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Design Education in the Virtual Studio

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The paper presents an approach to the re-orientation of computational studies in support of the didactic role of the design education program. A definition of computational design studies is proposed which identifies the transfer of explicit design knowledge as one of the functions of this academic field. The concept of design knowledge modeling is introduced as an important component of the knowledge formulation role of computational design studies. A current project is discussed which employs knowledge modeling in a VR system to develop an interactive design environment.

Redefining the Role of Computers in Architectural Education

There is a current need to re-define the role of the computer in professional studies programs in architecture. As students enter the university increasingly more computer literate and as more students have independently gained capability in modeling, major staff efforts to teach applications and to develop basic computational, drafting and modeling skills become less and less a justification for the existence of dedicated computer groups. Often, the question of the function of such groups is easier to address in schools with specialized professional programs (for example, in building informatics) or well-developed graduate studies and research programs. However, sooner or later, all of us must face the necessity of re-defining our role vis a vis contemporary professional education. We are currently in the process of undergoing such a re-evaluation and establishing new objectives for the continuing development of our teaching and research programs. Among the various global goals which we have tentatively established is strengthening the interface with the design education program in the design studio cycle. Rather than interacting exclusively in a service role by providing visualization skills, we are attempting to find an active role in the didactics of design which differs from, but supplements, the current didactic program of the design studio. In effect, we plan to develop and teach a computational approach to architectural design within the framework of courses which combine theoretical lectures in these subjects with work in the computer lab.

As part of this re-orientation, we are attempting to develop a theoretical approach to the computer as a design learning environment. The paper describes one of our current experimental programs in computational design education. Early applications of CAD in the design studio fit conventional teaching paradigms to the computer medium. The current program attempts to identify and exploit the uniqueness of the medium as a pedagogical environment. The subject of this particular study is an experiment in the use of virtual reality (VR) technology as a design teaching environment. While conventional approaches to studio teaching employ a model of a demonstrative tutorial relationship between teacher and student, virtual reality potentially enables learning through a collaborative exploratory process. Furthermore, interaction with a VR model makes possible the introduction of temporal and constructive qualities in the experience of a design. The teacher and student can potentially jointly move through the model. Verisimilitude can be also be enhanced by the provision of such architecturally qualitative aspects of design performance as lighting conditions. In addition to enhanced and shared visualization capabilities, the enabling of collaborative, real-time interventions with the model is another of the objectives of the experiment.

We begin by identifying what is unique about the computer as a design learning environment. Here we identify the *transfer of explicit disciplinary knowledge* as an attribute of computational design studies, and an important new role for computer groups within the architectural education program. These ideas are developed through a comparison with current approaches to education in the traditional design studio. We then introduce the important concept of *knowledge modeling* as a design learning task in computational design studies. Having identified certain structural problems of the design studio, and having defined knowledge modeling as a means of explicit knowledge formulation, we discuss the implementation of these concepts in a design environment employing virtual reality techniques. Finally, we briefly introduce BOUNDARIES, a VR system currently under development for the collaborative exploration of spatial qualities in architecture.

Implicit and Explicit Knowledge in Education: Computational Design Studies as a Medium of Knowledge Transfer

Traditionally, design studio teaching involves learning by example, and tacit, rather than explicit, knowledge (Robinson, 1994). In current architectural education, a second model of knowledge transfer currently exists beside the professional studio model and this is based upon the teaching of the professional knowledge base through lectures and seminars. In the case of this latter model, knowledge, much of which has been derived from architectural research, is transmitted as explicit knowledge. There is potentially broad pedagogic significance to what might be termed, a knowledge-based approach to design education. Whereas in traditional design studio teaching tacit knowledge is embedded in the teaching of personal approaches to design practice through the 'making of designs', in computational modeling knowledge of design must be made explicit.

