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Form Processing Workshop: Architectural Design and Solid Modeling at MIT

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Introduction

Computing impacts the preliminary architectural design process as a tool for observation and analysis, as a formal prototyping tool, and as a vehicle to generate variations of objects and assemblies. Through the use of both traditional and computing tools, the Form Processing Workshop examines the relationship between design decisions and design tools. The Workshop utilizes several software applications, with emphasis on the use of a solid modeler. This curriculum was developed with the support of MIT's Project Athena.

Observation, Documentation, and Analysis of References

"When one... works with visual things-architecture, painting or sculpture-one uses one eyes and draws, so as to fix *deep down in one's experience what has been seen. Once the impression has been recorded by the pencil, it stays for good, entered, registered, inscribed... To draw oneself, to trace the lines, to handle the volumes, organize the surfaces... all this means first to look, and then to observe, and finally perhaps to discover... and it is then that inspiration may come."* Le Corbusier

The Discipline of Seeing

Design learning is importantly linked to developing new ways of perceiving and describing the built world. The computer has joined the pencil as a significant tool in this documentary process. The Form Processing Workshop includes a series of exercises intended to sharpen students' analytic capabilities and explore the role of the computer in architectural observation. This project also serves to introduce students to the concepts and functionality of the CAD solid modeler used during the subject.

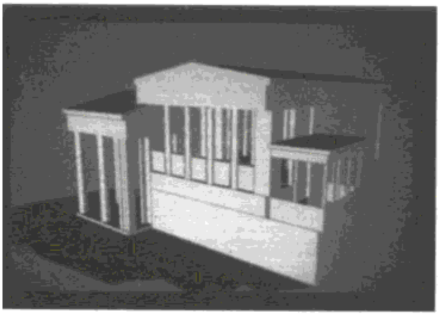
Students are asked to select a significant work of architecture and adopt one of several points of view as a perceptual framework within which to observe and describe the project. The solid modeler is used as the primary tool with which to build a three-dimensional model of the building.

During the past several years this process has produced a growing number of documented buildings which are available to students for analysis. This collection of architectural references represents the reincarnation of an old institution in the MIT Department of Architecture. Up until the 1960's, there existed a collection of scale models of classical architecture which was referred to unofficially as the Model Morgue. These models were loaned out to studios for the analysis of organization, construction, and various formal characteristics. It is the intention of this new collection of digital models to reestablish this idea and extend it to studios by incorporating the use of computer modeling.

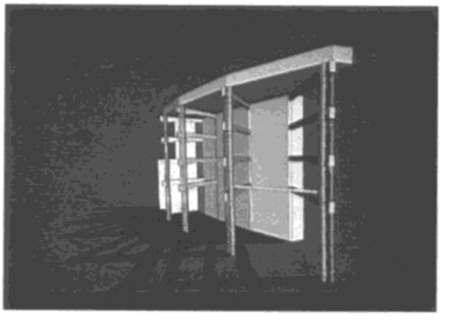
The sources of information from which to build digital models of existing buildings can be found in published books, journals, site measurements, working drawings and photographs. The strategies for constructing these models reflect the available documentation of the building, the structure of the building, and the design issues being explored by the student. These strategies include assembly of parts, subdivision from whole objects, and different techniques for aggregation of assemblies. Some of the design issues which have been explored include:

Primary / Secondary Structure
Dimensional! Modular Studies
Form of the Primary Access
Relations of Public / Private
Light / Shadow Studies

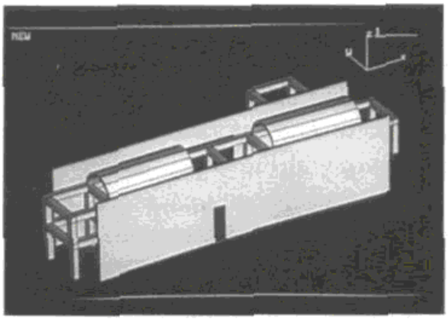
The digital models have also been utilized to generate previously unpublished projections and to animate sequences of views.



