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Abstract:

This is a period of relative detente among academics in the field of computers and architecture. Advocating the use of computers in a design studio is today received more politely than, as in the past, when it was received like a declaration of war. Among some research groups at M.I.T. and Harvard to first engage in this field, the approaches were so dissimilar to one another that they could be considered as constituting separate schools of thought. Over time, however, a number of paths have led to a similar direction, if not agreement among principal investigators. The lack of sharply competing ideologies today may be a little less exciting; however, the enormous growth of the academic discipline seems now to allow for a fruitful exchange of ideas between positions that no longer seem mutually exclusive.

Two views are important, among others, at M.I.T. and Harvard. The classic M.I.T. view looks upon the AI lab as a microcosm for examining how architects think. Underlying this view is the position of 'lets examine the way architects think about design and build tools which can reflect that process'. Another point of view, as expressed at Harvard, is speculative on what architects seem to do in design practice and education, rather than speculative on the nature of thinking per se. Both views seem ultimately to be concerned with representing architectural design knowledge within computers, and in the role of computers as a design medium. This paper examines how the M.I.T. view and the Harvard view have superficiality been associated with separate research directions. As these contrasting points of view incorporate many common themes, the author finds that it may be possible to take an eclectic position in teaching computer aided design.
Introduction

Generalizations about design thinking are controversial. Some theorists have attempted to characterize aspects of design thinking in terms of explicit formalisms (Habraken [1]). Other theorists are persuaded that many aspects of design thinking can not be formalized (Whiteman [2]). There are also theorists who believe that any significant progress in understanding such formalisms may need to await further advances in cognitive science (Bindslev [3]). Given that the field of cognitive science is still fairly young, however, it may at least be some time before corroborative and incontrovertible evidence can be found to support a theory about design thinking. In the meantime, lacking cognitive science as an arbitrator of different design theories, many investigators have attempted to examine their design theories by developing computer aided design tools. This paper contrasts some of the theories of computer aided design and computer prototypes that have been explored within two settings, (1) the School of Architecture and Planning at M.I.T., and (2) the Graduate School of Design at Harvard. The research at these two places may reflect similar themes elsewhere, and perhaps more significantly, some similar counterpoints in research direction and uncertainties over the nature of design thinking.

Different Perspectives On A Design Formalism

Early research in computer aided design at M.I.T. was predicated on the investigation of specific design formalisms. For example, the Sketchpad experiment by Ivan Sutherland and Timothy Johnson in 1963 explored the formalisms of parametric variation, instantiation and constraints. In his opening remarks to the 1989 CAD Futures Conference in Cambridge, Massachusetts, July 1989, Harvard Professor William Mitchell suggested that a number of these initial formalisms have been taken up by commercial vendors, and that different formalisms are now becoming significant concerns in academic research (e.g. shape grammars, top-down schemes for parametric description). Still, the extent to which commercial vendors have understood and been able to implement the formalisms of Sketchpad has been questioned by at least one of its pioneers (Johnson [4]). At M.I.T., the academic investigation of constraints has been given further attention and new turns by some researchers (Habraken [1], Fleisher and Gross [5]).

The design formalism of constraints has been adopted to a variety of contexts, and therefore, it is difficult to provide an example that can serve as an adequate reference for all cases. Within the Sketchpad system, the intention was to fix some parameters within a design when it was appropriate, and to allow other parameters to be varied until it was appropriate to fix them. For example, a fine can be fixed to be tangent to a circle. Whenever the circle's diameter may be changed, the line will move and retain a tangent relationship to it. This example of a constraint was demonstrated by the Sketchpad three dimensional modeling system in 1963 (Johnson [5]), and more recently by an experimental two dimensional modeling system in 1989 (Gross [6]). By comparison, it is not typically possible to set up a constraint within a commercial CAD system today so that once the circle has been changed in diameter, the line will retain a tangent relationship to it. Within some CAD systems, constraints are embedded within the software in a form that does not provide for easy user access, and not in the best way to be exploited as part of the design process (Mark [7]). For example, a typical 'walls' rendering package will allow the user to constrain the dimensions of walls according to a predetermined variety of shapes, but does not allow the user to invent unprecedented wall shapes and constrain them.
The Sketchpad experiment is perhaps undervalued in terms of its contribution to design formalisms, and most appreciated for the harnessing of cathode ray-tube technology with a user interface that allowed a person to automate drawing production. Other researchers in computer aided design at M.I.T. also experimented with so called 'man-machine interface' issues, (Negroponte [8]). As in the case of Sketchpad, each investigation of the man-machine dialogue was typically focused on an implicit design formalism, sometimes based on very ambitious objectives. For example, the Urban5 project at the The Architecture Machine tested the use of computer to keep track of a dialogue that a designer has in arranging the physical form of the urban environment. The Urban5 computer tracked consistencies between a designer's action and predefined prerequisites embedded within the machine (Negroponte [9]). The machine would ring a 'nauseating' bell when an incompatibility error was found:

