Linking the Virtual to Reality: CAD & Physical Modeling

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Using both study models and digital models for schematic design allows its to take advantage of the strengths of each. Models constructed manually benefit from spontaneous juxta positions and serendipitous interactions with light and gravity. Converting these models into the digital realm allows the computer to take over in areas that it does best: geometric transformation, rigorous analysis, elaboration and co-ordination of details and complexity. As a project develops, CAD/CAM methods can generate forms or components for verifying the virtual representation. The paradigm *of porting data to appropriate software tools needs to be extended to exporting out of and into the physical realm. Connecting to models in real space allows its to use senses that are not yet completely addressed by digital models.*

Keywords: modeling, representation, design

1 Introduction

A critical problem for young designers is the inability to integrate building technology and structures into design projects. The increasing complexity an specialization of construction has increased the distance of architects from the construction process. Furthermore, the widening use of CAD modeling has pushed design towards the abstraction of geometry and away from the intuitive understanding of material properties and assembly processes. This paper explores:

(a) How physical and digital modeling can be used to complement each other for an intuitive understanding of using materials in design.

(b) How the act of translating from one medium to another provides an opportunity for enriching the design process.

(c) How the re-interpretation process can enhance understanding in design studios and collaborative design experiments.

2 Designing with models

2.1 The physical experience of architecture and architectural models

Rather than being a nostalgic retreat to an outdated medium, the use of physical study models can be a method of enhancing the immediacy of projects developed with the computer. Physical models communicate better than their flat screen simulations because sculptural objects inhabit the real space of the viewer, while frames isolate imaginary spaces. [1] 3D objects confront the viewer with their presence; interacting with the viewer by providing different appearances from different angles and reflecting lighting and images from the enclosing room. The viewer does not have to adapt to the convention of the media as required by the flat rectangular frame of paintings, movies and monitors. While virtual reality (VR) developers strive to break through the frame and establish new conventions, we can work back and forth between real and digital models to understand the way we interact with them and what qualities to seek in the new simulations.

For VR, we must be very specific about what is missing from digital simulations and what perceptual mechanisms are at play. It is instructive to look at the physical nature of inhabiting space and the continuing attraction of scale models. While it is exciting to have interactive simulated environments, we need to feel the textures and weights of objects, feel our breath bounce off of enclosed spaces, hear the echoes of the high spaces and feel the angle of the ramps that we walk on.

In "Body, Memory and Architecture, Bloomer and Moore remind us of the role that the senses play in our enjoyment of architecture. They expand the definition of the sense of touch to include orientation, pressure, temperature and kinesthetics as well as physical contact inside and outside the entire body. [2] Exactly these aspects, which occur naturally through the forces of nature (light, gravity, heat, wind, humidity, and acoustics) on our own bodies, are the most difficult to simulate digitally. Modeling with materials which are subject to some of the same physical forces (light and gravity) provides an intuitive connection to our sensory experience of the environment.

2.2 Structural legibility

As a starting point, a wood and wire model gives more clues as to structural soundness compared to a CAD model created in abstract Cartesian space. Material properties such as density, grain, mass distribution and flexibility which can easily be felt and observed provide a basis for intuitive designing. Even though we must substitute miniature materials for the real ones, we can still read the certain properties through the analogous parts: structural instability becomes obvious, deflections and tensions reveal weaknesses. The models can clarify the modes of failure, the appropriate type of connections and the effect of different kinds of loading conditions. [3] Sometimes manipulating models can generate new structurally-based forms, as Gaudi's funicular chain models and Frei Otto s tension structures. While structural forces (as well as other environmental factors) can be calculated, study models provide a shortcut for working with structural and aesthetic aspects simultaneously.

2.3 The interactive appeal of the tactile, the miniature and the unfinished

In addition to giving technical feedback, study models can affect us emotionally. Most media can be used to communicate both to the intellect through abstraction and to the emotions through through suggestion. Models appeal to the emotions through the tactility of materials, the miniaturization of scale, and the mark of the human hand. They invite the imagination to participate in creating the illusion of reality. A desire to make-believe is shown in the fact that we can enjoy the tactile quality of even the most ersatz material if we can adjust it in the light. The same motivation compels us towards multimedia which by contrast can only give us pre-planned responses.