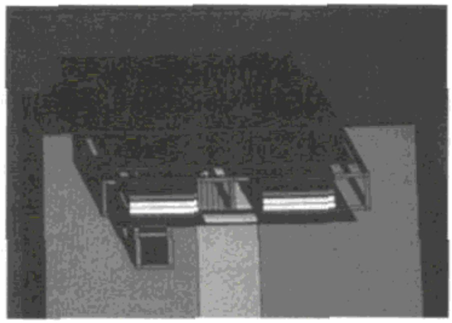
Erectheum, Athens



Boston Five Cent Bank



Residence, T. Ando



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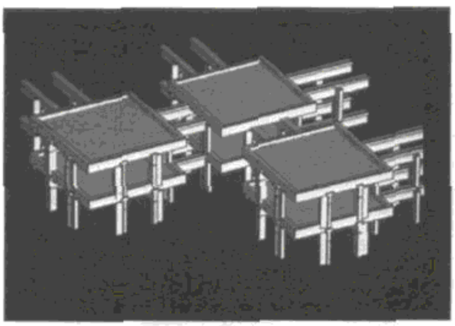
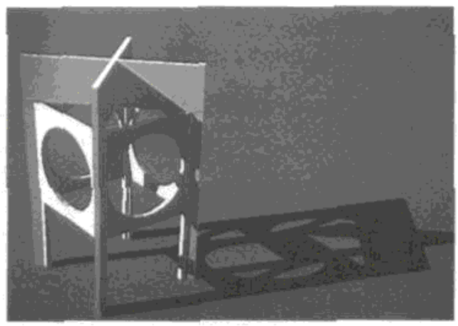
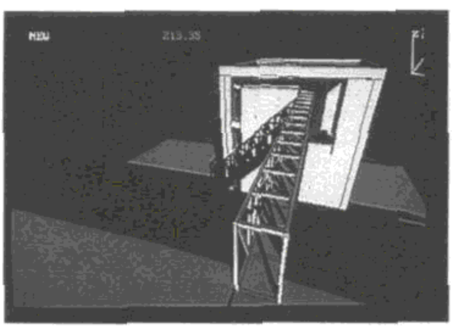


