist between objects in different disciplines. For example, a single wall object in the structural engineer's model may be associated with three walls (one above each other) in the architect's model. The bounds relationship provides for bounding associations between objects. For example, in the early conceptual design stages, an architect may only create spatial objects, whereas a structural engineer may create wall and slab objects. The relationship between the structural engineer's objects and the architect's object will be through a bounds relationship, e.g. Wall1(engineer object) bounds Space1(architect object).

A relationship is created by selecting a relationship type and then selecting two objects in the relevant models. Figure 4 shows the DesignWorld interface for creating relationships. On the left is the second Life window showing a wall in the engineer's model. On the right is the Web browser window showing the creation of a bounds relationship between that wall and a space object in the architect's model.

4.2.1.3 Discipline View Agent

The discipline view agent creates and displays the views of an object in Second Life as relevant to a particular discipline. A user may request a particular view in the web browser and the agent builds the view according to the objects belonging to that discipline. The

discipline view agent retrieves relevant information from the external model.

4.2.1.4 Object Property View Agent

This agent allows designers to view those non-geometric properties of objects which are not visible in the Second Life interface. These properties, stored in the external model, are displayed in the Web browser. At present, the non-geometric properties that can be attached are the discipline to which the object belongs and the relationships associated with that object. These properties are attached by DesignWorld. At present, properties are not imported from the IFC model but this is envisaged for the future.

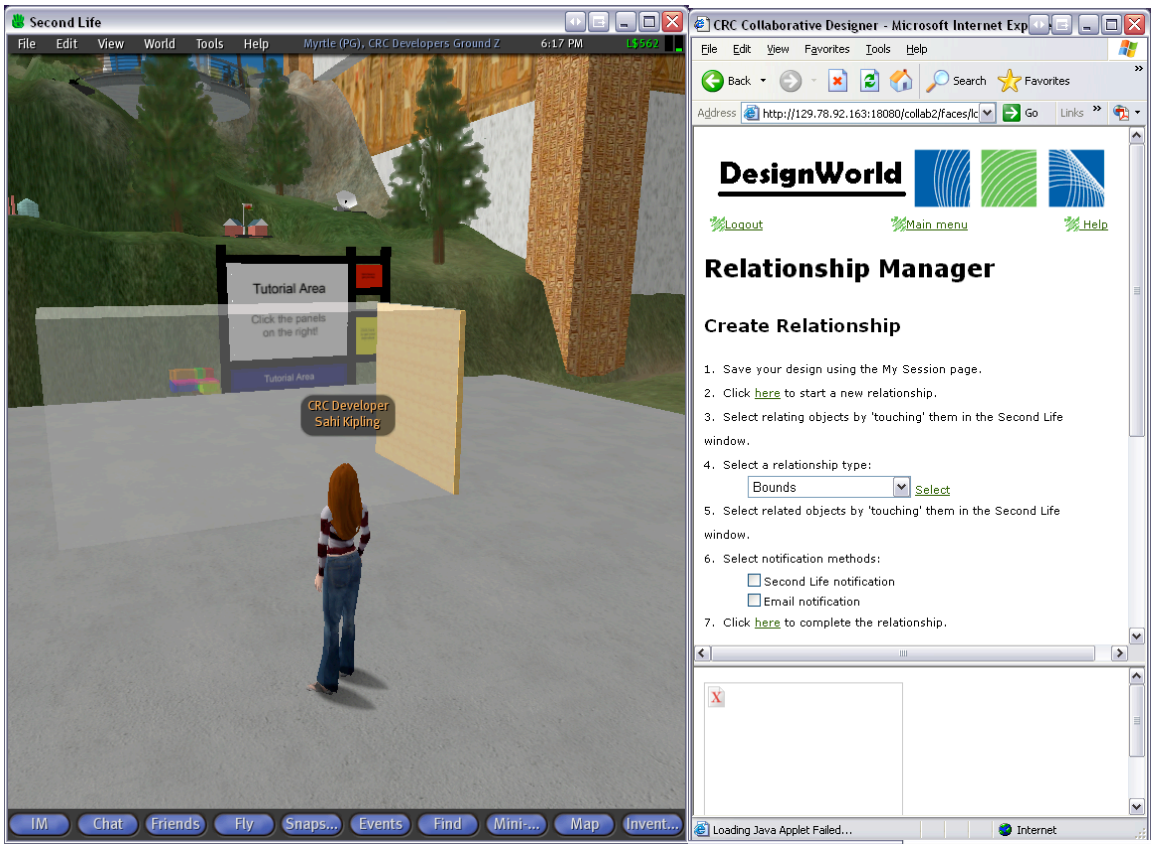

Figure 4. The Relationships Manager

4.2.2 Communication Tools

Typically, avatars communicate in 3D virtual worlds using chat. This becomes inadequate in designs situations where there is a need to convey complex ideas while manipulating objects in the design. DesignWorld offers video and audio transmission facilities to support communication during design.

4.2.3 Sketching

While designers can collaborate on the 3D model of the design in the virtual world, many design ideas cannot be expressed in a 3D model. DesignWorld provides a sketching tool that allows designers to share their design ideas before committing them to a change in the 3D model. This part of the environment uses the Groupboard (www.groupboard.com) sketching tool. This tool enables designers to draw on a blank page, or over a snapshot of the site or current 3D model.