The formulation of architectural and design knowledge is part of a long historical process to build the foundations of an architectural discipline. The knowledge base of this discipline is also the foundation of architectural education. Design computational research in the formalization of design knowledge and processes related to design has begun to make a contribution to the founding of disciplinary knowledge. This is among the unique contributions of design computation and education. Such an approach demands that the teaching staff in computational design subjects also possess knowledge in design theory and architectural theory, a situation which is becoming common in many universities. The body of professional teachers now have the responsibility of developing and formulating the knowledge base of the discipline through research. Researchers are beginning to formulate explicit disciplinary knowledge, particularly about the design process. Research has become an integral part of this process and computational design studies have begun to function as a theoretical base for design research. The teachers of computational design who are becoming, de facto, the formulators of the body of knowledge in the area of design studies and design theory.

The emphasis in design computation has been shifting to a partnership concept of human computer integration. As this occurs, there has become a greater need to study cognitive processes in design. Computational research groups are, therefore, also involved in researching the cognitive aspects of design as well as computational modeling of design. This shift is also affecting the content and form of computers in education and design education. The boundaries between research and teaching become blurred as the emphasis of teaching shifts to design inquiry, learning about design thinking, and the computation of design. Much current design research has becomes focused around the cognitive as well as the implementation aspects of subjects such as visual knowledge bases in design (Oxman and Oxman, 1992). The research and development process itself functions as a medium for learning. Much of the pedagogic benefit derives from the process of knowledge formulation which the student undertakes in order to develop a system, or a knowledge base.

If the making of design knowledge explicit is one educational problem which *computational design studies* appears to address, communication as an educational problem is another. In a recent paper (Schön, 1992) he has characterized the problem of the derivation of tacit knowledge in the studio teaching situation as a problem of communication between the design teacher and student. First of all, students are taught a new world view and new conceptual vocabulary, as they are 'inducted into a new and privileged systems of understandings, descriptions and notations'. The nature of collaboration as the basis for design education is a joint process in which, 'each party shapes a problematic situation and is shaped by it, instituting new environing conditions and new problems'. Finally, the problem of conveying rationale while acting out a transaction on a representation is the essence, as well as the central problem, of the empathetic approach to design studio education. Schön describes it as follows. 'A good educational conversation is a reliable, reciprocal process of *giving reason*. 'Teacher and student must somehow discover how each other one sees the object in question and what features and relations in the object make such a view reasonable. They must also somehow test their constructions of one another's meanings *in relation to the object.* They tend to see the object itself in new ways and so face new occasions to give one another reason'.

In this communications model of design studio education, the teacher and student are linked in a process of untangling the rationale underlying the tacit knowledge of the teacher. Computational design studies is diametrically opposed as a process in which design learning is derivative of a collaborative research activity. Design education becomes characterizable as a collaborative exploratory process in which knowledge is always explicit. These three points: design theory as one of the computer lab's contributions to professional education; knowledge formulation as a design learning process; and the computer as a collaborative exploratory didactic environment are among the foundations of computational design studies. We believe that they are among the potential contributions to an emerging paradigm of design education.

Design Knowledge Formulation as a Modeling Task: Modeling Computational Design Worlds

How can we establish a theoretical role for computational studies in design learning ? Rather than simply a locus for making presentations, the problem is to define a function for the computer lab and establish a relationship with the design studio which potentially can become pedagogically significant. This is really the challenge of a computer-integrated approach to design didactics. How can the medium actually become an environment for learning about design and for acquiring knowledge ?

One of the unique characteristics of programming and working with applications is the sense of 'building' a program or an application. Papert (1991) has contrasted 'pipeline models' of knowledge transmission, i.e., knowledge transfer through direct declarative verbal presentation, with 'understanding through construction'. These two approaches have been termed, instructionist versus constructionist teaching. He defines constructionist teaching as 'forms of models based upon working with concrete materials rather than abstract propositions'. His research in the learning experience indicates that such an educational approach directly addresses the key objective of education, the building of knowledge structures. By analogy, we may apply his ideas to design learning and attempt to postulate the content of *design knowledge structures*.