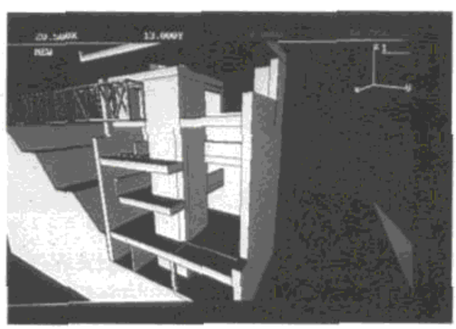
Centraal Beheer, H. Herberger



Exeter Library, L. Kahn



Residence, M. Botta

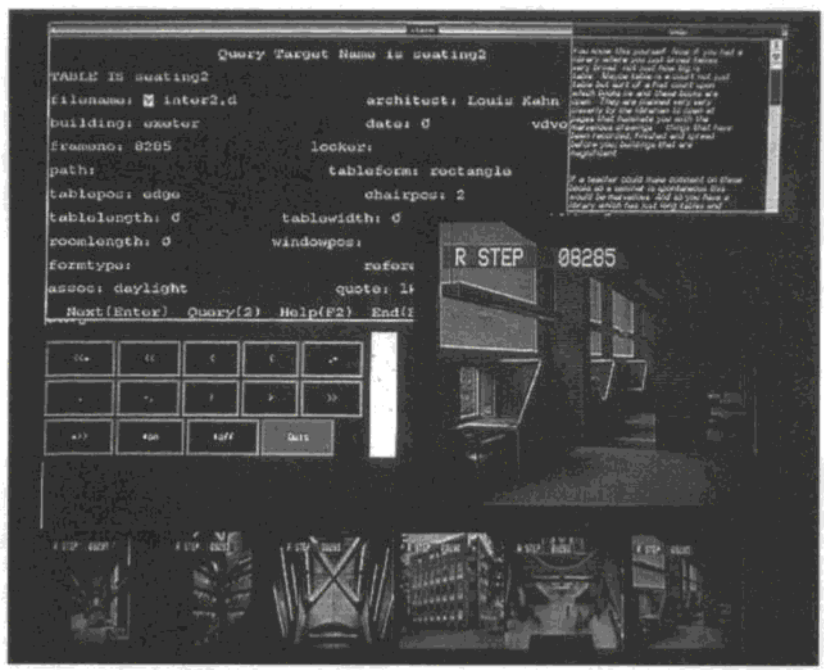


Section through solid model

Forms of Documentation

in analyzing architectural references, students commonly use many tools in addition to 3D models. These include drawings, diagrams, photographs, text, audio and even motion pictures. The management of this diverse information during the design process in the typical studio is often achieved with the display technology of homosote tack boards and file folders of potentially relevant images. Typically, standard-sized boards serve to group images and permit associations between them. The strategies for organizing the individual images and groups of images vary widely, and reflect the particular design method being explored.

While these references play a crucial role in establishing critical positions and in analysis of precedent, there exist few if any interactive links between CAD application software and these extended collections of reference material. Utilizing Project Athena workstations, we have built a prototype system for collecting, storing, managing and displaying these reference resources. Images can be captured from hardcopy, slides, video and computer screens and stored in either an analogue video format or a digital bit-mapped format. Access to these collections is facilitated



Design Reference Management System. For the key image at right center, the supporting resources include a relational database record at upper left, a quote by the architect about the image, and at bottom, a set of images with which the key image has been associated.

by means of either a relational database (Ingres) or a rule-based shell application (Knowledge Engineering System). While development of this prototype system falls outside the scope of the Workshop, it has proceeded in parallel and has benefited from the image collections and explorations of the problems of using references encountered during the Workshop. One of the primary problems in the effective use of these references is establishing the categories for collecting, grouping,and retrieving images.

The Problem of Classification

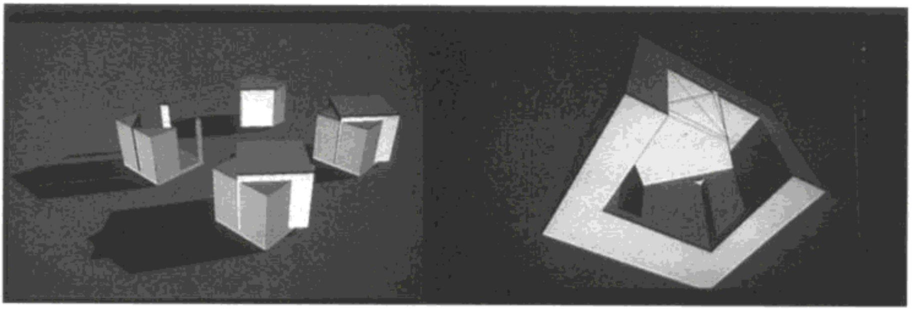
"The world was made before the English language and seemingly on a different
design." Robert Louis Stevenson

The classification of books and periodicals is standardized through the Library of Congress system. Images, audio and motion picture have no parallel classification system, and library collections of audio-visual material have had to improvise their own schemes. Typically, they make use primarily of simplified but generally useful categories, and to a lesser extent respond to the local description priorities of departmental teaching and research. The classification needs of studios are usually derived from the design methods used, and therefore vary widely among studios. This situation challenges the capabilities of a computerized reference management system, in that the database tables and relations that describe images suitably for the slide library may be of marginal use to a studio, and a scheme which suits that studio may be of little use to another studio.

The problem of architectural classification is intimately linked to the way in which one structures and represents design knowledge. During the Workshop, this relationship is discussed in an effort to more clearly articulate and elaborate the descriptions essential to the design methods at hand. This problem is explored in greater depth through the parallel research seminar.

Prototyping Artifacts and Formal Organizations

Another primary design issue in the Form Processing Workshop is that of architectural prototyping. While this subject has wide interpretation, our emphasis has been on methods of prototyping structural elements and on the formal organization of the public access in a building. CAD modelers are acknowledged as powerful tools for generating variations of objects, yet we have found that the geometric primitives created with CAD modelers tend to have little intrinsic formal complexity or associative connection to external ordering systems. CAD modelers lack some of the basic constraints found with physical models such as gravity, mass and connection. Exercises which



Solid modeling boolean operations: left, difference; rear, intersection; right, union,

The double cube solid converted to a void and placed within a larger cube to create a space

introduce external constraints into the prototyping process have been developed. The goal of these is to encourage use of source objects with origins in structural vocabularies, construction processes, or formal / organizational types.