In contrast, open-ended exploration is possible in working with models. The miniature nature of scale models also draws us in. Gaston Bachelard explains, *"The cleverer I am at miniaturizing the world, the better I possess it . Values become condensed and enriched in miniature. .. One must go beyond logic in order to experience what is large in what is small."* [4] As in the cinema, our participation requires a suspension of disbelief. Awareness of the artificial quality of the medium plays a part in our involvement in it. [5] It is different from navigating through hyperspace because our feet are always on the ground: we always maintain the frame of reference of our own bodies to the object which inhabits the same space. While this is banal for fantasy adventures, it works well for imagining proposed architectural projects.

Grounding the models to our own world while letting the imagination soar helps generate early design variations. Bachelard explains *"the imagination does not want to end in a diagram that summarizes acquired learning. It seeks a pretext to multiply images, and as soon as the imagination is interested by an image, this increases its value."*

The imagination is charmed by little quirks and asymmetries that belie the human touch. The gestural sketch or the plot that is enlivened a shaky pen [6] provides little niches for the imagination to rest. Model building has a similar spontaneity that comes from being surrounded by the serendipitous scraps that can be juxtaposed in ways that would seldom occur in algorithmically defined digital systems. Since happy accidents encourage freedom in changing metaphors, there is more chance of new insights through model building. [7] The unfinished and unpredictable invite exploratory answers.

3 Translating between media

3.1 Different constraints & operations yield different insights

The rich possibilities of study models doesn't mean that computer models can't surpass them. Rather, we need to see how we can use the advantages of both to create synergy. Every tool has its own biases: we turn to a solid modeler versus surface modelers because certain forms are sensibly created by Boolean operations. So we rely on file converters to address different aspects of a single project with different applications.

If we could port data smoothly into and out of the computer, then we could choose the most appropriate tool even if it exists out of the digital world. For example, in early brainstorming it does not make sense to create a complex CAD model and animate it realistically when simple planes of cardboard adjusted under natural light can yield attractive possibilities more quickly. While visualization tools are beginning to rival study models in ease of use, the models still are still worthwhile since they allow us to see the work in a different way.

3.2 Enrichment in the translation process

The value of working in more than one medium and translating an idea through different media is explained in Robin Evans' essay, Translations from Drawing to Building. [8] He explains that while most artists work directly with a medium, whether it be paint or clay, architects have to work on creating buildings through the medium of drawing rather than through the actual bricks and mortar. While architects lose the immediate feedback that comes from manipulating materials and seeing their properties, they gain from the precision and abstract nature of drawing. Drawings, particularly digital ones, allow us to project and manipulate complex geometry in ways that would not occur by working in stone.

Not only can the specific qualities of each medium enhance the final product. but the conversion process itself provides opportunity for reflection and refinement. When the transition is not seamless and automatic, it requires consideration of what is essential and how to express it. In the case of translating from drawing to building, there is usually a negotiation between the contractor and the architect so that the design intent is realized most effectively. It follows that potential enrichment can take place when re-articulating into any new medium.

3.3 Getting in and out of the physical realm

Translating from study model to CAD provides a similar opportunity for enrichment as the design concept must be re-articulated. Starting from study models allows quick experimentation. Once the concept is set, the basic version can be digitized. 3D digitizing tools provide a means to translate from the physical world to the digital world, simplify the modeling of non-rectilinear forms. They can liberate designers using computers from the bias of CAD systems towards regular shapes which are easy to model. While automated laser digitizers are still prohibitively expensive, simple touch-probe scanners are becoming more accessible. [9]

Even with the assistance of 3D digitizers, choices must be made so that the database reflects the order of the design. CAD systems require us to organize information by grouping similar parts into layers or levels, by defining library symbols and by developing hierarchical families. The process of defining categories and relationships is a form of the translation process mentioned by Evans: it forces us to clarify the project. Beginning with these first definitions, the computer program enhances refinement of the study model.

As the project matures in the computer it is possible to use CAD/CAM methods to create new physical versions. The computer-generated object acts as a check plot: providing a different way of seeing the digital model. Incorporating adjustments made to one of these forms back into its database is currently difficult, as crude digitized data has to be reconciled with the previously developed precise database. Until tools for working across the raster/vector interface get optimized for 3D, it is practical only to go in one direction with the process: from the developed digital form to the physical one, not back again.