Any formal approach to the making of a design representation, or a procedural description of design generation, or of heuristic processes may be considered a design knowledge structure (Oxman, 1990). In part, design learning is the building of these knowledge structures related to the making of designs.

Cultivating design minds is a broad objective which also includes values, and judgmental and evaluative knowledge. However, we believe that the sequential formation of design knowledge structures strongly depends upon the growing ability to generate designs. Papert's approach is that in building knowledge structures, constructing something, rather than the more conventional 'banking of knowledge', is a deeper and more effective process. We share with Papert the belief that computers provide a medium for constructionist learning, and particularly in design.

One approach to constructionist learning in design with which we have been experimenting is the modeling of design knowledge. The student learns through, and about, design by constructing a model of a *world of design knowledge*. Learning is the building of a particular knowledge structure, 'where the learner is consciously engaged in constructing a public entity' (Papert, 1991). The metaphor of construction is very strong in this process. The derivation of knowledge is through 'knowledge formulation' of the particular design world. It provides learning though new awareness of the conceptual vocabulary and systematic qualities of the design world and through learning how to deal directly with the making of designs as the manipulation of representations in that world.

We refer to this approach as *design knowledge modeling.* Modeling demands the externalization and formalization of tacit knowledge. Knowledge formulation as a modeling task is the externalization of design knowledge through formalization, or systematic rigorous description. This process formalizes knowledge that is often internalized in conventional design processes and in traditional design studio teaching. Modeling of design descriptions and processes can also provide valuable insights into design reasoning. We also believe that modeling as a collaborative, research-like, exploratory process addresses some of the structural faults of design studio education by making possible a setting in which teacher and student jointly participate in design research. Design learning takes place without the communications problem of giving reason.

In modeling, the concept of a design world (Mitchell, 1990) is employed to create an architectural vocabulary of elements which complies to certain formal requirements, accommodates certain design rules, enables particular design behaviors, etc. A world may be a formal vocabulary which includes information regarding design objects, their composition, procedural rules of design generation, organizational characteristics, and design constraints are incorporated in a formalization of knowledge related to the world. A high-level world is an internally consistent formal system encompassing a significant and recurring formal aspect of design. It is a formal system at a level of generalization, e.g.. grid architecture', above that of a particular style (Flemming, 1989). The design world specifies the formal variables and the basis for generation of formal variants within the world. It is a particular high level formal language which can be shared. As such it differs from two other formulations of design knowledge, a 'library' of design examples or 'model shop' as a set of basic building components. Design world formalization is one medium for knowledge formulation about design.

A design world is either part of an existing body of knowledge, or an existing convention system. Usually the knowledge is tacit and has to be formulated through, for example, the formal analysis of instances. Because available knowledge is generally tacit knowledge, it is usually necessary to select a small, well-defined design world to model (Oxman and Oxman, 1992). The creation of a design world is based upon the generation of a formal language in the modeling system. In contrast to project-oriented studio work, learning to model the formal qualities of designs becomes an important component of the design learning process. This integration of design and design research was considered one of the pedagogical attributes of the experiment. In the current project, the design world is that of 'boundary conditions in architecture'. It constitutes a general language which could potentially be manipulated collaboratively while 'within' the VR model.

Virtual CAAD: Some Requirements for VR Design Environments

How can these concepts of design knowledge modeling be incorporated in a VR environment ? Our research group has several years of experience in VR. Work has been done on simulating physical qualities in the modeled environment, and on supporting various input devices. The emphasis of the group is currently less about photo realistic illusion than it is about the nature of 'smooth' interface with the model. Other work in the group such as the Dyna-CAAD System designed by Jo Mantelers has studied possibilities of dedicated architectural sketch modeling systems. The current project explores the theoretical aspects of a combination of these two prior directions in attempting to develop a pilot *Virtual CAAD Environment*. In the following we provide a theoretical introduction to the components of the research and development on a collaborative interactive design environment. Within the context of the previous discussion, in this section we consider some of the issues related to interactive design systems and to collaboration in the VR environment.

