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Design Studio of the Future

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abstract

New communication media enable new design technologies. To investigate the mutual influence of a new medium like Virtual Reality (VR) and architectural design technologies, a laboratory called 'the design studio of the future' is established. In due time a design system will be developed offering different design technologies in an integrated environment. Interfaces within VR will support various approaches to the design problem. A large research program (Virtual Reality - Distributed Interactive Systems) is carried out to provide state-of-the-art tools for designers to experiment and to give feed back on the results.

1. Introduction

Specific tasks of the design process are effectively supported by computer applications. Nevertheless the design process as such has not changed much under the influence of these applications. Technical issues and reluctance of traditionally trained designers prevent the introduction of new design technologies. As with the introduction of other new technologies, (such as electricity) it takes quite some time to find the proper application. The first step in this process usually is to apply a new technology in a conventional way. It seems that the application of computer systems in designing is now at that stage. The 'natural' use of computers and the 'natural' interface with computers has still to be found.

Considering architectural design systems there is a very long tradition in solving design problems. Even before the introduction of computer systems in architectural design much research was spent on systematically describing the design process. Especially the creative part of the design process is very hard to be grasped in a formal way. Though one should not intend to formalize the design process, it seems obvious that specific tasks within the design process could very well be supported by computer applications. The approach towards the design problem using nowadays applications is still left unchanged. To make effective use of the computer environment new design technologies must be developed that fit its nature.

A relatively new medium of interacting with computer systems is Virtual Reality (VR). Virtual Reality offers new opportunities for the creation of architectural design systems. Though at the moment VR mainly is used for visualization it is evident that having an immersive three dimensional workspace allows for new design technologies. If the VR interface is combined with the power of a computer to handle large amounts of data, a new way of designing will emerge. To experiment with VR based design systems, a 'design studio of the future' is furnished with state-of-the-art equipment. The equipment is used for constant development of new additions to the design systems. Meantime experienced and inexperienced designers are invited to use the equipment for their design tasks to get feed back. In this paper the IT architecture of the 'design studio of the future' will be described, the theoretical background that it is based on and the current status of the research.

2. Studio architecture

The design studio can be regarded in two ways:

1. The layout and equipment of the room or building where studio is located.
   The current situation will be described at the end of this paper. However this will constantly change because of new hardware and software developments. A less implementation dependent way to describe the information architecture therefore is the second approach:

2. A group of workstations where specific design tasks will be performed.
   Design tasks will be executed using one or more design techniques. Whether or not different design techniques can be used on the same computer equipment depends on the computer environment. *Design techniques* are closely related to the way the design object is represented. Design techniques can be used in any order by the designer to support a specific *design methodology.*

To explain the information technology (IT) behind the 'design studio of the future' the last approach will be followed. First design techniques in a IT context will be elaborated. These techniques can be used in traditional presentation media and in new ones. Virtual Realty being a new medium will be analyzed due to the internal representation of information. At last the interfaces necessary to manipulate entities in VR will be considered.

2.1 Design technologies

Design techniques and design methodologies have been defined in order to create a clearer view on the design process and in doing so to support the designer while performing his/her design task. In this paper design technologies are introduced as a specific class of design techniques in an IT context. *A design technology is a specific way of creating and manipulating design objects that requires a specific design information representation.* Starting point in the survey for design technologies is the assumption that no traditional means (such as a sketch board and a pencil) will be used. This assumption is made to intentionally force our selves to look for new ways of creating and manipulating design objects.

Design technologies that are distinguished:

A. sketching

   Sketching is a design technology that produces shapes with no explicit dimensions. Since computers only can handle explicit values the sketches have somehow to be translated into known geometric entities. The traditional approach to this problem is trying to find a way to make the computer recognize what the designer has sketched. The translation process is very difficult, especially the recognition of the meaning of the shapes (floor, tree, etc.).

B. drawing

Drawing is a design technology that produces shapes with explicit dimensions. Almost all CAD systems support this technology. Only few of them are capable of attaching a semantical meaning to drawing entities. As a precondition such drawing systems must be (building) object oriented.

C. simulation

Simulation is a design technology that tries to predict the behavior of the design. Behavior can be regarded towards behavior of the building such as structural behavior, thermal behavior, etc. It also can be regarded towards behavior of the occupants such as perception, way finding, etc.

