Semantic-Based Virtual Design Environments for Architecture

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Abstract: 3D Virtual Environments (VEs) have the potential to reach beyond the limitations of CAD systems and can be utilised as design tools for architecture. This paper introduces a framework of semantic-based Virtual Design Environment(VDE) that aims to provides designers of VEs with virtual observers of designers' actions (intelligent design agents and collaborative assistant agent) to investigate the current design and respond to these actions when the need arises. The paper presents the development of a representation structure of building-objects and their relationships to be used in constructing building designs in the 3D VDE and outlines sets of design semantics to be incorporated within the VDE.

1. Introduction

The ability to design interactively, test the consequences of actions and to explore different ways of solution refinement is crucial in design and architecture. A design medium that provides such capabilities would benefit the experienced designers and strengthen the novice designer's ability to gain depth in designing. 3D Virtual Environments (VEs) are currently used as visualisation tools for communicating design ideas and teaching tools for design education. However, VEs have the potential to reach beyond the limitations of CAD systems and can be utilised as design tools for architecture (Beckmann, 1998).

The computational value for efficiency, visualisation and communication are evident in many advanced CAD systems in which 3D models can be generated, rendered and animated. 3D Virtual Environments in design domains have been able to mimic the spatial configuration of physical worlds, changing the role of CAD systems, partly, from being drafting tools to producing the building blocks of these new environments (Maher et al, 1999). Virtual Environments provide powerful communication and navigation environments within which users and designers interact either in asynchronous or synchronous mode within centralised or distributed environments or share their designs, knowledge and experiences. VEs allow designers to visually walk through, inspect and present the designs in immersive 3D environments at the proper size and scale.

Attributes of a multi-user Virtual Environment software platform, e.g. Activeworlds, include community access, client access and control, and scope for feedback in addition to participation. A multi-user platform also provides "traditional", familiar collaborative Internet technologies, e.g. file and document sharing (Sherman and Craig 2003). Augmenting, evaluating and studying virtual environments and evolving communities gives rise to a collaborative memory space, of benefit to every user adding to and participating in it (Schnabel and Kvan 2001).

Applications of Virtual Environments in design and architecture include the Conceptual Design Space CDS (Bowman, 1996). CDS is a real-time, interactive virtual environment application which attempts to address the issue of 3D design in general and immersive design in particular. Users of CDS can create simple conceptual building designs in an interactive, intuitive manner, simply by choosing vertices on the ground, then adding the third dimension by specifying a height for each vertex. The walls and ceiling are created automatically by CDS. Once the basic structure is in place, users may experiment with different colours, textures, add furniture to the interior of the space, or change the roof line, for example. Within CDS users will not only be able to inspect and inhabit their buildings, but will also have the ability to modify them, add details, or create new designs, all while immersed in the VE.

The paper introduces a semantic-based Virtual Design Environment (VDE), that is distinguished from existing Virtual Design Studios, such as ETH (Engeli, 2001), COVEN (COVEN), MASSIVE (Greenhalgh 1995), DIVE (Frécon et al. 1991), by providing a new dimension to the use of the 3D Virtual Environments – i.e. to provide an intelligent, interactive and creative medium for designing. COVEN and MASSIVE projects are two systems aimed at improving rich group support and spatial modelling. They are not, however, primarily concerned with real-time (synchronous) multi-user representation of information and dynamic models. The environment offers document sharing and multiple interpretations of designs but does not enable collaborative designing on a single shared model in real time. The DIVE platform focuses on developing support of standardised tools and multi-user applications for networked participation. Collaborative Virtual Environments (CVEs) of the nature of COVEN support a wide range of disciplines, e.g. design, visualisation, simulation, training, education and entertainment. The DIVE technology provides the platform on which the MASSIVE networked virtual environment technologies operate. MASSIVE is essentially a teleconferencing system. The collaboration in these environments occurs primarily between human-human users, rather than between humans and agent-filtered knowledge. The intention of the DIVE and COVEN platforms is extensive visualisation but the systems are seemingly more concerned with delivery than designing and collaborative processes themselves. Furthermore, these systems offer no intelligence at a system level. Most importantly, these systems demonstrate an evolved protocol for online 3D environments but neither offer agent-advice nor semantics arising from multiple sources (Reffat and Beilharz, 2003).