“A conflict is an inconsistency discerned by the machine relating criteria specified by the designer to forms generated by the designer. A conflict is thus generated when there is an inconsistency between what the architect has said and what he has done. ”

Given what inconsistencies often may exist in the earliest stages of the design process, however, it is a wonder that the bell did not ring constantly. As an accommodation to the ambiguity in the early stages of the design process, Urban5 would allow for many inconsistencies to survive if desired by the architect. Within such a scenario, these incompatibilities could be resolved towards the end of the design process if necessary. Yet, it would be difficult to determine in advance which inconsistencies should not disturb the architect until sometime later in the design process if at all.

The Urban5 system and Sketchpad are both concerned with ensuring consistency of design action. On the one hand, Urban5 was designed to ensure that the designer's manipulations of urban form are consistent with certain predefined design criteria. Similarly, the Sketchpad system ensured that geometrical constraints, such as those between the line and the circle, are maintained. The design paradigm of Urban5, however, encompasses a broader area of man-machine interaction. Whereas the constraints within Sketchpad were explicitly defined by the user by means of graphic input, the Urban5 system was developed to monitor inconsistencies between what a designer said (linguistically) and what the design had done (graphically). The implicit formalism of Urban5 is that of design as process which can grow out of reconciling the inconsistencies between linguistic declarations and graphical operations. This investigation of a what a designer 'thinks' as well as what a designer 'does' has become associated with much of the work at M.I.T.

The particular assumption that linguistic thinking is highly pertinent to graphic/visual thinking, however, is not endorsed by all investigations of the brain. On the one hand, the Soviet neuropsychologist Luria would likely support it. According to his findings about the organization of the brain, Luria claimed, with some reservations, that all higher forms of abstract thought involved the close participation of speech (Luria [10]). On the other hand, this claim about the close participation of speech has been subject to criticism on the basis of contrary evidence of abstract thinking. Luria recognized that further study was necessary (Luria [11]). A case study by Cronin-Golomb of commissurotomy patients suggests that abstract ideas can be mediated by a thought process that is not related to speech. Her so-called split-brain subjects were able to demonstrate their grasp of higher level classification concepts on the basis of processing only pictorial information. These patients were not provided with the opportunity to mediate the information by accessing areas within their brain that are believed to be associated with speech (Cronin-Golomb [12]). Another case study by Potter and Falconer suggests that human subjects perform more quickly at visual thinking than
they do at verbal thinking when performing parallel cognitive tasks (Potter and Falconer [13]).

In contrast to Urban5's coupling of linguistic and visual thinking, Robin Evans, a visiting design critic at Harvard, who teaches a seminar titled 'What Architect's Say and Do', suggests that it is difficult for an architect to talk meaningfully about his or her work. According to Evans hypothesis, an architect's verbal description of a design project may have little direct descriptive value about the work itself, but rather is a way of drawing attention to it (Evans [14]). The theorist John Whiteman at Harvard goes one step further (Whiteman [15]). He chooses not to presume too much about what an architect may say or represent about a design. Whiteman cautions that both the verbal and, in addition, the graphical description of a design object are distinct from the design object itself. According to his view, the design object is not an instance of its linguistic and graphical referents, but has a separate and not necessarily well understood existence. Taking this view a step further, it could be inferred that the representation of a design object within a computer has no greater validity than any other verbal or visual representation, and therefore, it too is not necessarily a faithful description of the design object. At Harvard, therefore, although the nature of design thinking is a significant field of inquiry, there is perhaps a reserved attitude about proceeding quickly on the basis of an assumption about how architect's think and retain knowledge about design. As an alternative, researchers may attempt to examine, not what architects think, but their design studio habits, and attempt to uncover design formalisms related to those design habits that can be assisted by computer aided design tools (see reference to Schodek [28] at the conclusion this paper).

Negroponte did not attribute the weak performance of Urban5 as a problem of representation per se, but rather the subtlety of the representation achieved and the richness of the dialogue between man and machine. He claims that the main difficulty with Urban5 was its inability to accommodate a wide range of discourse that a designer may typically engage in, and its inability to provide a better representation of the design object. The implication, therefore, is that the results of Urban5 can be improved upon if both the computer based representation is more comprehensive and if the breadth of the dialogue can be improved upon.