A basic definition of VR, or Cyberspace, is that it is a technology for human sensory and cognitive experience through computer integrated display and control in an interactive computer-generated and computer-mediated environment. The idea of an immersive environment which envelopes the viewer relies upon supporting direct and intuitive interaction through natural behavior. It is this interactivity which creates the sense of presence and instrumentality in a VR environment. Usually this aspect of presence is emphasized in referring to VR as the 'space of feed-back and control'. However, new directions are attempting to expand this to a 'space of knowledge'. In addition to being immersed in a computational scene, the viewer may potentially be in a knowledge-base related to that scene in which it is possible to visualize, and navigate through the visual knowledge base. We are working on this concept of a visual knowledge base as a 'design knowledge space' providing interaction with, and an understanding of, a design world. Design in the sense of the proposed system is manipulation of the elements of the design world from within the scene. Potentially, knowledge about the possibilities of design is also accessible from within the scene.

The five basic components of the VR system are considered relative to research and development issues in developing virtual design worlds. The five components are: worlds, views, presence, sensing and control.

worlds

a) scene

This is the environment, or scene, which is experienced as the virtual world. It usually requires a computer graphic system and/or video capture device for creating the modeled environment and objects. The model is imported into a VR programming package in order to add interactivity. Ideally, the scene provides a direct experience in which, as compared to drawing, the depicted objects have a sense of presence. The provision of gravity in objects in the model is a known example of attribution of physical properties to objects in scenes. In modeling a design world, the scene can become a virtual environment in which the design can take place, that is, the design field. Therefore, in a design world, the scene must be malleable. Rather than a three-dimensional interactive 'model shop' , in which construction is possible by moving and assembling objects, a design world is a scene constrained by a formal language. The model supports design within the formal language. Some of the modeling issues include how to model transformational procedures in the world, e.g. continuously or discontinuously.

b) scene design support knowledge base

In addition to a scene which depicts a virtual physical world, the model may provide support for design within the language. The scene composition rules, the design variables and the possibilities of transformational operations upon the scene are types of knowledge which should be present within the scene and provide design support to the user. This is the knowledge base underlying the scene. In the VR constructive environment it is possible to manipulate objects with knowledge provided and viewed in (or 'behind') the depicted environment. We can potentially embed within the model informative characteristics of the environment in which objects are to be interactive, metamorphic, and malleable.

views

a) display

This is the sensory mechanism providing the physical display of the view and the sensory experience of it. It achieves the sensory experience of the world as realistic through audio-visual simulation. Currently requires a computer display device e.g. head mounted eye display or helmet display while other diverse possibilities include stereo display and projected stereo display. Employs such devices as head mounted displays.

b) representation of knowledge base

How is it possible to create a sense of the potential variables of the design system in the model ? The knowledge interface might provide for visualizing the design variables and design potential of the system. Instead of physical properties such as gravity built in to the objects, you would have knowledge built in. One approach is in the form of providing a visualization of the knowledge base.

The spatialization of knowledge is an important and recurring theme in Cyberspace (Benedikt, 1991a). The general goal is to provide a direct and intuitive interaction with information. This is part of the exciting general concept of VR as providing a technology for a knowledge environment which can be explored. Some techniques for this are metaphoric organization of knowledge or design variables through a graphic (knowledge) matrix which is activated while traversed. The concept frequently involves the exploitation of the metaphoric structure of a knowledge matrix as a medium of search. The matrix may support a nested system for the hyper-space representation of knowledge which the designer can traverse by activating nodes which introduce new scenes. This potentially provides a display of the knowledge base through the three-d matrix structure.