Hitherto VEs for architecture are lacking appropriate tools for 3D design. One would expect such VEs for architectural design to have knowledge about the designed entities. Navigating and manipulating in 3D requires not only 3D geometrical primitives, but also a set of 3D design tools. The focus of the semantic-based agents in a Virtual Environment is constructive informational and design-shaping feedback. The semantic-based framework proposed in this paper is distinguished by delivering intelligent response and feedback to the designer during the initial design phase as well as at evaluation stages of designing.

2. A conceptual framework of semantic-based virtual design environments

The significance of the proposed semantic-based approach to virtual design environment is that aims to provide users and designers of virtual environments with virtual observers of designers' actions (intelligent design agents and collaborative assistant agent) to investigate the current design and respond to these actions when the need arises. The response of intelligent design agents and collaborative assistant agent is dependent on the set of relationships between building elements (e.g. rooms and spaces) on a semantically high level. If such relationships of building elements can be formalised then the behaviour of VEs will be more natural. Natural behaviour in this context means that the VDE responds to the designer's expectations. Moreover, the set of relationships should be accessible using a vocabulary that is close to the designers' natural language.

This research provides the potential to develop an intelligent and interactive VDE for architectural design through providing an interactive counterpart (virtual observers) to the designer and offering useful assistance in designing by supporting behaviour and semantic-based concepts within VEs (Reffat and Beilharz, 2003). The semantic-based VDE allows the designer to inspect design ideas and to discover new solutions to a design problem via related design concepts provided by intelligent design agents and triggered by designer's actions. Such capabilities would benefit the experienced designers and strengthen the novice designer's ability to gain depth in designing. Also the semantic-based VDE provides a platform for inspiration and creativity through providing various design moves by the collaborative assistant agent.

The semantic-based Virtual designing environment is particularly important to support the designer not only with potentials for collaboration and information sharing (common to existing 3D VEs) but also to facilitate semantic-based support to the designer during the designing process. This design support is based learned design semantics and design concepts while being involved in designing. The proposed semantic-based VDE has the potential to provide opportunities for community feedback and contribution to the design outcomes in real-time. Two main attributes of the proposed VDE are its ability to provide useful design knowledge that may aid and support the designer in real-time and the capacity to combine influences from human sources and formalise an appropriate conception to the designer based on this. Other systems do not perform this role of an intelligent conduit between multiple human opinion and information sources and do not offer instructive, constructive design suggestions

The conceptual framework of developing a semantic-based virtual design environment to support e-designing in architecture incorporates an integration of the following:

- Develop a representation structure of building-objects and their relationships to be used in constructing building designs in the 3D virtual environment.
- Develop a formalisation of design semantics of buildings (housing) including functional, spatial, esthetical, environmental and contextual design knowledge to form an initial knowledge base of intelligent design agents.
- Develop intelligent behaviour and semantic-based design agents within the VDE to: (a) track designers actions in the VDE and construct an internal model of the current design situation to provide relevant design knowledge; (b) learn from designers actions, client and community responses and update the knowledge base of design semantics; and (c) find patterns of design semantics' relationships and classify sets of concepts to enrich the agents response to changes in the virtual design environment.
- Develop a real-time collaborative assistant agent that provides innovate design moves to enrich the process of design exploration through intelligent collaboration.

This paper focuses on the first two elements of the proposed framework as presented in the following sections.

3. Development of a representation structure of building-objects and their relationships within the VDE

In architectural design, architects are accustomed to investigating objects, spaces in their designs whereby objects play a dynamic role in building design. Current virtual environments such as Activeworlds provides users with the ability to build their own 3D structures using objects that are available in the Active Worlds objects library or imported from CAD systems to augment the existing library. Building new objects with Activeworlds Browser is a three-step process. First users need to find some existing object to copy, or clone; that is the only way you can create a new object. This will be the starter object. Then, the object can be moved to the desired location. This object can be turned into an entirely different object by changing its object field in the object Properties. Finally, the new object description and action can be changed. Activeworlds provides a platform within which complex models of interior and exterior designs can be created as shown in Figure 1. Each model is constructed from a set of objects, each object acts as a class of objects where its instances can be assigned different behaviours and attributes. However, direct manipulation of building-objects is extremely limited in current 3D virtual environments and objects' relationships are not supported in most of the current virtual environments.

