A Virtual Reality Design Environment with Intelligent Objects and Autonomous Agents

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1. ABSTRACT

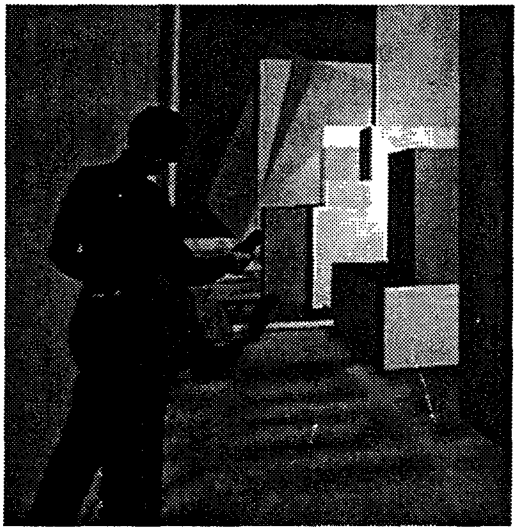
New technological achievements and research results allow for the creation of innovative design tools for architects, that do not originate from paper-based paradigms but instead make optimised use of the present technology and programming concepts. The core of our system is comprised of an intuitive interactive modelling tool. It runs in a virtual reality set-up, where the user can use 3D glasses to experience rooms and 3D input devices to model in three dimensions. The interface is free from widget-like buttons or menus, so that the user is undisturbed when moving into the virtual world of the design. The system can also run in a distributed fashion, so that a number of users can look at and modify the same design. The 3D model can be generated in a sketch-like fashion using solids and voids, void modelling turns out to be very valuable for architectural design. The objects in this system can contain forms of intelligence to produce such behaviour as: falling because of gravity, collision avoidance, and autonomous motion. Interactive behaviour can also be assigned to the objects. Autonomous Agents are added to the system to enhance the designer support. These are agents that enhance the virtual environment, agents that take over tasks, and agents that help to test the design. The system shows new interface and interaction approaches that support the architectural design process intelligently.

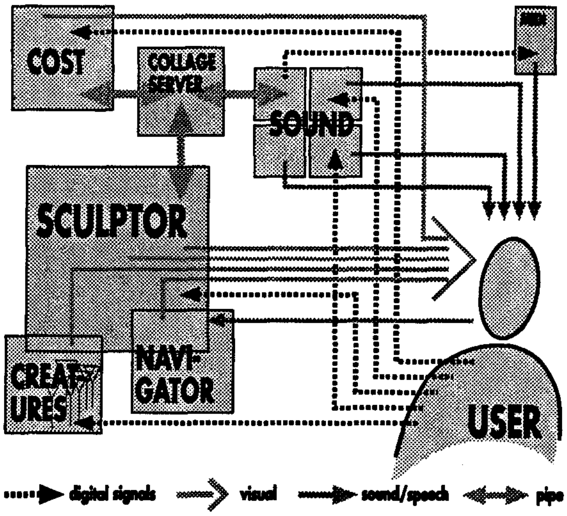
2. INTRODUCTION - VISION OF A NEW DESIGN ENVIRONMENT

The motivation for our work is to invent a design environment for architects, based on the most recent hard- and software developments. These are mainly Virtual Reality (VR) interaction tools, fast graphics libraries, and new approaches in Artificial Intelligence (AI). The work is further guided by research on human computer interaction as well as the architectural design process. The goal is to find a new approach which improves upon the design process and therefore the quality of the design result.

The visionary design studio is embedded in a VR environment. In addition to viewing plan views and model views in different scales, the architect has the ability to virtually enter the design and experience the spaces that are created. Thus the architect can experience the building from inside and outside (Figure 1), in many scales, and in different kinds of simulations. The visual representation can be enhanced by simulating different lighting situations and adding sounds and sound effects. Using these techniques, more of the designers' perceptive senses become involved, leading to a higher commitment and also an easier concentration on the task (Engeli, Kurmann, Schmitt 1995). The interaction happens only through 3D interaction devices and spoken commands, thereby replacing the typing on a keyboard and clicking with a mouse. Designing can be done in an intuitive fashion, the interface is seamless. The graphical representation is fast and responsive, every change in the design happens dynamically and therefore augments the immediacy of the project as well as the process to the designer (Schmitt 1995). The environment assists the designer intelligently, and helps to find new design solutions.