The computer-generated pieces allow confirmation of the later stages of design when dimensional refinement is critical. In contrast to the crudeness of early study models, computer-driven cutting, milling and rapid prototyping devices create components with the fine tolerances necessary for industrial design. The tools facility in precisely forming 3D curves and irregular geometry makes it possible to explore these forms more fully at any scale: from the urban strategy to component fasteners. [10]

4 Using the translation process in education

4.1 Precedents in using physical processes with computers

Some architecture schools have been exploring how to maximize the combination of traditional processes used with digital ones:In 1989, Frank Miller at MIT looked at parametric variation of solid models. [11] Forms were generated on the physical analogy of solid modeling: Styrofoam carved with a hot-wire cutter. After recreating the forms in a CAD system, their geometry was stretched and re-scaled to become architectural elements. The computer allowed Boolean intersections to be taken as well as additions and subtractions. Multiple variants could be easily generated and combined into architectural compositions.

At Rensselaer Polytechnic, Peter Parsons has used woodworking along with computer modeling. [12] By introducing students to woodcarving, he gives them an intuitive understanding of the corporeal nature of the material, for example, the knowledge that carving with the grain is smoother than carving against it. In translating the carved projects into the computer, the students had to apply co-ordinate systems and transformation operations. This helped them see the correspondence between the physical and the digital world

More recently at MIT, a studio built on work led by James Glymph at Frank Gehrys office has exploited the computer's ability to record and manipulate complex forms. [13] As one of the instructors, Andrew Scott explained, free sculptural designs generated from the physical properties of wire, wood and glass were digitized in three-dimensions to provide the basis for architectural spaces. The computer was then used for structural analysis, construction detailing and computer-aided milling of large-scale components.

4.2 Improving a CAD studio with wooden models

At the University of Hong Kong, we are studying how the translation process can be used as an educational tool. In the most direct example, we have modified a second year undergraduate design project from a completely CAD exercise to a hybrid exercise. The project leads the students through creating a modular bay and designing a larger building from the standard bays. To stress the structural and construction aspects of the project, the building is to be assembled from pre-fabricated components of their own design. Because the structural components can be hierarchically composed, they provide a natural vehicle for learning about hierarchical data structures and symbol libraries. Before doing the project, the students have taken a required computer course including 2D and 3D AutoCAD.

In 1993-94, CAD dominated the project. After spending a preliminary week on examining precedents, the students split the remaining 6 weeks on the modular bay and then the building design. The largest problem that emerged was that the students were unable to understand what they were drawing: there was little understanding of lateral bracing or appropriateness in structural sizing. Since the work was mostly examined in the form of ambiguous wireframe plots, confusion about structural stability was widespread.

The next year, we addressed the problems by restructuring the project into specific phases which would integrate more physical modeling. Before the precedents study, we kicked off with a 3 day challenge: create the lightest possible bridge of standard cardboard to support two heavy water bottles over a 900 mm span. This classic problem of utilizing minimal materials was heavily discussed among the students. To follow this line of thinking, the students had to construct physical models of

(1) a bay from a historical precedent,
(2) their own bay in simplified form and

(3) their site design. Starting from the large bay models made it easy to see deflection and instability.