The spatial notions utilized in generating these source primitives include solids, voids and territories. Solids are described as the positive physical objects and elements of enclosures which are deployed to divide or enclose space. Inversely, voids are the negative spatial shapes which are defined by their own boundaries independent of the objects placed in or around them. Designers commonly manipulate both of these, alternately defining the elements of physical enclosure and shaping the spaces contained within and between these physical artifacts.

The relationship between these opposing space defining principles of solids and voids has a long history, and is vital to the contemporary aesthetics of architectural placemaking. Fifteen hundred years ago, the Taoist tradition emphasized the primacy of space:

'We make doors and windows for a room. But it is these empty spaces that makes a room livable

This position reveals a bias in favor of the contained, the space within. The belief that the nonexistent is essential, that it is made tangible by the material form, established the understanding that the true potential of architecture lay within the intangible.

Plato held that space wa composed of air, a *tangible* substance distinct from the other elements. During the Renaissance, Neoplatonists defined the proportions of buildings by the subdivision of finite tangible forms.

The third notion used in the workshop's design method can be identified as territory' or place', and adds the crucial consideration of perception and inhabitation to the objective geometric representations of solid and void. This notion has origins in Aristotle's theory of place as being distinct from either form or material:

"... yet form and place do not delimit the same thing: form is the limit of the thing circumscribed; place is the limit of the circumscribed body... Thus the place of anything is the first unmoved boundary of what surrounds it."

Descartes extended this understanding with the important idea that spatiality is identical with the extension of matter. If you take away the matter, their exists no space as an independent entity; there is not anything left at all. Therein lay the unity of the historically opposing principles of matter and space, and set the stage for Einstein's proposition that reality consists of neither space nor matter, but rather of the sum of various fields of force.

"This total field [is] the only means of description o/ the real world. The space aspect of real things is then completely represented by a field, which depends on four coordinate parameters; it is a quality of this field. If we think of this field as being removed, there is no 'space' which remains, since space does not have an independent existence."

This provides a relevant metaphor for the notion of territory as neither solid or void, but rather as the region of optional use which is enabled by the formal and geometric relationship between artifacts and their associated spatial regions.

Out of this perception has come the description of architectural ordering systems based on the continuity of change and the possibilities inherent in a situation. Use, in this context, can be defined as the stream of situations in a setting rather than some mechanistic reference to singular, discrete functions. The involvement inhabitants have with a building is, like history, always richer in content, more varied, more spontaneous, lively and subtle than even the best designers (or historians) can imagine. Inhabitation, like history, is full of curious accidents and juxtapositions of events, revealing the complexity of human interaction, change and association. In this sense, 'territories' can be described as the sum of the possible events which might occur in relation to architectural interventions.

In response to this architectural agenda in the Form Processing Workshop, how do CAD systems enable or constrain the ways by which designers perceive their work? How do CAD systems tend to limit the design concepts which architects employ?

Most CAD systems provide the capability of creating and editing geometry which is composed simply of lines. Some systems include the description of surfaces, or polygons. In contrast, solid modelers, based on constructive solid geometry, are able to represent both solids and voids and often also provide options for editing both lines and surfaces. While solid modelers most closely match the representational needs described above, none of the available CAD applications packages has the ability to recognize or instantiate territories providing options for current or potential use by people. These considerations are therefore pursued though discussion, annotation, arm waving, and sketching, and emerge as a description of the relations between form and use.

