ADVANCES IN IT FOR BUILDING DESIGN

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ABSTRACT

Computers have been used building design since the 1950s. Their first use was in structural analysis and construction planning. The use of computers in building design analysis has included extensive developments in structural analysis as well as programs for the analysis of the HVAC and environmental performance of buildings. Recently, more sophisticated analyses of environmental behaviour and the behaviour of building users have been developed and implemented. Computer graphics was developed initially in the 1960s and formed the basis of computer-aided drafting systems – called CAD systems. These early CAD systems were used during the documentation phase of building design. These CAD systems developed beyond simply drafting to modelling the geometry of the building. Today's commercial CAD systems are used at various stages in the building design process and are integrated with analysis tools. This paper briefly traces these developments before introducing current research on IT for building design that has the potential to impact the way buildings will be designed in the future. Three strands of research are presented. The first strand deals with virtual environments for designing and designing virual environments. In virtual environments the focus moves away from documents to models and from a virtual building model on a designer's computer that is then sent to other members of the design team to a building model in a virtual environment that is accessible by any authorised member of the design team anywhere at any time. The issue of designing within virtual environments is raised. The second strand deals with new ways of carrying out simulations of the behaviour of the building users rather than the behaviour of the building. The third strand deals with novel computational agent technologies and examines the potential of their use in building design.

KEYWORDS

CAD, building design, virtual environments, virtual models, simulations, design agents, computational agents

BACKGROUND

The invention of the computer goes back to the 1940s, however, their industrial use commenced only a decade later. The University of Sydney built and installed its first computer in 1953 for research purposes.

The possible use of computers in the building industry commenced with research into automating structural analysis through the development of the matrix method of frame analysis. Thus, by the late 1950s/early 1960s exceptionally unusual buildings (such as the Sydney Opera House) were having their structures analysed by computer. Standardised structural analysis programs appeared in the late 1960s and the early 1970s. Today the finite element method has the capacity to analyse virtually any building structure to a sufficient degree of accuracy. Further, the cost of analysis has dropped dramatically in the intervening 30 years. This cost reduction has been brought about by three factors: the reduction in the cost of computation, the reduction in the cost of describing the structure and the reduction in the cost of presenting the results in a coherent graphical form. The effect of this increase in ability to analyse building structures and the reduction in the cost of analysis has been to allow designers to explore a much wider range of structural forms and shapes than would have been feasible earlier.

Figure 1 shows an example of the complex three-dimensional shapes that can be readily analysed today.

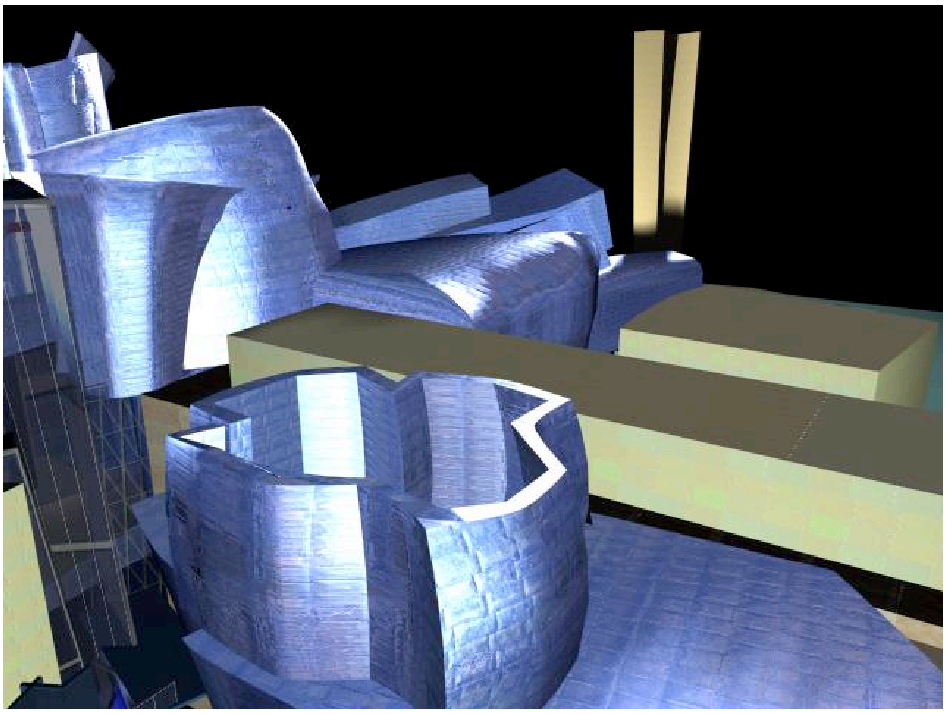

Figure 1: The Guggenheim Museum in Bilbao, Spain, designed by Frank Gehry
(model by David Ju, University of Sydney)