Figure 1: **A user entering the virtual building.**
Figure 2: **The connections between user, modelling tool and agents.**





In the current state of the project, the described properties are implemented in prototypical ways. The core of the design environment is comprised of the 3D-modelling tool "Sculptor" (Kurmann 1995), that allows intuitive and interactive modification of intelligent objects. The designer can interact directly with Sculptor or employ different kinds of agents for further help. Figure 2 shows the various parts of the environment and the channels for interaction.

3. SCULPTOR - INTELLIGENT OBJECTS

The modelling tool "Sculptor", was developed over the past three years under several research contracts. It is an experimental computer tool, that has enabled us to integrate direct specification and manipulation of intelligent objects and scenes in 3D. Not any one single feature in Sculptor, but a judicious combination of many separate features, makes it possible to generate and explore 3D models in a very fluid and visually engaging way. The next sections describe some features, that make Sculptor a unique and supportive tool for designing.

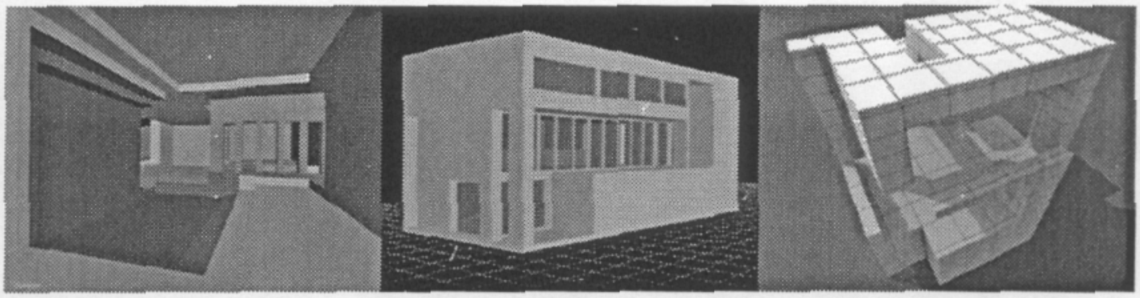
3.1. Interface and Interaction

3.1.1. Widget-less Interface and Sketch-like Modelling

Sculptor's interface is almost widget-less. It is very important that the view is undisturbed, while one looks at a virtual building. Therefore menus and buttons have to be avoided. In Sculptor there is one pop-up menu, which can be shown during the course of designing, but is not needed during navigation.

Sculptor is very well suited for the conceptual phase of object and architectural design. It allows a sketch-like approach. The designer can create and modify objects without having to specify exact dimensions or co-ordinates. Moving and scaling of objects happens interactively and in real time, every change in the design becomes a dynamically shown action.

Figure 3: **Modelling with Solids and Voids: Fictitious interior (left), a residence by Snozzi (center), grid overlay as modelling support (right).**



3.1.2. Solid and Void Objects

In addition to the possibility to model with massive, closed objects or solids, Sculptor offers the opportunity to model with spatial elements, also called voids or negative volumes. Negative volumes, that create a space when intersected with a solid object, can be manipulated and moved in the same manner as solids, because they are based on the same data structures. Modelling with negative volumes in Sculptor differs from solid modelling in that a negative volume always creates a space; two negative volumes do not add to a positive object. We made this decision after observing that designers and sculptors always handle negative volumes as material that has been removed and the idea that voids could add to solid material again does not fit their scheme of thinking .