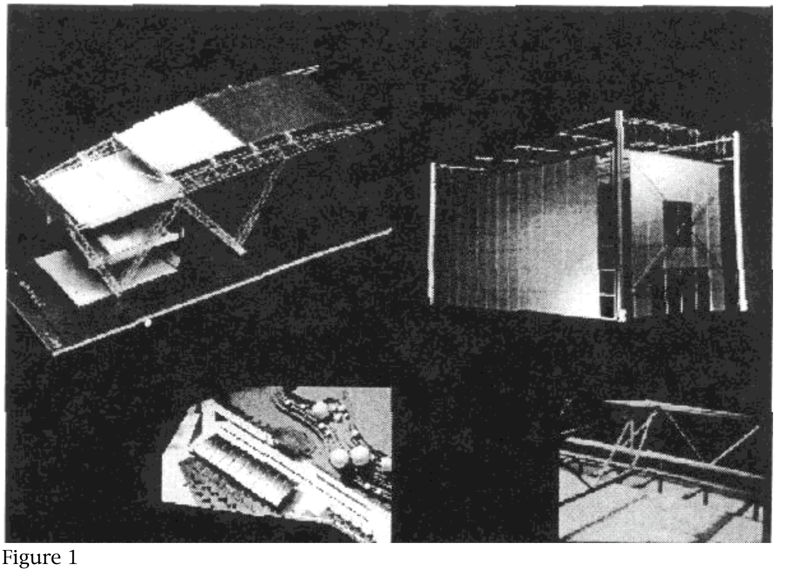

Figure 1

So, while the wood and cardboard models were used for the close-up design and the urban massing, the CAD was used for explaining construction and the building scale. Students caught on to how easily they could make an exploded axonometric drawing to show the layering of components. They appreciated the ease with which the computer helped them manipulate and multiply parts of their design which would have been tedious to build by hand.

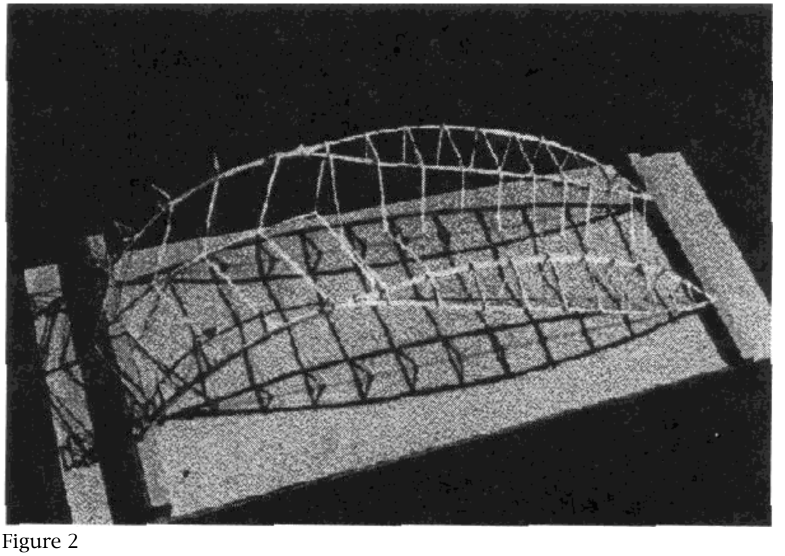

Figure 2

The study model can provide a deeper understanding of the physical phenomenon, while the digital model provides powerful tools to transform or extend a design. One way they can work together occurred when one student became fascinated by another's well -crafted wire and thread model of a bay from Nicholas Grimshaw's Waterloo International Terminal. For his own design, he used a similar three-dimensional 'banana-shaped arched truss as the main support. Working completely in 3D CAD, he exploited the tools geometric precision to extend the arcs of the truss past their intersection at the joint with tangent lines. From the tripod formed by these lines, he created a sculptural concrete pier form with arcs and offset lines.

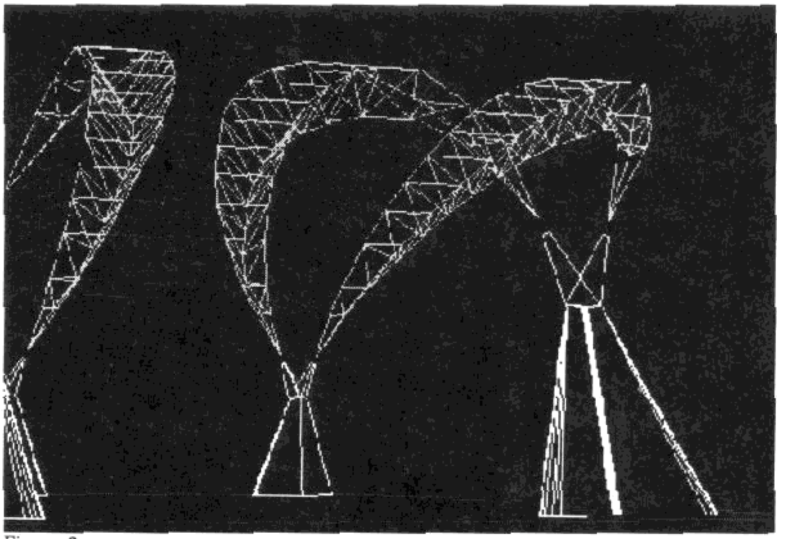

Figure 3

Since the shape of the pier would have been hard to visualize without geometric tools and tricky to build in cardboard, it is unlikely that it would have been made without the computer.