Strategies for Prototyping

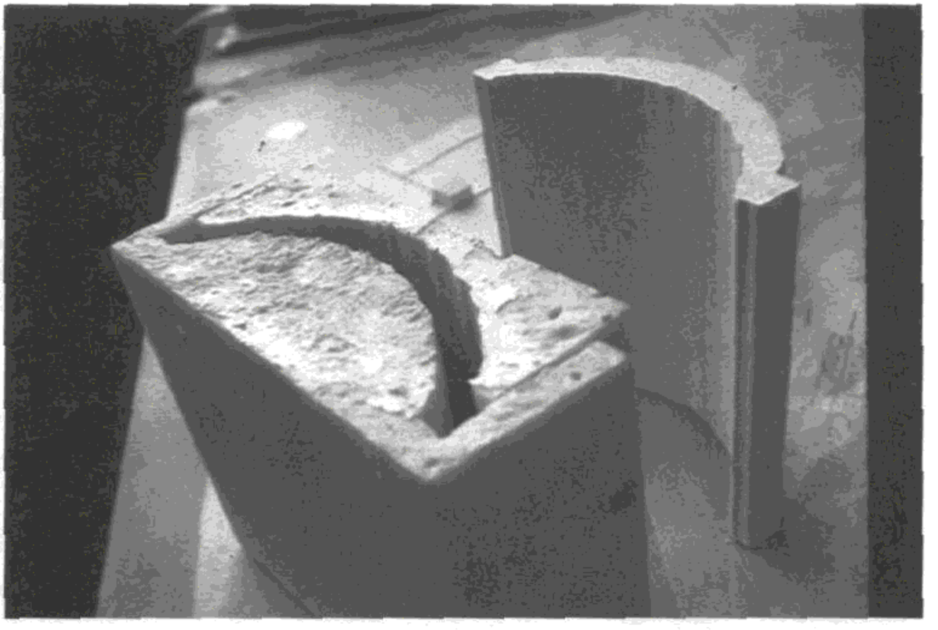
During the Workshop, three primary strategies are employed in the process of prototyping artifacts. One of these strategies incorporates reference to the constraints and possibilities of processes used in building construction. Secondly, an attempt is made to create the best fit possible between the stated goal of the design and the tools to be used. Thirdly, the artifact being prototyped is evaluated through successive representation in different modeling and drawing media. These are described below.

One of the archetypal form-making methods in building construction involves casting materials into molds. The primary constraints of this process include preventing the mold from leaking the casting material, providing for the removal of the mold from the casting, and securing the structural integrity of the mold during casting. Through the use of plaster casting by students in the workshop, these considerations are used to steer the prototyping process. Students are given blocks of rigid foam measuring four inches square and two inches thick. Using a hot wire cutting table, they are asked to cut the block into two pieces, to be displaced from one another creating a void into which to pour plaster. The exercise is repeated with two cuts, resulting in three pieces of foam with which to build the formwork.

In an effort to evaluate and extend these results, students replicate this process with the solid modeler by making the same cuts to a solid in the software, and using the Boolean operations to make a 'cast" of the mold. The resulting object is essentially identical to the piece cast in plaster.

The next step was to instantiate variations of the object in the solid modeler, simply through controlling XYZ proportions of the original. These variations are evaluated with respect to their architectural potential, and the most promising ones are incorporated into a vocabulary of structural elements to be used in assembling a building.

Sometimes, the limitations of the original casting are addressed by altering the foam cutting exercise and cycling through the entire process. In fact, some of the foam cuts yield no possible mold options, and in other cases the cast object seems barren with respect to its architectural potential. In a few cases, castings cannot be removed from the mold, and others leak or explode. In any case, the constraints of casting establish a conceptual frame work within which the form making process occurs, and lends to the CAD models a sense of association and reference to a clear external ordering system.



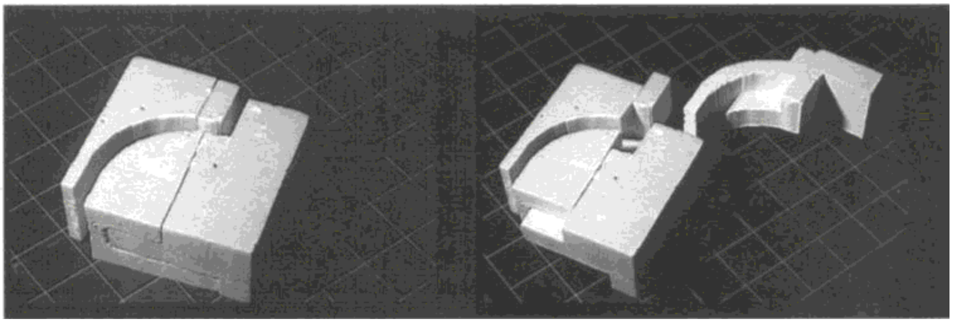
The one-cut exercise. After the foam block is cut once with a hot wire cutter, the two pieces are displayed to create a formwork void for casting the prototype element in plaster.