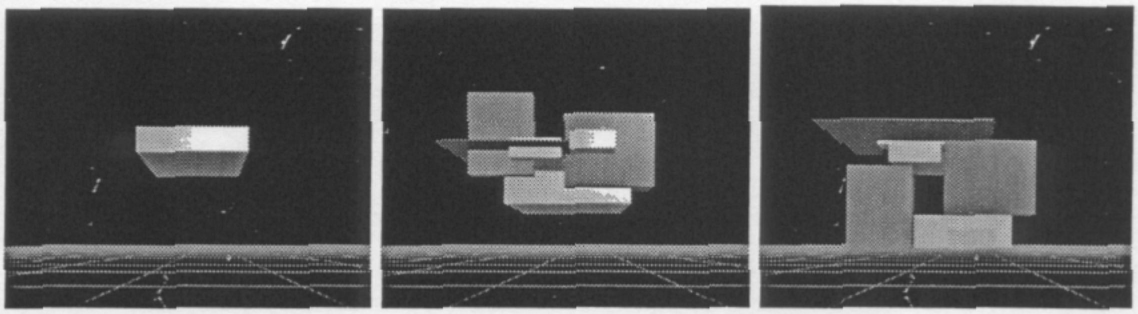
The importance of a simple and direct composition of spaces for architecture is supported by the interactive and real time intersection of positive and negative volumes. This results in a freedom of modelling which has not been achieved so far. The operations on room and space are fundamental in architecture and their introduction to Sculptor greatly enhances the usefulness of the tool for architects. Spaces as modelling entities also have the advantage that a single additional attribute, that describes the purpose of the room, can be used to place valuable information about a building into 3D models. This information can later be further interpreted by intelligent procedures.

3.2. Behaviour of Objects

3.2.1. Reactive Behaviour

Gravity simulation is considered one of the most interesting features of Sculptor. It can be applied to any object or any group of objects. It signifies a departure from traditional modelling techniques in that objects can now fall down on a reference plane or on other objects. Also collision avoidance can be added as a property, so that an object will refuse to intersect with others. These reactive behaviours give intuitive feedback while modelling, and enhance the feeling of modifying objects in a real, physical design. These features also help to position objects correctly in the three-dimensional space and replace the snap modes used in traditional CAD programs.

Figure 4: **Design in the Sculptor environment: An object (left), its decompositions (center), gravity and collision applied (right). Sculptor's user interface is intentionally simple and not based on graphical interface elements.**



3.2.2. Autonomous Behaviour

An interesting type of behaviour that was added to the design objects is autonomous motion and transformation. To every object, a certain kind, intensity and speed of motion can be attached, so that these objects change over time. The designer observes this autonomous movement and can stop it at any point she likes it most. Therefore we denoted this expansion of the architectural design process through autonomous behaviour the 'I like it' principle. This should not replace the designers own creativity, rather push it to a very intense level. Instead of spending much effort on generating different design solutions, the important work of the designer shifts more towards recognising and selecting from dynamically presented possibilities and then reason about the decision that was made. This is paralleled by a design strategy formulated by Bill Mitchell: "Designers frequently recognise emergent subshapes and subsequently structure their understanding of the design and their reasoning about it in terms of emergent entities and relationships." (Mitchell 1989)

3.2.3. Interactive Behaviour

An extension of the autonomous behaviour is the ability to attach artificial life behaviour to the objects (Levy 1992). This requires additional interaction and communication capabilities between the objects. In addition to gravity, collision avoidance and autonomous motion, three kinds of interactive behaviours can be attached to an object: producing, attracting, and destroying. A producing object creates new objects within a certain time interval. These objects will move around autonomously and eventually towards objects that have the attracting behaviour attached. A destroying object deletes other objects if these come close. Peter Eisenman has formulated the consequences of such an approach as follows: "It will take various formal organisations depending on its own internal movement and growth. If there was the capacity in architecture to begin from such kind of modelling we would begin to have a kind of new architecture, an architecture that was no longer phallocentric. Now that does not mean that we could not be sheltering and containing, rather the containing would be seen as the residue of the process. In other words, the process image and its analogous meaning would come from the self-generating activity as opposed to the enclosing activity. In this sense nobody is saying that architecture would not shelter, enclose, contain, etc. but it will not necessarily make metaphors of these organisations." (Eisenman, 1994).

3.3. Computer Supported Collaborative Design

Sculptor can also be used in a distributed fashion. This allows for the possibility of Computer Supported Collaborative Design (CSCW) (Dave 1995). Several users on locally distributed computers can modify the same 3D-model. To avoid conflicts 'the pen' was introduced. The designer that momentarily holds 'the pen' is allowed to make changes, while the others can observe the transformation of the design from their individual points of view. This functionality is also required when multiple software agents interact with Sculptor. If one of these agents needs a lot of computing power, a distribution of computation is necessary to have a satisfactory performance of the system.

Another aspect of CSCW is supported by the ability to export Sculptor models into Virtual Reality Modelling Language (VRML) models, so that these can be accessed over the World Wide Web.