Negroponte has developed a more broad based research agenda for the The Media lab at M.I.T., where speculation on the 'man-machine interface' has expanded to non-architectural contexts in which a dialogue can occur. Currently, as if in atonement for the lofty assumptions of Urban5, the Media Lab is investigating basic issues of learning epistemologies and machines. The research program within The Media Lab has become so broad-based and interdisciplinary that it would be difficult to associate it with any singular direction or with any particular mindset (Purcell [16]). Some of this research activity may ultimately have bearing upon the future development of CAD systems, such as one which is faithful to the physics of the design object (Pentland [17]). In the meantime, however, can we assume that a modest formalism, such as the constraints method of fixing geometrical relationships within Sketchpad, is one that is of practical value to the design process if not yet wholly understood in theory?

The practical application of constraints to an architectural design problem may involve fixing relationships between some architectural elements up front while allowing for relationships between other architectural elements to be fixed later. For example, while laying out some walls., an architect may be concerned with both (1) the dimensions of Individual walls, and (2) the spatial relationships between walls. The architect may fix the dimensions of some walls at the outset, and then only consider the spatial
relationships between the walls. At some time later, it may be useful to fix the spatial
relationships between walls, and to reconsider the dimensions of individual walls. A
number of architectural CAD systems typically provide for this level of dialogue, but are
limited to a very isolated domain. In particular, they allow for only a limited number of
wall types and spatial relations. Moreover, the opportunity for the designer to apply
constraints across domains of building elements and by means of a facile language interface
has not accommodated by most conventional CAD systems (Mark [7]).

The Uncertain Origins of Emergent Form

Some design tasks, such as the layout of walls, provide a clear opportunity to apply the
design paradigm of constraints. It has been suggested that other design tasks, however,
such as working with ‘emergent form’, may not provide as clear an opportunity to work
with constraints (Mitchell [18]). For example, the so-called paradigm of working with
emergent form is that of discovering forms that become apparent in the fleeting moments
of a rapid sketch, but which are not apparent at the outset of taking on a design problem.
The process of arriving at emergent form has been viewed as a process which is
discouraged by the use of constraints. The designer may not want to want to ‘dance around
at the edge’ of architectural design by means of a formal system of constraints, but want to
jump into it with both feet and with no restrictions imposed.
It may be difficult to ascertain what thought processes are at work when one is fully
engaged in design. These processes may carry information that may be repressed under the
imposition of one design method. Although one particular computer based design method
may be effective (e.g. constraints, shape grammars), it may be of value to simultaneously
initiate other computer design methods which are discovered ad hoc in each instance of
design, Whiteman claims that ‘each instance of design is a unique instance of one’ to assert
the novelty that can characterize both design objects and methods (Whiteman [15]).

It is not necessary, however, to justify a formalism by reducing all other human design
activity to be compatible or logically consistent with it. In a discussion of shape grammars,
Professor William Mitchell has described a range of circumstances over which they may
be applicable (Mitchell [19]). On the one hand, it is possible to write a set of grammatical
rules which will derive the forms of a Palladian Villa (Mitchell and Stiny [20]). On the
other hand, in the case of a deconstructivist building, each form within the building may be
a unique instance of a shape grammar. Since each form is but a unique instance of a shape
grammar, then, on the whole, shape grammars may not be effective in examining the
relationships between several forms in a work of deconstructionist architecture.
Accordingly, a deconstructivist building reflects a least Interesting or most trivial
application of shape grammars.

Different Domains of Interest in Parallel

According to Mitchell’s theory, a shape grammar is but one of many representational
worlds. Some of these worlds may have equal applicability to a design problem. For
example, Professor Stanford Anderson at M.I.T. has described several aesthetic order’s to
describe Le Corbusier’s Maison Domino (Anderson [21]). One ordering gives precedence to
a system of frame infill. A second ordering gives evidence to its modularity. Each of these
orderings could be thought of as a representational world. In the first case, it might be
inferred that the representational world consists of potential structural systems. In the
second case, it might be inferred that the representational
world is dominated by potential systems for ordering space. George Stiny, a co-investigator of shape grammars with William Mitchell, recently proposed that (Stiny [22]):

'A more complete account of design thus requires that the algebra of shapes be combined with other algebras, so that shapes and useful descriptions in different domains of interest can be computed in parallel.'