In the proposed a collaborative and interactive semantic-based VDE, architectural design space layouts of buildings are interactively composed by designers in the VDE using a set of building-objects rather than automatically generated by a computational system. The proposed set of 3D building-objects to be constructed in the VDE and manipulated by designers includes walls, doors, windows, floors and roofs.

The proposed set of building-objects can be defined in many ways. If the representation of building-objects is based on coordinate values representing geometric form in absolutely defined space, it is possible to ensure the existence of building-objects in the space individually. However, in case of adopting the definition of space from the field of cognitive science a theory with relatively defined space needs to be employed (Watanabe, 1994). In this research the frame-based object oriented representation

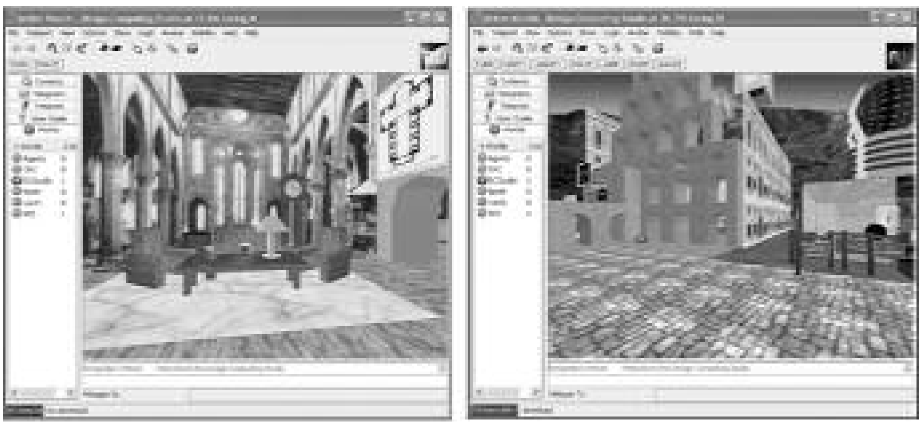

Figure1. Examples of interior and exterior designs constructed in the Design Computing Studio, hosted by the Virtual Design Studio at the Faculty of Architecture, University of Sydney, (DCS, 2002).

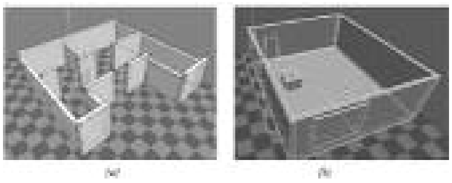

Figure 2. (a) An example of a design composition of a house using the wall as a building-object; and (b) A design composition of a room using walls, windows, doors and floor as building objects (after de Vries et al, 2000).

method (Carrara et al, 1994) has been chosen for its appropriateness and accuracy. Information in building-objects is divided over attributes (or properties) of object including relationships between objects. Objects are connected to each other through relationships as shown in Figure 2 that form assembly hierarchies between the parts of a building. A room, for example, can be considered an assembly of parts such as walls, doors, windows, roof and floor. Assembly hierarchies allow propagation of changes from objects to their dependent and related objects. For example, when a wall is relocated, so are all its parts (windows and doors), floor, roof and connected walls. This automatic propagation of changes helps to maintain the integrity of relationships between building-objects.

Designers and users express their intent on a higher level of abstraction than geometrical constraints, that is they use explicit and implicit relationships between building objects. Therefore, a useful set of design constraints at a semantically higher level using the geometrical constraints includes (de Vries et al, 2000) where Figure 3 shows some of the geometrical constraints between building object:

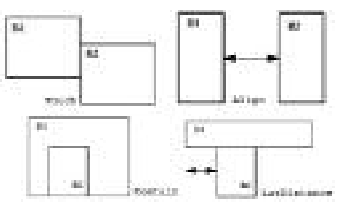

Figure 3. Some of the geometrical constraints between building subjects including Touch, Align, Contain and LatDistance (after de Vries et al, 2000).

- Building_Object_B1 adjacent to Building_Object_B2. This relation can be implemented using the Touch constraint. The axis along which the building elements must touch is determined from their current position.
- Building_Object_B1 in Building_Object_B2. This relation can be implemented using the Contain constraint.
- Building_Object_B1 above Building_Object_B2. This relation is implemented using the Touch constraint. The axis along which the building elements touch is always the Z axis.
- Building_Object_B1 aligns Building_Object_B2. This relation is implemented using the Align constraint and the LatDistance constraint. The sides of the building elements that need to be aligned must be specified respectively.