Following on from the developments in structural analysis were the developments in environmental analysis of buildings. These commenced with energy analysis and expanded to include a variety of other environmental factors as well as the influence of building services on the environmental performance of buildings. Today with computational fluid dynamics it is possible to model of environmental behaviour including smoke spread and fire spread in buildings.

The development by the US Navy of the PERT (Program Evaluation and Review Technique) and the later development of the CPM (Critical Path Method) based on the mathematical technique of dynamic programming provided a formalisable means construction project management that was readily computable. As a consequence this was also amongst the early applications of computers in the building industry.

In 1963 Ivan Sutherland submitted his PhD thesis titled *Sketchpad: A Man-machine Graphical*

Communications System to MIT and in it he invented interactive computer graphics. *Sketchpad* (Sutherland 1963) pioneered the concepts of interactive graphical computing, including memory structures to store objects, rubber-banding of lines, the ability to zoom in and out on the display, and the ability to make perfect lines, corners, and joints. This was the first GUI (Graphical User Interface) long before the term was coined. It also had parameterised objects. Figure 2 shows Sutherland using the system.

Figure 2: Ivan Sutherland with the *Sketchpad* system at MIT in 1963

The concepts in *Sketchpad* laid the foundation for computer-aided drafting systems for years to come. These concepts along with research on object modelling continues to provide the bases of current commercial CAD systems. More recently commercial CAD systems have begun to implement object-oriented technology that allows users a greater flexibility in their use. Most current CAD systems are world-wide web enabled, meaning that users can access them across the web.

VIRTUAL ENVIRONMENTS FOR DESIGNING

Virtual environments are computational representations of objects and spaces in "cyberspace". They fall into two distinct classes. In the first are virtual environments that are CAD models generated using the standard CAD packages. Here the focus is entirely on the CAD model that happens to be accessed in a virtual space. There are advantages in placing CAD models into virtual environments since this allows designers to collaborate asynchronously, without being co-located. One of the issues in this approach is the size of files that need to be transferred from one designer to another is generally increasingly large. This has performance effects.

The second approach is to design within a virtual environment where the model of the building is developed as it is being designed. It can then be converted into a CAD model. The advantage of this approach is the ease with which members of the design team can gain access to the design and the means by which they can communicate with each other. In general the technology that supports this is different, often having come from the distributed computer games world, and as a consequence the files that are moved around are very small and hence performance is high. Each member of the design team can be connected to the same virtual environment at the same time and can have a different view of it than any other member of the team (Maher and Gu 2001).

Figure 3 show a virtual design environment made up of objects. The virtual environment is being used by a number of designers concurrently, designers who both design within it and communicate with each other in it.