In a design world, a spatio-temporal code can be employed to activate the model. For example, a coordinate system, a linear spatial ordering, a series of rings or zones. Physical movement may activate search as an operative medium for interaction with a knowledge base. By moving through this metaphoric world, you activate the variables, or generate in the design world. The metaphorical structuring device can also act as a device for orientation and navigation within the design world. The user learns to activate the design world through kinematic activity, oral commands, etc. An objective is to make this smooth and natural, so that , as is drawing, he actually learns a design command language which is cognitive as well as kinematic.

What constitutes 'user friendliness' in such an environment ? The possibilities for operations upon the object must be visible, or suggested, by the model. How is it possible to act upon the world through actions (moving, pointing, naming) rather than a conventional user interface ? Is it possible to organize the variables in a spatial matrix which is the volume and activate different design variables by physical movement through the space ? Or should the design field and design knowledge base be two separate representations ?

presence

a. interface

The projection of the user (s) into the world. Projection of kinematic and sensory experience into the representation supports a sense of presence in the representation and potentially also of control of objects in the environment. They perceptually surround and include the user in the display space. Requires VR software as the interface between sensing (input) devices and modeled, or captured, environment which provides 'the sense of presence' and 'control' connecting the user's real space and virtual display space. The user's image may be projected into the program by video capture and this may include self-viewing of the whole body, the hands, etc. Coupled with this sense of presence are strategies for user-object and user environment interactivity.

b) multiple presence (collaboration)

Distributed simulations are multi-user VR environments. Currently, we are considering the performance requirement for a two participant environment (teacher and student). Collaborative VR environments have a set of unique and interesting problems. These include the problem of mutual visibility, what you see is what I see, who controls, etc. In a collaborative design world, the model must provide a shared vocabulary which potentially enables collaborative exploration of teacher and student.

c) presence and interface

There may be integration between the view of the presence and the user-interface which controls the model. For example, the hands projected into the scene control the manipulation of objects in the scene. In a collaborative VR environment this again presents special problems such as requirement for special software (groupware), synchronizing displays, shifting control (what and who affects object behavior).

sensing

a) natural interface device

A natural interface device provides familiar intuitive interactivity with the depicted environment and objects. Through this provision, the VR system exhibits the built-in 'understanding' of human conventions, such as movement of bodies or heads to see better. This functionality is achieved through sensing and tracking devices. Requires VR hardware such as user tracking and sensing systems, e.g. head, eye, movement, or gesture tracking systems for position and orientation sensing. Motion of the user results in new information to the system. Hardware may include data gloves, magnetic trackers for head position and orientation and exoskeletons for gesture sensing.

b) design-like interface

Flight simulators are an example of interactive systems employed as educational media. They provide a three-d world that the learner can 'enter' and combine physical and computer-generated elements in a learning environment. They provide an interesting analogy to potential design learning systems in that the learner undertakes psychomotor and cognitive activity to perform instrumental behavior within the system.

What are the possibilities for interactive design in a VR environment including real-time dynamic modification of the design while in immersion ? Can we also build in design-like conventions, or learn to associate basic body conventions for design moves? Is there a particular type of interface which is design like ? Can you learn to do design in such an environment kinesthetically, through learned movements as in drawing ? Should transformations occur by physical gesture, by movement of the body, by voice, etc. Also requires a metaphorical convention system, e.g. up-down, in-out. Spatial location and movement may be a potential control mechanism for operations causing variable states in the model.

One possibility is the video capture and projection of the user's hands into the image space (Krueger, 1993). This technique can also provide the ability to adapt the depicted condition 'by hand'. This uses a 'sample plane' technology. The user's hands are photographed with video from above and from the sides. The hands can be projected onto the plane position in the computer model. Locational data is derived from the position of the hands and fingers which can be used as in-put for the three-d model. This supplies data without the need of a data glove and provides a tactile interface device. A vocabulary of basic interactions with the system, e.g.., grab, move , drop must be developed and programmed.

control

a) independent input device

In addition to natural interaction, independent input devices may be employed for controlling the model while immersed. This may be an independent input device such as a three-d mouse, voice input or an input device built into the visual representation such as an a touch sensitive mechanism.