The different algebras of constraints and shape grammars could co-exist. At M.I.T., John Habraken is interested in the issue of constraints through the specification of design rules to the extent that design is 'conventional and systematic' (Habraken [1]). At Harvard, William Mitchell is interested in shape grammars, it is presumed, to the extent that the formal elements of a design can be described according to a set of generative sentences. To the extent that design is unconventional and unsystematic or resists grammatical description, it may be possible provide a pluralistic representational world that - a voids any tightly defined scheme and which at the same time provides a normative standard for examining architecture. Two design theorist of M.I.T. have proposed that the Lakatos' pluralistic methodology of research programmes can guide the development of a normative model for studying architecture design (Anderson [23] and Andreotti [24]).

A number of other distinct representational worlds, such as that provided by rule based systems and frames (Mark [25]), have been explored within the Department's of Architecture at M.I.T. and Harvard: however, as attributed above to Professor John Whiteman, it is necessary to treat any of these representational worlds with some caution. Harvard philosopher Nelson Goodman also illustrates how a standard representation that we have accepted in architecture may be a poor referent for the design object itself. (Goodman [26]). By giving this example, Goodman suggests that the distinction between referent and design object might be more apparent in a significant work of architecture than it is in a commonplace work:

"Plainly enough, all houses complying with the plan for Smith-Jones Split-Level #17 are equally instances of that architectural work. But in the case of an earlier architectural tribute to womanhood, the Taj Mahal, we may bridle at considering another building from the same plans and even on the same site to be an instance of the same work rather than a copy."

A Questionable Difference Between Design Research M.I.T. and Harvard

Acknowledging the difference between a representation and the real object does not minimize the research Interest In developing good representations. It may, on the other hand, justify the acceptance of multiple representations. It seems superficially that there are two divergent strategies in design research at M.I.T. and Harvard. On the one hand, the computer lab may be viewed as a microcosm for examining how architect's think (Fleisher [27]). This approach is similar to that of a cognitive scientist that might study some aspect of perception by building a computational model. In one such experiment, referred to as 'design as the exploration of constraints', the authors begin with the following goal (Fleisher and Gross [4]):

'We want to learn how to think about design - m architects do if. We have an idea or two, We propose to make a computer program. If the computer then acts a bit like an architect, then the experiment will have succeeded. We shall be pleased. Our theory survived; the program is worth a round of elaboration'.

On the other hand, an alternative strategy, as is identified with the Graduate School of Design at Harvard, is to assess the pedagogical content in design education, and to begin to introduce computer technology on the basis of potential relevance to a
particular area of study (Schodek [28]). This approach, it seems, presumes less to model the way in which architect's think, but rather to take advantage of readily available pedagogical models in which computing may make a significant contribution. The former M.I.T. approach proceeds on a holistic basis to speculate about an architect's thought process, The later Harvard approach is more based on the specific investigation of ongoing design formalisms, and emphasizes the disciplinary use of computers in such areas as energy analysis, site engineering, geometrical modeling, etc..

The variety of strategies explored at the Schools of Architecture at M.I.T. and Harvard, however, may not be as easily distinguished by institution as suggested by the analysis above. For example, an advocate of 'Design as the exploration of constraints' project at M.I.T. recommends a so-called 'horseless carriage' approach to introducing computers into education design curriculum (Fleisher [29]). The 'horseless carriage approach', similar to the Harvard strategy, consists of supplementing some segments of traditionally taught subjects with computer based tools as gradual means of integrating them into the general curriculum of the school. At the same time, the PH'D, students studying design computing with the Harvard Graduate School of Design are encouraged to consider how architects think, and in particular, have all undertaken disciplinary minors in cognitive science.

Yet, despite the partial integration of teaching and research strategies, many of the initial paradigms that were proposed in the pioneering days remain somewhat enigmatic. Whereas the early pioneers freely speculated about what topics to investigate, it seems that they have passed on pathways to retrace, and have discovered ticklish issues to contend with in such formalisms as constraints and shape grammars. Today, it may seem less awe-inspiring to systematically explore the implications of one of these longstanding design formalisms, to make a contribution to nailing down the less fantastic aspects of what it had proposed, and to lay down a clear and methodological approach. For example, it seems necessary to examine how well constraint based computer aided design tools hold up under a more holistic set of architectural design problems. In the case of shape grammars, the issue of shape recognition has been solved in well defined cases, but not as well, for example, where shapes are at other than right angles.