4. AUTONOMOUS AGENTS

Autonomous agents are added to the environment to enhance the support of the user by solving specified tasks. Agents in our definition contain knowledge, are designed to work on a specific task, can work autonomously, act on behalf of the user, and have the ability to learn. The introduction of agents has many advantages on the level of human computer interaction. Agents have many characteristics similar to employees. Agents can be addressed by their name and fulfil a specified purpose. A user can add, remove or replace agents. Agents can be criticised and learn from the input by the user. This is not possible with traditional programs, which can be customised but do not change as a response to criticism. Agents make it possible to embed AI in defined entities, which can inform about the quality of their performance and therefore help to demystify the results achieved through AI procedures.

During the development of different agents we distinguished three important categories: Agents that enhance the virtual environment, agents that take over tasks, and agents that help to test the design. Examples for each of these categories are described in the following sections.

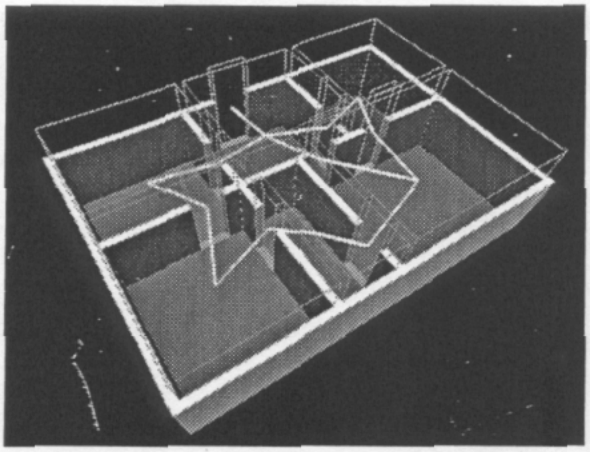
4.1. Agents that Enhance the Virtual Environment

4.1.1. Navigator Agent

The Navigator Agent helps the user to find specific locations in a model or to compose tours through buildings or parts of buildings. The Navigator is able to use the data structure of the modelling program Sculptor to generate a graph of all possible connections between rooms. In order to guide the user to a specific room, it composes and optimises a path based on these connections (Figure 5). It is important to remember that Sculptor uses voids to represent the interior spaces of buildings, rather than collections of walls that enclose spaces.

The Navigator Agent employs the taxi driver approach. That means, that the designer or client tells the agent the name of a certain room where she wants to be guided to. The agent starts moving immediately and optimises during the course of its movement the exact path to take. The agent understands spoken commands that start with a verb such as 'go', 'go to', 'show', 'jump to' and are followed by an adverb that tells the direction to be taken: 'left', 'right', 'north', 'south', or a noun that names a place: 'living room', 'kitchen', or an entity for which a tour should be composed: 'this floor', 'the site', 'the building'.

Figure 5: **The graph of connections between rooms generated by the Navigator.**



The Navigator Agent generates the graph of the movement after analysing the scene. It calculates the possible path to its goal, and it considers the constraints at hand, such as no-collision and moving-up and down stairs. All these constraints are integrated into the modular program Sculptor.

The Navigator can also be used after a project is built to help people find their way, for example in hospitals, office buildings, or universities. Better analysis and path planning is still needed to make the Navigator Agent a truly useful tool. Learning must improve as well, so that more possibilities can be considered when an obstacle appears. This will become very important in case of fire or other emergencies when agents must propose different emergency routes and inform the building emergency and guidance systems accordingly.

4.1.2. Sound Agents and Sound Effects Agents

Different Sound Agents and Sound Effects Agents enhance the environment by playing melodies, spoken labels, footsteps, and by changing the sound effects in different rooms. The use of sound in the virtual environment is very important, because through listening additional senses become involved, this lowers the chance for distraction and makes it easier for the designer to focuss on the design task.

The Sound Agent travels with the visitor through a building and can be used in conjunction with the Navigator Agent. It selects and plays an appropriate sound for every space that is visited. Size, kind, shape and colour situation of a room are considered for the selection of a sound.

This agent can be trained by the user and taught to select the appropriate sound tracks. Initially, training of the agent was implemented using a neural network. The results were difficult to control and required a large number of examples. Therefore the learning algorithm has been changed to a memory based approach. The training of the Sound Agent is interactive. The agent learns from examples, as well as from critique and corrections by the user. According to a confidence level it defines when selecting a sound for a space; the agent can show insecurity when it is not sure about a decision. This is accomplished with a stuttering onset of the sound.