The CAD model forces precision in defining geometry and requires an understanding of the abstract organization of the design while the physical model emphasizes the sensual properties of mass and transparency. Furthermore, the digital world allow us to go beyond what is immediately apparent to the senses, to rigorously understand a project through structural analysis, environmental analysis, and artificial intelligence tools.

4.3 Caveats

Creating both CAD and physical models can show students the different strengths of each as design tools, but it can increase the amount of busywork. Rather than duplicating what was done before in another medium, the models should be created to explore a different aspect or scale. Working in multiple mediums requires more skill building, but can yield more insight.

Another potential difficulty in either the digital or miniature world is the danger in getting lost in scale and needless complexity. The fascination which attracts us to the scale model can hypnotize us into accepting spaces of different sizes as we accommodate ourselves like Alice in Wonderland to the scale clues of different spaces. The same mental distortion can occur in viewing CAD models as the infinitely adjustable zoom, depth of field and point of view gives the omnipotent power of shrinking and aggrandizing to even the novice user. Scale figures and restraints on viewing parameters can alleviate this problem.

The problem of finding the right level of detail aggravates both kinds of models. Detail in presentation is often incorrectly understood to show detail in conceptual development. Therefore, it is easy for sleep-deprived students to mindlessly add mullions and railing spindles, with the feeling that they are knitting their way to a higher grade. In computer modeling, a similar inefficiency can come through if students take elements like bolts and truss members into the urban level. Students need to be guided in working at appropriate levels of abstraction.

Despite the difficulties, encouraging students to work in both kinds of models will teach them how to choose the most effective means for exploring a particular problem.

5 Translating for different audiences

5.1 Translation for virtual design studio communications

Converting a project from study model to CAD model is just one example of the many translations that are commonly needed in the process of design. As a project develops, different modes of representation are needed for the designer's internal use as well as for communicating with colleagues, clients and consultants. [14] Traditionally this is done by creating a variety of artifacts like sketches, rough models and fancy renderings, using suitable material at hand. Each of the manifestations can show a different side or version of the design. Digital design makes it easier to maintain a consistent model through different types of exploration.

A recent experiment with networked communication elucidated the general need to master the translation process in order to address different kinds of communication requirements. In the Virtual Design Studio project organized by Jerzy Wojtowicz of University of British Columbia [15], students communicated their evolving designs over the World Wide Web (WWW), supplemented by e-mail and short synchronous communications. Because an ACSA competition was the vehicle for the joint project, the students found their presentation goal splintered into multiple targets:

(1) A hyperlinked presentation for individual browsing (by friend, critic and foe alike)

(2) A linear tour through that hypermedia document for the final video-conference review and

(3) A static presentation on boards for the competition submission.

In this case, it was difficult for a single Hypertext Markup Language (HTML) project to meet all three divergent goals. The multiple links that make individual exploration rich can be extraneous or distracting in a real-time presentation. While this transition from random access to linear tour within the digital world was a little bumpy, the transition into and out of the "virtual' world was much more difficult. The students working totally in the computer were frustrated at the quality and lack of reliability of the hardcopy devices. And the student who relied on traditional drawing and modelmaking for the panel felt that the scanner's was inadequate since a large drawing had to be scanned in strips.

The difficulties pointed out the need for architects to bring their concepts fluidly between formats to address different kinds of audiences. Networked communications can involve different kinds of communities and require advanced planning so that the communication channels used are appropriate. For example, design team members would need access to internal project information which would not be published to the client until it was finalized.

In the future, we will be working on how to make a project jump out of the digital world, using network wires as the jumping off points. Since we have not been able to achieve a paperless office, we won't be seeing a design office without drawings and models for a long time. Rather than work towards their elimination, we need to see how they can play a valuable role within the digital office.

So while our school begins its exploration of VR, we will also look at how to make the transitions to the real world. We are acquiring a 3D digitizer to simplify getting sketch models into the virtual world and we are seeking ways to access rapid prototyping machines so that forms can just as easily emerge. By emphasizing these connections to the tangible, physical world, we can use the VR lab to explore the pragmatic as well as the imaginary.