**Conclusion**

It may be superficially possible to make clear distinctions between research at M.I.T. versus' Harvard. At the risk of making too simplistic an analogy, it seems that some of the exaggerated post differences between the two approaches to design computing at Harvard and M.I.T. are like the differences between behavioralists and cognitive psychologists. Whereas the behavioralists (Harvard) prefer to limit their field of investigation to what can be observed from an external view of what people actually do, the cognitive psychologists (M.I.T.) are willing to speculate more on the difficult to unravel inner processes of what architects think. On the one hand, design computing at Harvard is identified with the investigation of working formalisms that can be observed within the design studio. On the other hand, design computing at M.I.T. is identified with unraveling not only what architect’s do, but how they think and what they say, and the inconsistencies between design thinking and design habit.

Yet the activities of researchers and educators within each institution are not so easily identified within two distinct schools of thought. At M.I.T., for example, the investigators of design research consider themselves to be a loosely coupled alliance that is 'not devoted to a single approach or question' (Schon [30]). There is a significant exchange
of ideas and occasionally people between the two institutions. Although a number of
researchers in design computing at Harvard may not be willing to presume what
architect's may 'think' (as opposed to what architect's 'do'), any proposals with regard to
an architect's cognitive abilities would be energetically debated there. Similarly, it seems
that speculation on what architect's 'do' may involve some implicit assumptions about what
architects 'think' At the very least, researchers are called upon to make some provocative
assertions about what they 'think' architects 'do'.

Examining design formalisms that have been successful in a studio may provide a useful
field of investigation for those at M.I.T. who believe it is fruitful to explore how architects
think. Conversely, inquiries into the cognitive abilities of architects may inform those at
Harvard who's primary interest is in speculating on what architects do that may be adapted
to the development of computer aided design tools. At this stage in the history of the two
schools, research methods seem less obvious as belonging to a particular camp. More
typically, as this paper has attempted to do, design theorists with an interest in computers
seem likely draw upon all kinds of past inquiry and criticism in an attempt to isolate and
tease out the subtle questions posed within a specific topic of study.

References:
   Guildford Surrey, July 1984, p. 139
2. Whiteman, John, Inference is made here from discussions with Professor Whiteman in his office at
   Harvard University Graduate School of Design. October 1987.
3. Bindslev, Bjorn, Artificial Intelligence in building: Brain processes and artificial intelligence. The Journal
   of the CIB Building Research and Practice Volume 16, November 5, 1988
4. Johnson, Timothy, Guest lecture on Sketchpad to a Computers & Architecture subject of M.I.T.,
   October 1987.
5. Fleisher, Aaron and Gross, Mark, Design as the exploration of constraints. Design Studies Volume 5,
   Futures’89 Conference, Graduate School of Design, Harvard University, July 11 - 14, 1989,
7. Mark, Earl, A Design Automation Paradox. Pre-proceedings of the seminar ‘Conceptual Modeling of
9. Ibid., p. 83.
11. Ibid., pp. 238
12. Cronin-Golomb, Alice, Comprehension of abstract concepts in right and left hemispheres complete
    438.
14. Evans, Robin., Visiting Professor at the Graduate School of Design, taught a seminar ‘What Architects
    Say and Do’ in Fall 1987.
16. Purcell, Patrick, Presentation at the Media Lab, W.T. as part of a seminar ‘The Electronic Design Studio’,
    for the Professional Development Series Program, The Graduate School of Design, Harvard University,
    July 10, 1989
17. Professor Alex Pentland is experimenting with the development of a solid modeling CAD system at The
    Media lab, M.I.T. - The system incorporates knowledge about the physics of modeling components
18. Professor William Mitchell discussed the concept of ‘emergent form’ within a seminar ‘The Logic of
    Architecture’, at the Graduate School of Design, Harvard University, Spring 1988.
19. Professor William Mitchell referred to shape grammars with reference to deconstructivist architecture
    and Palladian architecture within the context of a CAD Studio at the Graduate School of Design,
21. Anderson, Stanford, Architectural research programmes In the work of Le Corbusier, Design Studies
Stiny, George, 'What Designers Do that Computers Should', Pre-proceedings of The CAAD Futures '89 Conference, Graduate School of Design, Harvard University, July 11 - 14 1989, p.10.

Anderson, Stanford, Architectural design as a system of research programmes, Design Studies Volume 5, Number 3, Butterworth & Co Publishers Ltd., Guilford Surrey, July 1984, pp.146 - 150


Professor Aaron Fleisher suggested the Idea of using the computer lab as a 'microcosm' for examining how architects think during a conversation at the School of Architecture and Planning, Computer Resource Lab, Fall 1987.


Professor Aaron Fleisher proposed a 'Horseless Carriage' approach to introducing design computing into the curriculum of the School at a faculty committee meeting, the School of Architecture and Planning, M.I.T., March, 1989

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