The strategy is as follows: The agent first observes the environment. When entering a space, it looks at features such as its kind, size, shape, and colour. It then tries to describe the appropriate sound with weighted attributes and tries to find the best matching sound in the library. It determines the level of confidence and plays the sound for a particular space. The Sound Agent acts similar to the stimulus-action behaviour of animals. The 'sensor' receives information, which gets processed by the mind and produces a result that is submitted to the 'actor'.

The Sound Agent has a number of intelligent features. It is modelled with a mind that is divided into two smaller intelligent parts, similar to the 'agents' described in 'Society of Mind' by Marvin Minsky (Minsky 1986). The Sound Agent has a memory to remember examples, and it can learn new examples. It can forget old examples and therefore adapt to changing preferences and to new users. It has a strategy to map room impressions with a sound description. It has the concept of level of confidence and informs the user about it through acoustic signals. If the level of confidence is below the 'tell me threshold' (Kozierok 1993), it asks the user for advice.

Three other programs are important for the Sound Agent. The Soundlibrary, an interface which helps to classify a number of sounds. A 2D training environment which makes it possible to create a large number of examples for the initial training of the Sound Agent. The collage-server by NCSA (National Center for Supercomputing Applications) which enables the exchange of information between Sculptor and the Sound Agent.

The Sound Effects Agent can create a variety of sound effects for each room. It can generate the sound of footsteps, which are linked to the speed of the virtual walkthrough. It plays audio labels when entering or passing a room. And it can apply spatial sound effects to these footsteps and audio labels, as well as to the user's voice when different spaces are visited. Strategy and learning are similar to that of the Sound Agent.

The Sound Effects Agent has a great impact on the understandability of a space. The ability to hear one's voice in a simulated space in conjunction with the visual feedback before the building is actually built, is very powerfull. Of all the agents studied so far, the Sound Effects Agents probably has the most practical use. By modulating an observers' voice in a simulated space it gives very important qualitative feedback about the acoustical quality of the space. Although the simulation of the audio quality in the space is not correct, because the real time calculation would exceed the computer's capacity, the effect is quite impressive. The approach can be compared to flat shading in computer graphics: Flat shading does not have the purpose to render a scene as exactly as a photo realistic rendering program, but to give a quick impression of the most important feature of the scene.

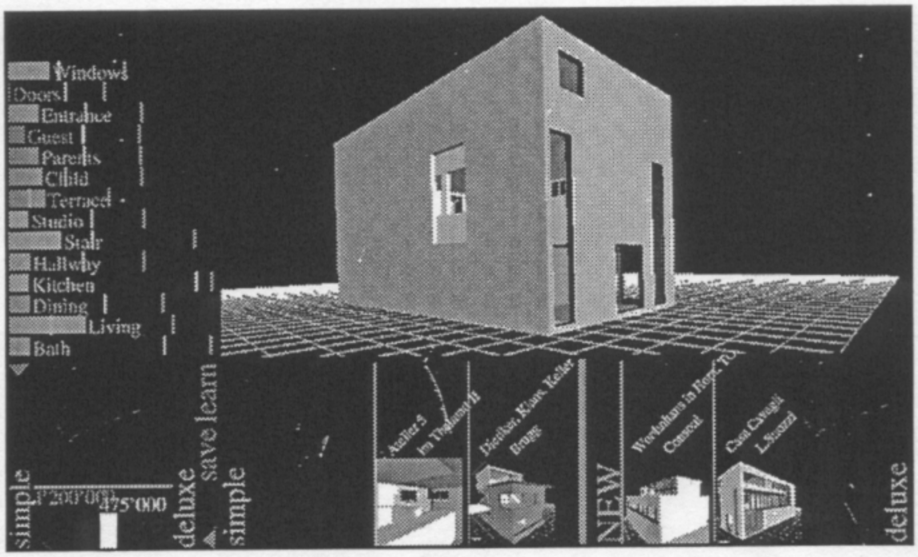
The generation of audio labels associated with rooms is an other useful feature of the Effects Agent. The spoken labels inform the visitor of the spaces she is passing or entering. This could be used for handicapped people to find a better orientation in a building. It is also entertaining to listen to the names of the rooms the agent is walking by when moving towards the actual destination.