Furthermore, moving the object between physical and digital modeling media provides a broader range of context and precedent for the evaluation of design decisions.

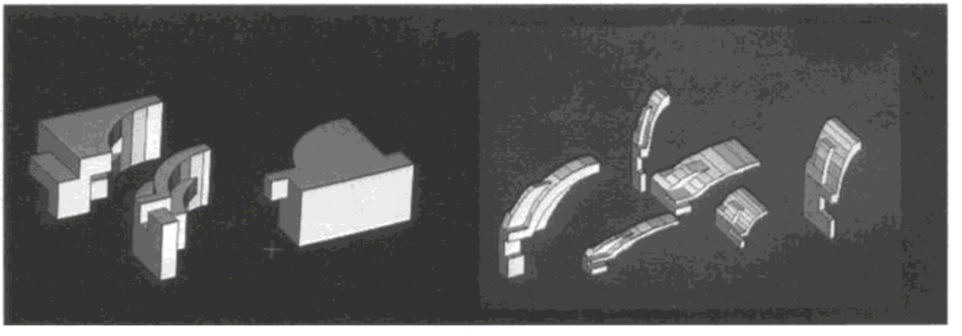
Variations of Artifacts and Formal Organizations

The third major focus of the Form Processing Workshop is on design procedures which generate variations of prototype artifacts by selectively altering proportional, dimensional and positional relationships. This activity of exploration and optimization is a standard part of design practice, and has traditionally been practiced b hand using drawing and models. The computer offers a powerful new capability in this regard, through its use of digital media and a model structure which distinguishes between the visual three dimensional model and the corresponding abstract representation in the database. By manipulating relations in the database, variations of the original object can quickly be generated through what is commonly referred to as parametric instantiation.

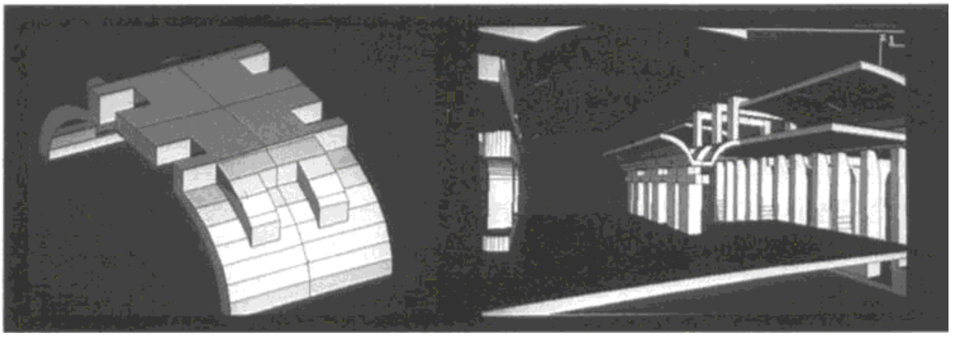
With respect to manipulating the database of the geometric model, several design topics are emphasized in the workshop. The first of these is controlling the size and scale of the architectural elements. This is achieved by altering the



a) b)



c) d)



e) f)

The two-cut exercise:
a) The foam block cut in two directions
b) the displaced foam pieces and the resulting prototype plaster casting
c) the analagous process of cutting and casting with the solid modeler
d) parameteric variations of the prototype element created with the solild modeler
e) and f) parametric elements aggregated into building assemblies

size of an artifact or opening by changing its dimensions while preserving its proportional relationships. In addition to controlling the size, any combination of the X, Y, and Z proportions of the object may be altered.

The second topic focuses on methods for making quick studies comparing alternative instantiations of sets of objects in a model such as columns, windows, or furniture. Through redefining the identity of these objects in the database, previously created variations of them may be swappped in and out of the building design.