4.3 The External Model

The external model is an SQL database which stores the information regarding the models and relationships in an SQL database. At present it allows for the extension of the geometric properties of objects created in Second Life to accommodate non-geometric properties. In the future, the external model will provide a filter to DesignWorld from the IFC model created from CAD systems. It will simplify the information in the IFC model so as to be more useful to DesignWorld. Additionally, it will allow the transfer of information derived from the creation or modification of objects in DesignWorld to be stored and transferred to the IFC model and hence back to the various designers' CAD models.

5.0 COLLABORATIVE DESIGNING IN DESIGNWORLD

A designer is assigned a membership in a discipline group, e.g. architect, structural engineer, etc. Any objects constructed by that designer are assigned to that discipline group. Any designer can view any model through the view facility or a combination of views by making models transparent or not. However, designers can only modify objects that they own. A designer can invoke the relationship facility and create, modify or delete relationships by selecting the type of relationship and the objects related. These objects may be in the same discipline model or in a different discipline model. When designers want to make a modification to an object, they will be notified of any existing relation to other objects. They can discuss the ramifications of such modifications with the appropriate discipline designer.

6.0 BENEFITS OF DESIGNWORLD TO INDUSTRY

In the AEC industry, most major projects involve design teams who have come together for that project and need to collaborate to arrive at a design solution. The members of the team are, in many cases, in disparate locations spread over the world. At present, collaboration is carried out through infrequent face-to-face meetings which are expensive and time-consuming or video-conferencing which only allows partial sharing of design information. It is not currently possible to share large CAD files in real time. DesignWorld allows participants in the design of a project to successfully collaborate towards a conceptual design. DesignWorld takes into account the needs of all participants, clients, architects, consultants and contractors, through its ability to allow the modelling of multiple views of a design object. The lack of a multiviews modelling capability has been an impediment to the ability of the various disciplines involved to work on their part yet work together in a collaborative mode. By providing an immersive collaborative environment responsive to the participants need, it allows participants distributed over distant locations to synchronously communicate and collaborate on a design project. DesignWorld provides the necessary tools for such industry collaboration, 2D sketching and 3D modelling, the ability to visualise in real-time 3D and video and audio communication in addition to text

communication. It is envisaged that once industry familiarises itself with the concepts and the technology, it will find that DesignWorld provides an appropriate environment for multidisciplinary design collaboration.

7.0 SUMMARY

This paper presents DesignWorld, a prototype system for enabling multidisciplinary, distributed collaboration. DesignWorld consists of a 3D virtual world augmented with a number of web-based communication and design tools for the creation of different discipline views as well as the necessary relationships between these views to provide and maintain consistency. Unlike previous approaches, DesignWorld, uses agent technology to maintain different views of a single multidisciplinary project. It addresses the issues of multiple representations of objects, versioning, ownership and relationships between objects from different disciplines.

Future work will extend the capabilities of DesignWorld to receive information from, and place information in, IFC models generated from a discipline's CAD modelling activity.

REFERENCES

Bucciarelli, L. L. 2003. Designing and learning: a disjunction in contexts. *Design Studies*, 24(3):295-311.

Conti, G., Ucelli, G., and De Amicis, R. 2003. JCAD-VR – a multi-user virtual reality design system for conceptual design, in *TOPICS. Reports of the INI-GraphicsNet*, 15:7-9.

IAI, 2000. Industry Foundation Classes-Release 2x, IFC Technical Guide. http://www.iai-international.org/iai_international/Technical_Documents/documentation/IFC_2x_Technical_Guide.pdf

Krishnamurthy, K. and Law, K. H. 1997. A data management model for collaborative design in a CAD environment. *Engineering with Computers*, 13(2):65-86.

Lee, K., Chin, S. and Kim, J. 2003. A core system for design information management using Industry Foundation Classes, *Computer-Aided Civil and Infrastructure Engineering*, 18:286-298.

Maher, M.-L. and Gero, J.S., 2002. Agent models of 3D virtual worlds, *ACADIA 2002: Thresholds*. California State Polytechnic University,, Pamona, pp. 127-138.

Naja, H. (1999). Multiview databases for building modelling. *Automation in Construction*, 8:567-579.

Nederveen, S.V. 1993. View integration in building design. *Management of Information Technology for Construction*. Mathur, K.S., Betts, M.P. and Tham, K.W. eds. Singapore:World Scientific. 209-221.

Pierra, G. 1993. A multiple perspective object oriented model for engineering design. *New Advances in Computer Aided Design & Computer Graphics*, Zhang, X. ed. Beijing: International Academic Publishers, 368-373.

Rosenman, M. and Gero, J.S., 1996. Modelling multiple views of design objects in a collaborative CAD environment. *CAD Special Issue on AI in Design*, 28((3)): 207-216.

Rosenman, M. A., Smith, G., Ding, L., Marchant, D. and Maher, M. L., 2005. Multidisciplinary design in virtual worlds, in *Computer Aided Architectural Design Futures 2005*, B. Martens and A. Brown (eds), Springer, Dordrecht, Netherlands, pp.433-442.

Savioja, L., Mantere, M., Olli, I, Ayravainen, S. Grohn, M and Iso-Aho, J. 2003. Utilizing virtual environments in construction projects, ITCon, **8**:85-99, http://www.itcon.org/cgi-bin/papers/Show?2003_7;

Wong, A. and Sriram, D. 1993) SHARED An information model for cooperative product development. *Research in Engineering Design*. 5:21-39.