4.2. Agents that Take Over Tasks

4.2.1. Cost Agent

The Cost Agent estimates the cost of the project and displays the result graphically. The user can indicate the desired standard of the building, choosing between simple and deluxe versions. The user can also define a cost limit graphically. The cost calculation occurs room by room by multiplying the learned base prize by the deluxe factor and adding the product of the cubic meters of the space with the learned room factor and the second deluxe factor. Factors are always specific to a room type. The total building cost is the sum of the cost of all rooms and the product of the learned building base prize with the deluxe factor, multiplied by the building cost index which is changing every year. This is an improved version of the current cost estimation formula by the SIA (The Swiss Architects and Engineers Association).

Figure 6: **The interface of the Cost Agent, with the analysis chart and the database of existing buildings.**



The Cost Agent has additional interfaces for a space by space cost analysis and to a database of built projects of which the costs are known. These are ordered according to their deluxe level. For new projects, the deluxe level can be indicated within the sequence.

The Cost Agent learns by collecting examples of completed buildings. The learning happens with the delta-rule algorithm, a learning algorithm that is often used for backpropagation in neural networks. The goal is to derive improved cost factors for each kind of room. The result of the learning can be observed and modified by the user in the space by space interface and re-evaluated by the agent. This leads to a simple form of real collaboration between the agent and the user. As can be expected, the Cost Agent has attracted most interest by users and observers of the program.

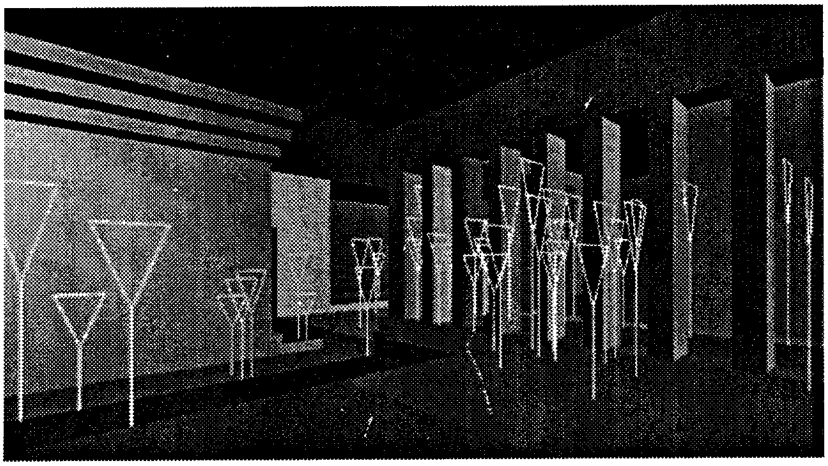
4.3. Agents that Help to Test the Design

4.3.1. Creatures

Creatures were first programmed with StarLogo, a "massively parallel programming language based on logo. With StarLogo the actions and interactions of thousands of artificial creatures can be seen and controlled on the computer screen" (Resnik 1994). In a recent programming effort, such creatures were translated and adapted to work with Sculptor. Their purpose is to simulate people populating a building. This includes the simulation of emergency situations, where a large number of people have to leave spaces and the entire building, almost at the same time. We are interested in finding the best evacuation routes and times for various emergencies that could occur in a complex building. The building control system should be coupled with the simulator in order to open and close doors in the correct directions under emergency conditions.

With the Creatures program, the agent takes on a totally new role. Whereas design is an activity that causes no immediate danger, relying on evacuation agents creates a difference, as it places aspects of human live in the quality of an algorithm. Whether or not evacuation agents will be used in practice remains to be seen, because it delegates an extremely responsible task to an agent.

Figure 7: **Creatures wandering around in a model that was designed with Sculptor**



5. CONCLUSIONS

With our environment we are able to show that design decision making can be supported by enhancing the design environment with fast and responsive graphics as well as intelligent objects and features.