D. managing

Managing is a design technology that refers to the manipulation of the design data or the data flow. Design data do not merely consist of geometrical data but also of additional attributes and functions that describe the characteristics and the behavior of a specific building object. Data flow exists within the building project and outside the building project. To keep the design information up-to-date and consistent control is required for the information exchange process.

2.2 Presentation media

Presentation media impose their characteristics upon the design technology being used. Designing a spatial object like a building in two dimensions is in fact very unnatural but nevertheless common in architectural practice. One of the main skills an architectural student acquires during his/her course is to create a three dimensional image from a two dimensional sketch or drawing. Especially for those not familiar with reading building drawings perspective views are created to give an impression of the building. The introduction of CAD systems has not changed much in this respect. Design activity still takes place in two dimensions but now on the monitor screen instead of a piece of paper. Recently released design packages draw 3D (solid) objects, so images of facades etc. can be generated very quickly. To make the next step in the development of design tools of an architect, a new presentation medium is required: Virtual Reality (VR). *Virtual Reality* is characterized by the illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on three-dimensional (3D), stereoscopic, head-tracked displays, hand/body tracking and binaural sound. VR is an immersive, multisensory experience [Earnshaw, Gigante 1993]. In VR the architect (or engineer) designs the building as if he/she is creating a full scale model. During the creation process the designer can take any position to work from such as in one of the rooms or standing in front of one of the facades. Obviously the designer needs appropriate tools to manipulate the building parts and to easily change view. In fact the design technologies sketching, drawing, simulation, and managing as mentioned in paragraph 2.1 should be supported.

2.3 Representation in VR

The application of Virtual Reality until now is mainly restricted to visualization of shapes including texture mappings. VR software (such as World Tool Kit, and Device) is optimized for generating pictures of a building model consisting of objects with a shape representation and a texture mapping while navigating through the model. Moreover objects can exibit some behavior like gravity and collision detection. With these capabilities very realistic images can be created of a building which only exists in the mind of an architect. The architect himself/herself or the principal can use VR to judge a design on its esthetical and its functional qualities.

Visualization in VR is dynamic but not interactive at all. To take VR one step further the designer must be able to interact with the design by creating, modifying and deleting design objects and by evaluating the design to certain aspects. Like in Object Oriented modeling design objects can be identified and they will have a specific behavior [Booch 1994]. VR offers new interesting possibilities for evaluation of the building design in terms of:

- thermal behavior

  The air flow and the air temperature can be visualized within the three dimensional model. Moving around the building specific locations can be inspected to see in which direction the air moves, at which speed and its temperature. The exact values can be compared with standards that must be complied.

- structural behavior

  Stress and displacement can be shown for structural parts. By adding a color gradient to a specific stress value, stress can be visualized. Displacement is exaggerated to get some 'feeling' of how the structure behaves. The exact values can be compared with standards that must be complied.

- human behavior

  The way people will walk around the building can be shown. Statistical or experimental collected data are used to depict the paths people will use and how much time it will take to get from one place to another. These data can be compared with for instance the fire regulations.

Separate packages for thermal behavior, structural behavior, human behavior, etc. already exist. Sometimes CAD packages are used as a front-end tool. Integration of evaluation tools with design tools has always been very difficult because of the difference of the internal information representation. VR will make no exception to that. However, since the VR environment is still in its premature stage it seems a good time to create a new kind of representation which allows for different views. At the moment we can take advantage of much research that has been done on this issue [Bronsvoort 1996, Luiten 1994].

2.4 Interfaces in VR

The nature of man-machine interfaces in Virtual Reality will depend on the design task. The windows interface which has become standard for almost all computer applications does not fit the three dimensional environment of VR. An *interface* is determined by a set of functions that manipulate the design data and by the way these functions are presented to the user. Functions that must be available in an architectural design system are:

- create, update, delete and select entity

  This set of functions is closely related to database management. The interface must be able to directly *manipulate entity attributes and entity relations.* From the available data selections can be made to focus on a specific part or aspect of the design. Entities and entity relations will develop in time. The development reflects the design process. Cyclic process steps require 're-activation' of older parts of the data structure. Some process steps need to be frozen since they reflect a certain design stage (e.g. preliminary design). *Workflow management* within a building project requires an interface that resembles office activities such as planning, archiving, version management, etc.