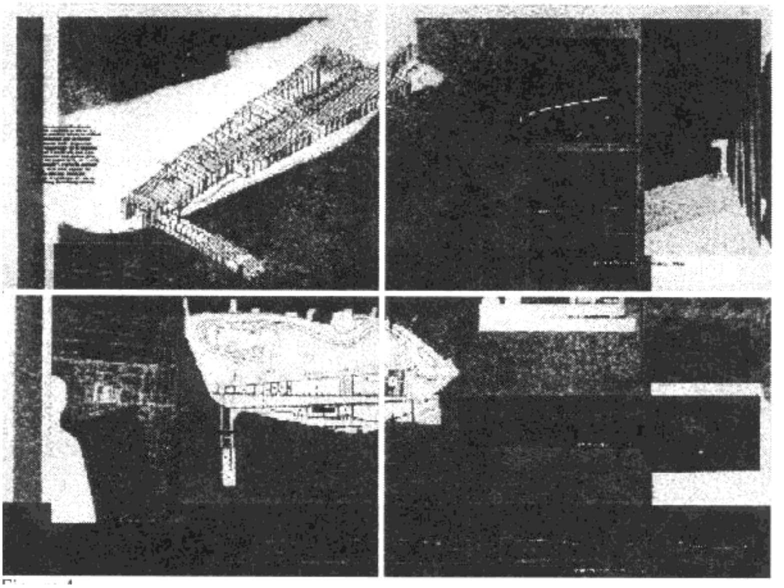

Figure 4

6 Endnotes

[1] Martin, F. D., Sculpture and Enlivened Space: Aesthetics and History, Lexington: The Univ. Press of Kentucky, 1966. Martin compares sculpture with painting to explain the mechanism of our perceptions.

[2] Bloomer, K. & Moore, C., Body, Memory and Architecture, New Haven, CT: Yale University Press, 1977, P. 3-35

[3] See Schodek, D., Structure in Sculpture, Cambridge, MA: MIT Press, 1993, pp. 16-17 and 25-26 for classifications of basic structural qualities.

[4] Bachelard, C., The Poetics of Space, Boston: Beacon Press, 1964, Chapter 7.

[5] See Arnheim, R., Film as Art, London: Faber & Faber, Ltd., 1958 for a description of why black and white cinema seem more compelling than the more 'realistic color cinema.

[6] Van Bakergem, Davis & Obata, in ACADIA90.

[7] To see how sketches and CAD can work together, see Herbert, Daniel, in Reconnecting, ACADIA '94, St. Louis and "Study Drawings in Architectural Design: Their Properties as a Graphic Medium" in Journal of Architectural Education, Winter 1988, v.41, no. 2, pp. 26-38.

[8] Evans, R., 'Translations from Drawing to Building', AA Files 12, London: Architectural Association, Summer 1986.

[9] "3D Digitizing for Engineering", Computer Graphics World, March 1995.

[10] Fisher, T., 'Model Making: A Model of Practice" in Progressive Architecture, May 1995.

[11] Miller, F., "Solid Modeling in the Preliminary Design Process" in CAAD Futures '89 Conference Proceedings, Cambridge, MA.

[12] Parsons, P. W., "Craft and Geometry in Architecture: An Experimental Design Studio Using the Computer", in Re-connecting, ACADIA '94,, St. Louis, Missouri.

[13] From an interview with A. Scott, June 1994. See B.J. Novitski's "Freedom of Form" in Architecture magazine, Aug 1994, p. 107+ for ideas explored in W.J.Mitchell, A. Scott, J. Glyph & 1. Nagakura's Digital Studio, Spring Semester 1994. Strategies used in this studio provided the basis for the sequencing of media described in section 2 of this paper.

[14] For a description of drawings as social mediators, see Robbins, E., Why Architects Draw, Cambridge, Mass: MIT Press, 1993, Section 1, 'The Social Uses of Drawing", pp. 1-26.

[15] Wojtowicz, J., (ed)., Virtual Design Studio, Hong Kong: HKU Press, 1995. and Cheng, N. et al., "Place, Time and the Virtual Design Studio" in Re-connecting, ACADIA '94,, St. Louis, Missouri.

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