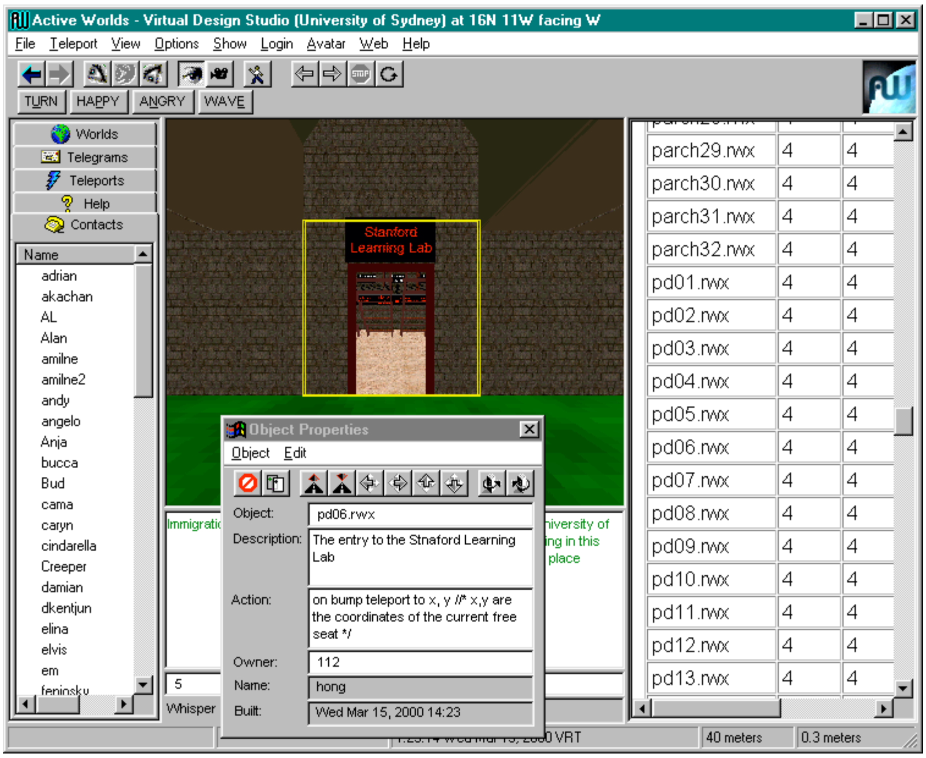

Figure 3: A virtual design environment showing objects whose information can be directly accessed

Virtual design environments offer functionality beyond CAD modelling in that all documents are treated as objects as well. So an office with all its attendant data and information content can become part of the environment (Maher and Gu 2001). Figure 4 shows a virtual environment where the office and design information is part of the environment. This opens up a variety of novel collaboration opportunities. Virtual design teams, within the overall team, can form and carry out sub-designs. Further each of the different design disciplines (architect, structural engineer, façade engineer, etc) can work on the current version of the design.

SIMULATING THE BEHAVIOUR OF BUILDING USERS

The user of buildings has been notoriously absent from most simulations of the behaviour of buildings. The behaviour of the building has been assumed to be largely independent of the users. In recent research into simulations of groups of animals Reynolds (1987) demonstrated that realistic results could be produced using simple computational agents. The "social force model" that is the result is a model of pedestrian behaviour, similar to animal flocking, used to model self-organising phenomena in crowds (Helbing and Molnár, 1995). Computer simulations have shown that the social force model is capable of realistically describing several interesting aspects of collective pedestrian behaviours (Helbing and Molnár, 1997).

A simple crowd management problem is used to illustrate the behaviour pedestrians. The problem is to design a doorway to facilitate the efficient and comfortable movement of pedestrians travelling in opposite

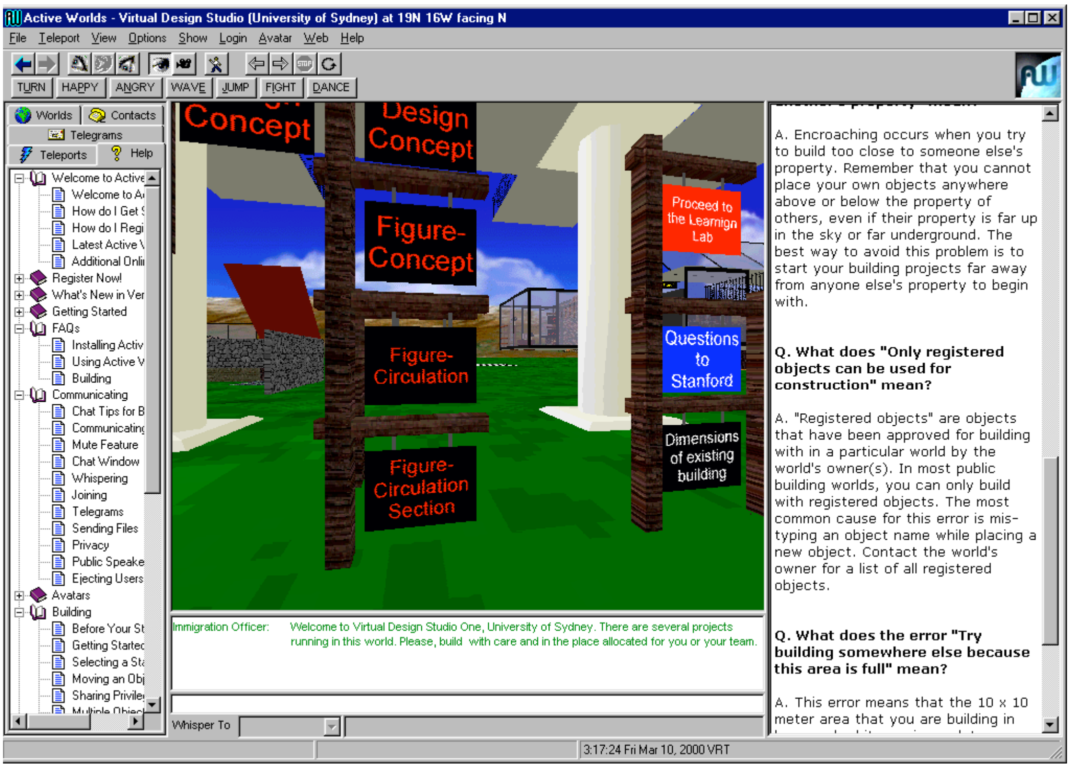

Figure 4: A virtual environment where both the design and the information about the design office are part of a single environment