The third topic is related to the above two, and addresses the need to manage the level of displayed detail needed for editing the model and making design decisions. The primary strategy is to match the level of abstraction of the model to the kinds of design issues being considered. For example, site design needs only a highly abstracted massing model of the building, while the layout of circulation in a space requires a higher level of detail in the nearby surrounding area, but only an approximate representations of the rest of the building. This serves to focus the designers attention on the most relevant features of the building, thereby sharpening the inquiry and highlighting the crucial design priorities. With traditional media, greater abstraction is achieved with study models and diagrams, while detailed drawings and models address more focused and precise considerations. No available CAD system directly or adequately addresses this familiar aspect of designing, so specific methodologies must be used to solve these problems.

Another reason to minimize the level of detail in a CAD model is in order to maximize the processing speed of the computer during editing and visualization processes. Regardless of the processing speed of the system, students consistently increase the level of detail in the model to the point where they can't stand to wait the several seconds or minutes it takes to complete editing commands.

Instantiation vs Diagnosis

In addition to controlling the XYZ sizes of an object, the relations between elements of an assembly can be controlled through procedures describing the constraints and rules for assembly. Such procedures model the process of assembly which generated the design rather than merely modeling the current geometry of displayed elements, and may be used for either generating design solutions or for diagnosing problems with an existing design. While the bulk of the work in this area occurs in the associated research seminar, the discussions in the Form Processing Workshop serve as a source of constraints and rules related to design case studies.

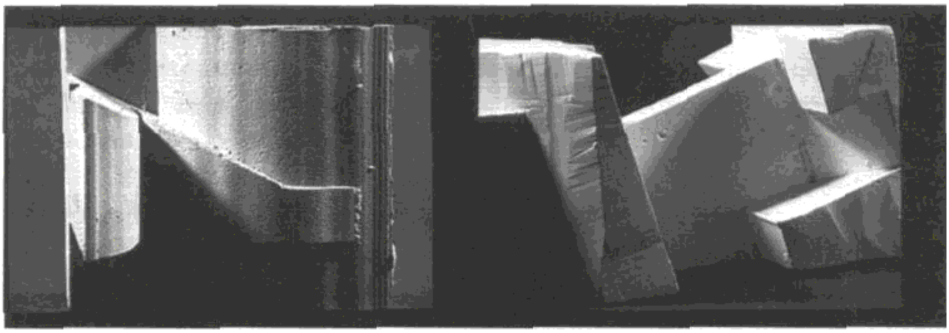
Most design decisions are made in relation to the constraints and options of an existing site or physical setting. The exceptions to this include generative formal techniques which instantiate building organizations based on a grammar of spatial elements. These procedures, typically referred to as parametric design, are most useful in making preliminary building schemes which will be subsequently modified in response to site conditions.

Parametric design processes were first developed for mechanical design problems, and later extended to the automation of repetitive components of architectural construction drawings such as fire stairs. In the realm of preliminary design, the effectiveness of parametric instantiation has been seriously limited by several factors. First, even simple design problems may contain a large number of rules and relationships, and the designer is forced to become a programmer in order to get beyond trivial design problems and overly simplistic representations. Secondly, parametric instantiation is useful only for creating variations of isolated objects or assemblies, for these procedures are unable to recognize the constraints or opportunities of the setting in which the designer is working. Architectural decisions made in the absence of context are the legacy of the worst of the modern movement, and designers do not need tools which encourage them in these bad habits. Thirdly, the options for representing design knowledge in these procedures is typically limited to rules, or conditional logic. The scope of architectural knowledge which can be coded in this form is very limited; additional representational schemes such as frames, semantic nets and neural networks provide the means to represent more complex design problems. Fourth, these procedures are only useful for generating variations on a theme or type which have been previously defined. The process of prototyping is often underemphasized, and left to other means.

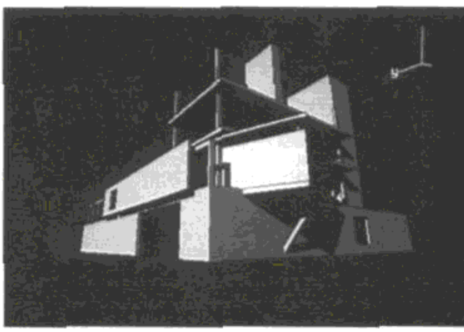
Design Themes

Central to the working method described above is the process of observation, creating prototypes and exploring variations. Utilizing this method, several design themes are explored in the workshop.