- **control** should be integrated with
  - **sensing** should be coordinated with
    - **presence** should be part of
      - **views** should display design potential of the
      - **world**

The Development of a Virtual Design World: BOUNDARIES

Volume and spatial quality is, inter alia, a function of the formal character of spatial boundary. The subject of the design world is the formal content of the physical boundary between interior and exterior. The nature and form of the exterior wall is one of the fundamental elements of architectural design. Usually boundary can be experienced only through multiple experiences of different spaces over time. We are developing a system which makes it possible to study space definition and boundary.

BOUNDARIES is a system which will provide the possibility of studying the relationship between interior spatial quality and the physical boundaries of a space. It contains a vocabulary of design variables which define a range of boundary types between interior space and the exterior. The design world is one space; the variables apply to the four walls around the space, which can be designed individually, or globally. The system should also provide experience of absolute boundaries as well as variety of 'implied' boundaries.

The objective of the VR system is to provide an exploratory design environment for the study of this building sub-system on the basis of a selected list of design variables. Components of the wall are treated as formal systems, rather than actual building details. For example, windows are treated as openings in walls, rather than displaying the diversity of window types, materials and details. The purpose is to be able to study the affect of large scale variations, such as penetrations versus surfaces, full height openings versus types of penetrations, vertical stratification of the wall, etc. Some effort will also be made to window surrounds (brise-soleil), which affects the experiential quality of the wall opening.

The definition of variables is based upon three primary sources in the literature.
The first includes comprehensive studies on the exterior wall as a building system. The second is literature on formal systems in architecture. Finally, are works which deal with the wall as a source of particular types of experience in architecture. The variables which are currently included in the model are:

-boundary demarcation line
-surface-penetration
types of penetration (opening size, proportion)
regularity-irregularity
opaque - transparent (quality of opening)
-surface subdivision (vertical)
panels: vertical subdivisions (full-height openings)
  location
structure: columns, piers, panels
-surface subdivision (horizontal) = stratification
basic wall section types (horizontal stratifications)
-brise-soleil (basic types:cap, panel, hood)
-continuities (implied versus absolute boundaries)
projection of horizontal roof surface beyond boundary
projection of floor beyond boundary
projection of interior panels beyond boundary

We are also attempting to provide a standard exterior lighting condition.

This is a pilot system which enables us to study research issues related VR design environments and VR collaborative environments. As such, the issues described above for VR design environments become relevant developmental problems. These include providing knowledge about the variables 'behind the scene'; manipulating variables while in immersion, providing continuous versus discrete changes of variables, providing a 'natural design interface' within the system, achieving a multiple user environment.

Discussion and Conclusions

Liminality is 'a realm of pure possibility when novel configurations of ideas and relations may arise' ; it is an 'intermingling and juxtaposing of categories of event, experience and knowledge, with a pedagogical intention ' (Tomas, 1992). These quotations touch upon two of the key attributes of VR in our experiment. The first of these is the nature and cognition of design Finding an analogy for this in design systems has so far evaded us. We expect that the design environment which we are seeking will provide a computational approximation for this phenomenon.

With respect to the educational potential of the medium, the idea of event, experience and knowledge as a potentially integrated triad in VR appears to address Schön's problem of communication in design education. The giving of reason, is potentially achieved by collaborative interaction with a design world activated by physical events.

The idea of constructing and exploring virtual design worlds is part of the underlying motivation for our pilot project. The concept of design by constructing within a virtual environment is an extraordinarily stimulating concept, and BOUNDARIES merely suggests some of the possibilities. It touches on the possibility of the computer as a supportive technology for design.

Acknowledgments: Marc Coomans is a graduate student at TUE Netherlands who is currently working on the BOUNDARIES VR Design Environment.

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