- create and modify shape and topology

  This set of functions is partly related to tools that can be found in CAD packages. *Shape edit* functions can support the creation and alteration of forms that are visualized instantly. Less common is the support of *topology* constraints between shapes. Adding topology constraints will keep building components (e.g. a wall and a floor) connected while moving one of the components. Sketches are used to support the process of the creation of new shapes as a response to former sketches. Shape algorithms *generate* new *shapes* under specific preconditions that are set by the designer.

- match design patterns

  The first application of this function is as an aid in trying to use existing *design knowledge* for specific design problems. Design problem (e.g. the layout of a floor plan, thermal requirements that must be met) and design knowledge must be described using the same methodology so that they can be compared. Design knowledge is available from design research. Possible solutions to the design problem can be offered and eventually adapted into the design model. Secondly this function is required to create *multiple views* on the design. Since each discipline (e.g. structural engineering, building physics, building contractor) uses its own data structure, matching of data structures is inevitable. Support of the matching process based on a common library of design patterns will improve the quality of information exchange between disciplines.

- apply engineering constraints

  This function is a collection of constraints that the architect or engineer wishes to impose upon the design because he/she wants the design to display specific *behavior*. For instance the designer wants a wall to behave as a bearing wall. Of course proposed behavior can interfere with form conditions. Thus the wall should in fact have sufficient contact area with the floor that it bears.

3. Systems architecture

In the 'design studio of the future' design technologies are supported by interface functions that are implemented in a VR environment. The system's architecture of the design studio consist of the interface, storage of information and dedicated computers. In *Figure 1: System's architecture*, design technology, interface function and information storage are related. Information storage is divided into five stores, each of them capturing a specific subset of information about the building design. A subset is a defined by a meta class. The meta classes are interrelated in *Figure 2: Meta class model.* For processing the data from the stores triggered by some interface function, computer systems are used that are optimized for the execution of a specific task. Interface functions might access one or more systems. These relations are not shown in the figure for readability reasons.