directions. A pedestrian simulator was developed to evaluate doorway designs. Pedestrian movement is simulated using a microscopic model of crowd behaviour developed to account for empirically observed self-organizing phenomena. The social forces modelled in the simulations of pedestrian crowds are listed in TABL, detailed mathematical descriptions of these forces can be found in Helbing and Molnár (1995).

TABLE 1

THE SOCIAL FORCES MODELLED IN THE SIMULATIONS OF PEDESTRIAN CROWDS

	Description of social force
1.	Pedestrians are motivated to move as efficiently as possible to a destination.
2.	Pedestrians wish to maintain a comfortable distance from other pedestrians.
3.	Pedestrians wish to maintain a comfortable distance from obstacles like walls.
4.	Pedestrians may be attracted to other pedestrians (e.g. family) or objects (e.g. posters).

This model is used to simulate the behaviour of pedestrians using three different designs for the doors. The three designs are: narrow door, wide door and two separated doors. The behaviour of the pedestrians using a narrow door can be seen in Figure 5, where pedestrians moving in opposite direction block each other's paths.

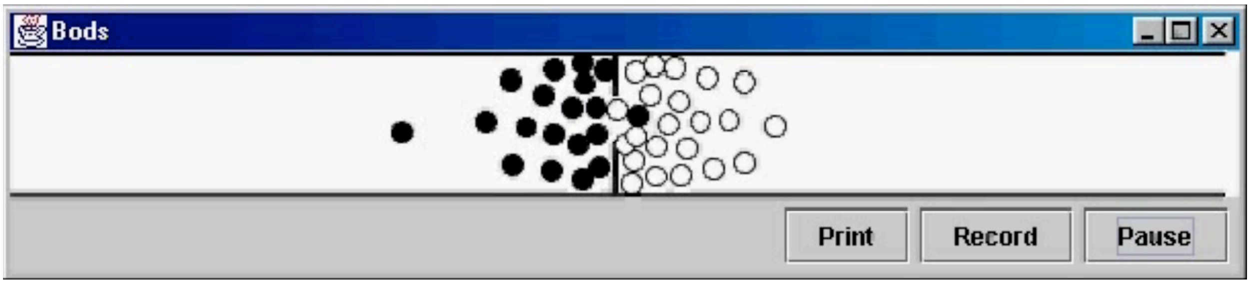

Figure 5: Simulating the behaviour of pedestrians using a narrow door (Saunders and Gero 2001)

Figure 6 shows the same pedestrians using a wide door. Here the pedestrians generate a behaviour that produces two passing streams, indicating that the size of the door is satisfactory.

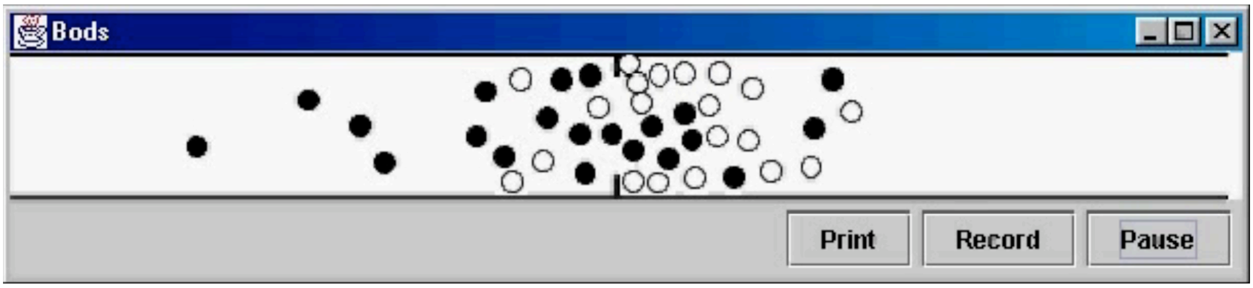

Figure 6: Simulating the behaviour of pedestrians using a wide door (Saunders and Gero 2001)

Figure 7 shows the same pedestrians using two separated doors. Here the pedestrians form two streams, one for each door. These streams are not programmed inot the system but emerge from the behaviour of each individual.