One of these themes focuses on strategies for aggregation and hierarchical ordering. Within the CAD environment, these issues have relevance to both the architectural scheme and to the options for manipulating the underlying database. While the hierarchical paradigms of top-down or bottom-up tend to dominate architectural discussion, the subject of aggregation serves to draw attention to the middle-up and middle-down options. Designers are continually grouping and regrouping elements, and creating overlapping hierarchies in the process. The grouping of elements into sub-assemblies, and subsequent creation of larger assemblies, stands in



Prototype elements cast by students with plaster and subsequently modeled with the solid modeler.



a)

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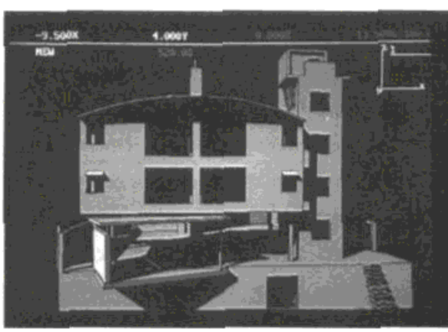

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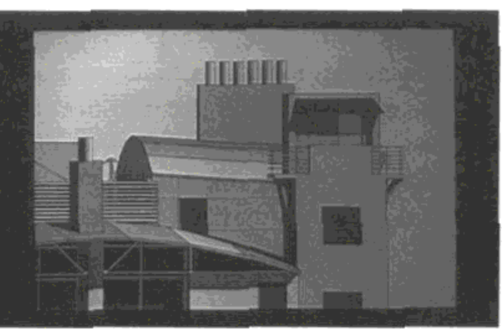

d)

Studio project for an Urban Inn by graduate student David McCulloch; a) CAD solid model using Solid Vision, b) physical model, c) CAD solid model, d) Multi-media drawing based on a plotted view of the CAD model contrast to methods which begin with an overall order and subsequently resolve the details. In order to accommodate growth and change, the relationship between the primary/ permanent structure and the secondary/ changeable infill raises issues of hierarchy. Also, the role of natural light is studied for its role in clarifying the organization of the public and private realms of the building.

Making interventions into existing settings is another design theme-emphasizing the techniques for understanding the physical, social and institutional context of a project. The CAD modeler is used to help generate and evaluate design decisions. Gaining new perceptions of a site is often aided by multiple representations of it through plans, photographs, sections, and physical models. The addition of a CAD solid model of the site permits a broader set of studies to be made, particularly with respect to visualization, walk throughs, and shadow studies.

Exploring Modeling and Drawing Tools

Design methods incorporate intentions, procedures, media and tools. Graphite on paper, modeling clay, foamcore and plaster are commonly used media, and are associated with such tools as lead holders, knives, glue and casting formwork. Digital computing represents the newest media platform on which CAD software tools are being developed. These media/tool combinations can be summarized into the following five categories:

Drawing Techniques (pencils, paint, etc.)
Additive Models (sticks, foamcore)
Subtractive Models (carved clay or styrofoam)
Cast Models (plaster, concrete)
Digital Models (CAD)

The form processing workshop takes the position that the relationship between design ideas and tools used to represent them is symbiotic, and that the designer must establish a critical stance toward them. In addition to the top-down and bottom-up tendencies of these different media/tools, there is an advantage to using combinations which are analogous to the real-world materials and properties which are being proposed. This strategy runs counter to the approach which seeks to constrain the design process to a single medium (e.g., CAD). This latter approach is oriented more to exploring the representational constraints of CAD, as opposed to the workshop's intention of exploring the role which CAD might play in relation to other media during the design process.

One important advantage of combining CAD with other media is related to the nature of the review process and the composition of the review audience. A mixed media presentation is able to engage a broader range of reviewers, and and the discussions tend to be more about architecture, and less about computers. In addition, the review is more interactive as a result of the increased accessibility provided by the range of drawings, physical models, and CAD image sequences.

Conclusions

While the design studio continues to provide a viable approach to learning architectural design, new computing tools still do not easily integrate with the concepts and methods being explored in that context. These tools need to be employed side by side with traditional tools-encouraging students to develop a critical stance toward them. It is only through such a critical approach that we may feel confident that the new design tools are being used in the service of architecture, and not vice-versa.