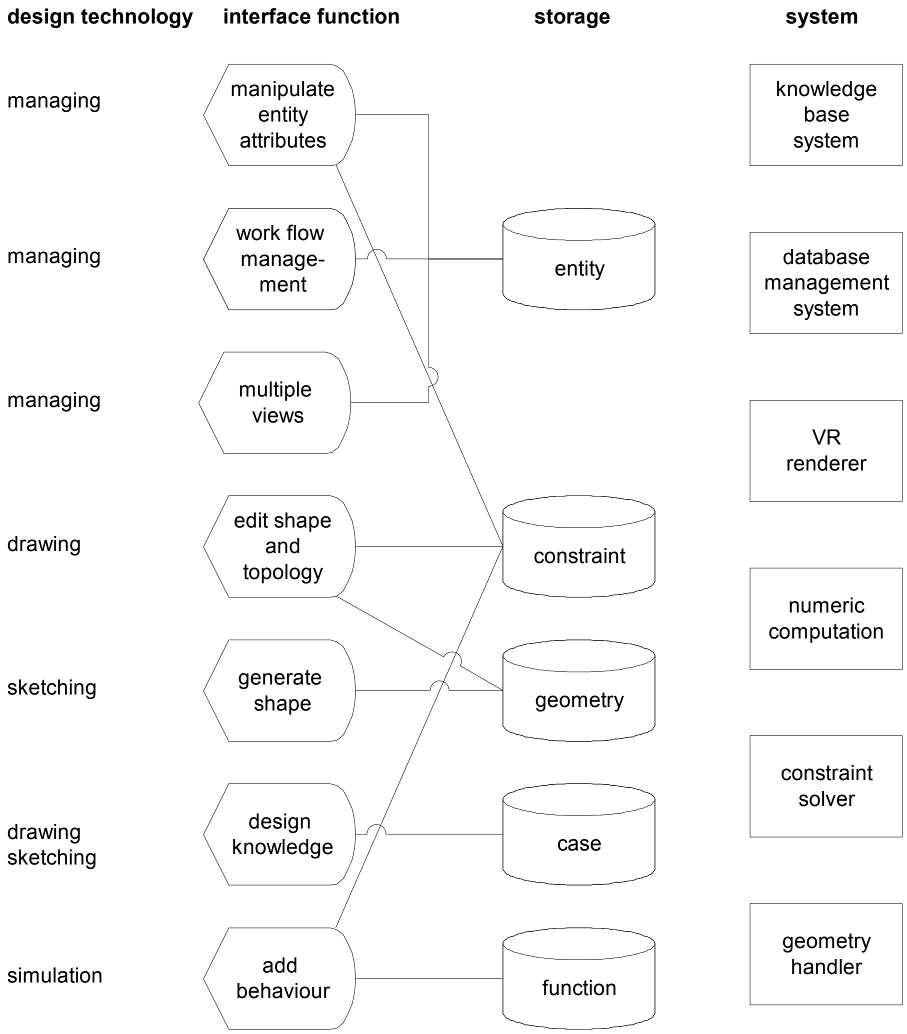

Figure 1: System's architecture

To show how the substores are related Object Oriented modeling notation is used in *Figure 2*. An entity (like an object from OO-modeling) is defined by a set of variables and a set of functions. Entities can be related by the following relation types: aggregation (part-of), specification (is-a) and constraints (e.g. coplanar, bears). An entity may have one or more geometrical descriptions (CSG, Brep). Functions can be added or overloaded to display specific behavior by entities.

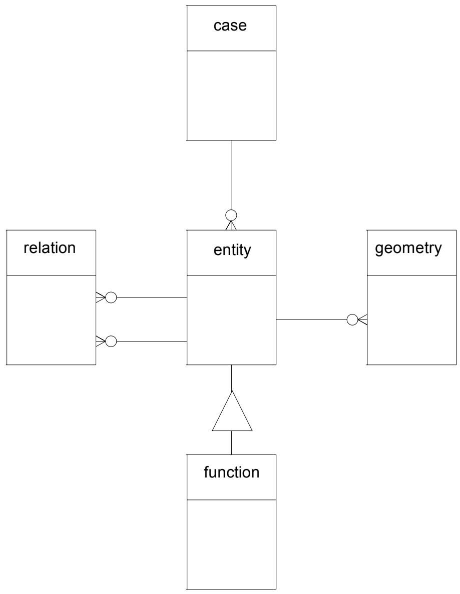

Figure 2: Meta class model

4. Concepts

The concepts being used to implement data storage and data processing are briefly described below. For a more extended explanation refer to the references.

4.1 Feature-based modeling

Feature-based modeling is a technology mainly applied in mechanical engineering. A *feature* is a collection of high level information defining a set of characteristics or concepts with a semantic meaning to a particular view in the life-cycle of a building. Features are proposed as the key concept to support dynamic information modeling. Feature types represent knowledge from a particular domain (e.g. a column) and can be defined during the design process. Feature types are not similar to building components since they can enclose any information that a designer wishes to be captured (e.g. thickness of all floors, material of bearing walls, etc.) Feature types are instantiated to create a feature model of the design. Relationships known from Object Oriented modeling are supported. Feature models are extended and updated during the design process [Leeuwen, J. P.,van, Wagter, H., and Oxman 1996].

4.2 Constraint management

Constraints are necessary to have the design display specific behavior. Two main categories of constraints can be distinguished in a design system: geometric constraints (e.g. wall are coplanar) and engineering constraints (e.g. wall bears floor). Constraint satisfaction requires a mix of constraint solving strategies (e.g. local propagation, relaxation, numeric equations) to provide the designer with a set of zero (over-constrained situation), exactly one or more (under-constrained situation) design solutions that meet the specified constraints. The constraint solving strategies are conducted to trigger the proper solver at the proper time. In an interactive design system constraints must be solved simultaneously [Donikian, S. and Hegron 1995].

4.3 Activity networks

Designing a building product is a cyclic process. This process can be decomposed into a series of activities. Managing design processes require well defined activities. For a specific building project activities are combined in an activity network. The network being a Petrinet, is capable of keeping the information consistent. Activity networks are useful on the single user level as well on the group level. In the last case the network acts like a kind of planning mechanism for a multidisciplinary design and building team. [Vries 1996]

4.4 Generic representations

To capture knowledge about building types generic representations of a particular building type are proposed. A generic representation (e.g. simple contour, schematic axial system, circulation scheme, etc.) is described by: name, source, graphic representation, textual description, graphic units and icon representation. They are established by means of analyzing architectural designs. The process of a building type can be encoded in a sequence of generic representations that develops a particular issue (e.g. shape, structure, etc.) [Achten, Bax, Oxman 1996].