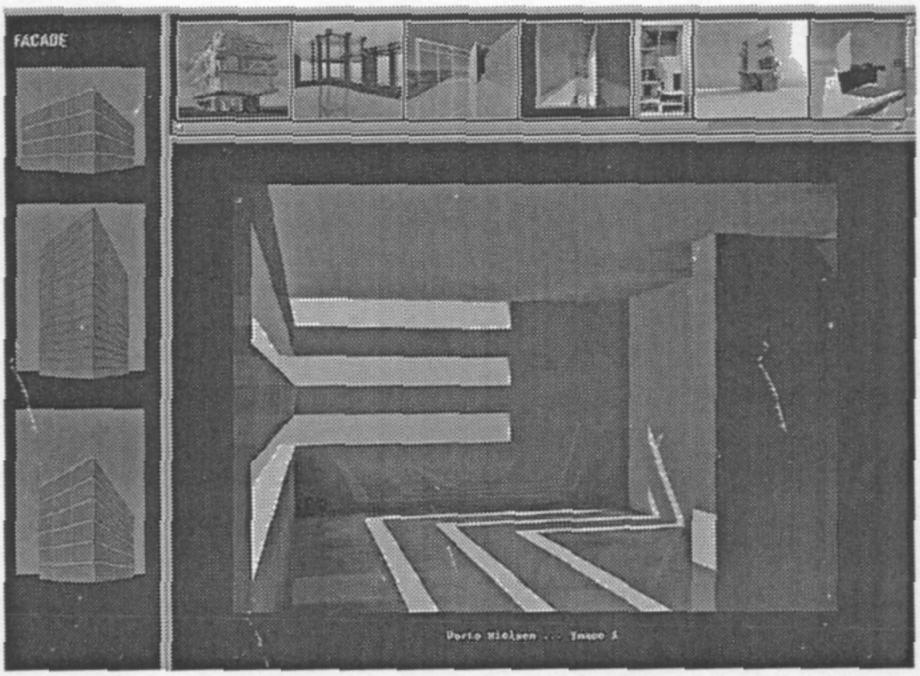
Sculptor was used in courses at the architectural departments of ETH (Figure 8) and Harvard. The feedback from the students and teachers was very encouraging. All users appreciated the quick and intuitive manner in which they were able to generate and manipulate objects in space. Criticism was useful to further improve the design system, like adding a grid, or making changes so that the interaction is comfortable even when the modelling has to be done through keyboard and mouse.

A drawback is that Sculptor, in its present implementation, only supports rectangular shapes. This is not a problem of the algorithms but of the computing time needed to calculate more complex shapes. Because more computing power will get available on affordable machines, we decided to focus our research on exploring dynamic interface and interaction possibilities. The next step will be to turn the objects of Sculptor into little design agents, that can be guided by the user with a simple language, similar to StarLogo (Resnik 1994).

The agents have not been tested as thoroughly as the features of Sculptor. The agents have been available for a shorter time and can not be used in every situation or stage of design.

The Navigator is seen as a very useful tool to get around in large buildings. Even for the researchers themselves it has become a necessary instrument to find spaces and lead visitors to rooms whose location they have forgotten. The Navigator's motion still needs to be improved, especially the way it moves through rooms, around corners, and around furniture. The sound agents have perplexed people in many ways and have generated ideas for new possibilities for the use of sound in CAD systems. They produce interesting effects when used in a VR environment, but can be annoying if used in an office, where others are working too.

Figure 8: **Screenshot from the final presentation of the CAAD course at ETH Zürich.**



The Cost Agent is of the highest interest to commercial developers and to clients, who constantly want to experiment with the deluxe factors and with the addition or deletion of spaces to see the effect on the total building cost. As they have a very good judgement about the cost of rooms and buildings, they immediately criticise when they think that the Cost Agent is not performing correctly. It is not clear whether they base their assumption on knowledge, on experience, or on intuition. The creatures are appreciated because these bring some life into a static environment. We expect a big impact on design decisions from these, but have not been able to conduct the necessary experiments. What all users of the system seem to appreciate most, is that the agents can be used alone or in conjunction. For example the Navigator Agent and the Sound Agent and the Sound Effects Agent can co-operate and give interesting acoustical and visual feedback while moving autonomously through the building to a predefined destination.

The autonomous agents are only in their infant stage. WWe envision a larger number of different agents, such as: energy agents, material agents, information agents, presentation agents, and co-ordination agents. These should also be able to operate on the intelligent objects of Sculptor and communicate among each other, so that an interactive system becomes possible that works in conjunction with the designer. In such a system the designer would freely choose the instruments to be applied, which would organise themselves to an effectively working environment.

6. REMARKS

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