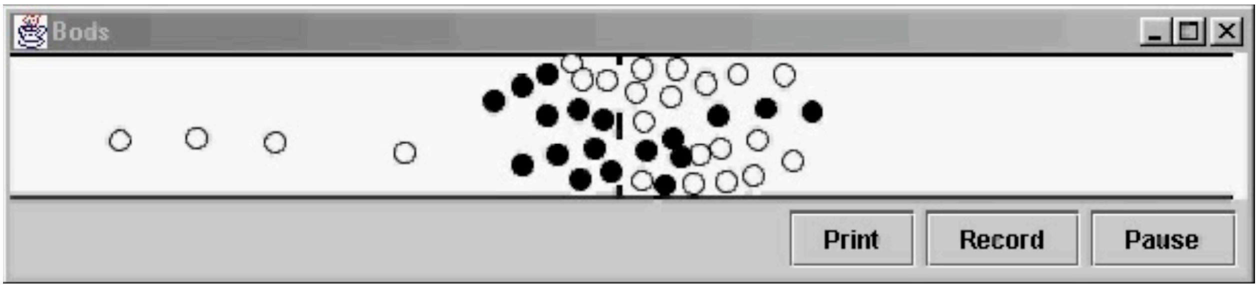

Figure 7: Simulating the behaviour of pedestrians using two doors (Saunders and Gero 2001)

DESIGNING WITH COMPUTATIONAL AGENTS

Computational agents are computer programs that are designed to exhibit a degree of autonomy and as a consequence are able to influence and change the environment within which they sit. Already many people who use the world-wide web unwittingly make use of agents during their web searches. Designing with computational agents is at the cutting edge of current design computing research. There are proposals to develop agent-based design systems (Maher and Gero 2002). These use a multi-agent system as the core of a 3D multi-user virtual world. Each object in the world is an agent in a multi-agent system. The agent model provides a common vocabulary for describing, representing, and implementing agent knowledge and communication. The agent can sense its own environment and can generate or modify the spatial infrastructure needed for a specific collaborative or communication need of the users of the world. Each agent has five kinds of reasoning: sensation, perception, conception, hypothesizer, and action (Gero and Fujii 2000). This agent approach is derived from recent developments in cognitively-based design agents, where design is considered as a situated act (Gero 1998). The agents are developed to interact with the design and the design knowledge (Smith and Gero 2001; Saunders and Gero 2001). The agent approach to virtual worlds provides for new kinds of interaction among the elements of the virtual world representation and between individuals and project teams with the components of the virtual world that makes both the virtual environment and interactions with it dynamic.

Agents can function in three modes based on their internal processes: reflexive, reactive, and reflective (Maher and Gero 2002). Each mode requires increasingly sophisticated reasoning, where reflexive is the simplest.

Reflexive mode: here the agent responds to sense data from the environment with a preprogrammed response – a reflex without any reasoning. In this mode the agent behaves as if it embodies no intelligence. Only preprogrammed inputs can be responded to directly. Actions are a direct consequence of sense data. This mode is equivalent to the kinds of behaviors that are available in current virtual worlds.

Reactive mode: here the agent exhibits the capacity to carry out reasoning that involves both the sense data, the perception processes that manipulate and operate on that sense data and knowledge about processes. In this mode the agent behaves as if it embodies a limited form of intelligence. Such agent behavior manifests itself as reasoning carried out within a fixed set of goals. It allows an agent to change the world to work towards achieving those goals once a change in the world is sensed. Actions are a consequence not only of sense data but also how that data is perceived by the agent. The agent's perception will vary as a consequence of its experience.

Reflective mode: here the agent partially controls its sensors to determine its sense data depending on its current goals and beliefs. The agent also partially controls its perception processes depending on its current goals and beliefs and its concepts may change as a consequence of its experiences. The concepts it has form the basis of its capacity to "reflect", ie not simply to react but to hypothesize possible desired external states and propose alternate actions that will achieve those desired states through its effectors. The reflective mode allows an agent to re-orient the direction of interest by using different goals at different times in different situations (Gero and Kannengiesser 2002).

We can expect such systems to change the way we design and potentially what we design.

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