5. Status of the research

Currently 'the design studio of the future' is equipped with two systems (PC running Windows NT) that are dedicated for drawing 3D models (Autocad, 3DStudio Max) and one system (Silicon Graphics ONYX) for fast rendering in a Virtual Reality environment (World Tool Kit, Device). Additional software is available for light simulation (Lightscape, Radiance). The VR user environment consists of a projector (Barco) displaying on a wide screen, a Head Mounted Display and several navigation interfaces like a 6D mouse and a joystick. A prototype of a VR design system was developed using a combination of Autocad en World Tool Kit [Coomans, Oxman 1996]. Research to fill in the system's architecture of *Figure 1* is going on now for:

- developing object classes for defining feature models

  The object classes define the entity storage data structure using a data base management system.

- developing an interface in VR for manipulating feature models

  The VR interface comprises the function: manipulate entity attributes. Through accessing the entity also the geometry parameters and constraint parameters can be updated.

- developing a tool for the use of design knowledge captured in feature models

  To support drawing as a design technology, design knowledge must be accessible in the case store using a knowledge base system and a database management system.

- developing a system for geometric constraint solving

  A constraint solving system is implemented to provide the designer with design solutions that meet the specified constraints in the constraint store.

- developing a system for the simulation of thermal behavior

  To simulate the thermal behavior of a building or building part entity functions will be available using the numeric computation system.

- developing a tool for accessing knowledge about building physics

  To support the use of knowledge about building physics of a building or building part a case store with requirement indicators will be available using a knowledge base system and a database management system.

- developing a method for measuring way-finding in VR

  To simulate the behavior of human beings in a building, functions will be available to accommodate circulation activity from the function store using the numeric computation system.

Most research programs will result in a thesis within four years.

6. References

[Bronsvoort 1996]
Bronsvoort, W. F. *Papers on Feature Modelling from the Computer Graphics and CAD/CAM group.* Delft University of Technology, Delft (1996).

[Achten, Bax, Oxman 1996]
Achten, H. H., Bax, M. F. T., and Oxman, R. M. *Generic Representations and the Generic Grid: Knowledge Interface, Organisation and Support of the (early) Design Process.* Proc. DDSS. Spa, Belgium, Eindhoven University of Technology (1996) pp.1-19.

[Booch 1994]
Booch, G. *Object-Oriented Analysis and Design with Applications.* Redwood City, The Benjamins/Cummings Publishing Company (1994).

[Coomans, Oxman 1996]
Coomans, M. K. D. and Oxman, R. M. *Prototyping of Designs in Virtual Reality.* Proc. DDSS. Spa, Belgium, Eindhoven University of Technology (1996) pp.20-34.

[Donikian, Hegron 1995]
Donikian, S. and Hegron, H. *Constraint Management in a Declarative Design Method for 3D Scene Sketch Modeling.*In: Saraswat, V. and Hentenryck, P. ,van. v. 1, (22):p. 427-444. Principles and Practices of Constraint Programming. The MIT Press, Cambridge, Massachusetts (1995).

[Earnshaw, Gigante 1993]
Earnshaw, R. A., Gigante, M. A., and Jones, H. *Virtual Reality Systems.* London, Academic Press (1993).

[Leeuwen, Wagter, Oxman 1996]
Leeuwen, J. P.,van, Wagter, H., and Oxman, R. M. *Information Modelling for Design Support - A Featured-Based Approach.* Proc. DDSS. Spa, Belgium, Eindhoven University of Technology (1996) pp.304-325.

[Luiten. 1994]
Luiten, G. T. *Computer Aided Design for Construction in the Building Industry.* Ph.D. thesis Delft University of Technology (1994).

[Vries 1996]
Vries, B., de, *Communication in the Building Industry: A Strategy for Implementing Electronic Information Exchange.* Ph.D. thesis Eindhoven University of Technology (1996).