Navigating and manipulating in 3D is provided with 3D geometrical primitives representing the set of building-objects as 3D tools. In this research, geometrical relationships between building-objects will be expressed using UML (Odell, 1998) as a formal specification language. Furthermore, many functional relationships of building-objects can be expressed as geometric relationships such as the wall must bear the floor which can be expresses geometrically as bottom of the floor should coincide with top of the wall.

4. Design semantics of buildings

Different building types have fundamentally different design rules and semantics, e.g. hospitals have one set and housing have another. Within these building types, different set of semantics arises (Eastman, 1994). In this research, housing design has been chosen for its significance in the building design and construction industry. The proposed semantic-based approach to VDE includes supporting functional, spatial, esthetical, environmental and contextual semantics of building design mainly in housing design. In architectural designing, as in many other design disciplines, design composition is an important design activity wherein designers use building-objects to construct design compositions. Through design compositions designers express ideas and represent elements of design, abstract concepts and construct situations through the relationships between the parts of design compositions, e.g. rooms in a house. The high level relationships (semantics) between parts of the design compositions include functional, spatial, esthetical, environmental and contextual as shown in Figure 4.

Figure 4. Sets of design semantics to be incorporated into behaviour and semantic-based intelligent design agents within the virtual design environment.

• Functional semantics reflect the purpose of the intended design. This includes identifying the essential constraints for each part of the building and satisfying the requirements for its use. These constraints include space, size, access and direction.

• Spatial semantics include segregation (privacy), interconnections (adjacency and links) where adjacency reflects the contiguity among elements in the design composition (Reffat and Gero 2000).

• Esthetical semantics include expression, symmetry and modality (Reffat and Gero 2000). Expression indicates the impression of a feature or a defined assemblage of features within the composition such as dominance. Visual dominance reflects the effect of an element size (e.g. a room or a space) and spatial location in relation to other elements. Symmetry indicates harmony and conformity among building elements within the composition such as reflective symmetry, cyclic rotation and translational repetition. Modality includes the characteristics of how these parts in the design composition are put together such as centrality, linearity and radiality.

• Environmental semantics include lighting, acoustic, thermal and air ventilations (Reffat and Harkness, 2001). These factors are reflected on room orientation, distance from street and sources of noise, wall thickness and materials including walls and roof insulations, and window sizes.

• Contextual semantics include: council regulations within certain areas including set back, hight, driveway access; neighbourhood restrictions including privacy constraining window locations and overshadow; and architectural style including colour, materials textures and facade design features.

5. Discussion and future directions

The conceptual framework of a semantic-based virtual design environment that aims to provide designers of VEs with virtual observers of designers' actions to investigate the current design and respond to these actions when the need arises is introduced. Two elements of the framework are presented including: (a) the representation structure of building-objects and their relationships to be used in constructing building designs in the 3D VDE; and (b) sets of design semantics to be incorporated within the VDE.

These sets of semantics require a formal structure to be devised within an integrated framework in order to be incorporated into semantic-based intelligent design agents. The development of a model of multi intelligent agents within the virtual design environment (VDE) provides the basis for this VDE to be interactive design medium. Each agent can respond differently to different design situations as it constructs new concepts (Reffat 2002; Reffat, 2001). A framework of a multi-agents system will be developed to represent the various types of design semantics that might be encountered while designers are constructing their designs in the VDE. Each intelligent design agent has a predefined knowledge that represents the conditions that each design semantic ought to satisfy. However, agent's behaviour changes with use based on the way designers manipulate and integrate various objects while constructing their designs; i.e. situated design agents (Reffat, 2002). Furthermore, agents develop and modify both their behaviour and semantic knowledge with use. Hence, the initial knowledge-based of each agent is modified and refined overtime based on designers' actions within the VDE. For the proposed intelligent design agents to be useful they must have the capability to learn from the designer actions in relation to the current design situation. The approach of situated learning (Reffat 2000) will be best utilised and extended to intelligent design agents. Based on this view, the virtual design environment becomes an intelligent and interactive design medium that relates and responds to what designers do while designing.

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