Beyond the CADD Laboratory: The Cornell Project and the Creation of the Cornell Synthesis Studio.

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Over the past year a project has been initiated at Cornell University's Sibley School of Mechanical and Aerospace Engineering to develop and implement a new direction in mechanical design education. The Cornell Project develops a teaching and working environment that fosters creative problem solving and visual thinking in the design of mechanical systems. The project is more than the creation of a laboratory; it combines curriculum, the designed environment, machinery and sophisticated computing resources in a comprehensive and critical vision of the future of design. The Cornell Project culminates in the Cornell Synthesis Studio, the primary facility for Mechanical Design and Synthesis (MAE 225), a new required course in mechanical design.

Keywords: mechanical design, design studio, curriculum.

The Cornell Project introduces innovations in the creation of a design studio and curriculum. These innovations have developed as a creative response to radically changing circumstances in design. This paper presents the Cornell Project as a constructive alternative to prevalent models of design studios and CAAD laboratories in both engineering and architecture.

1 The current state of design and the preconditions that spawned the Cornell Project

The Sibley School has long been a pioneering school of mechanical engineering in the United States. It has developed a rigorous technical curriculum preparing students for an ever more demanding marketplace. However, despite its advanced curriculum, the school has found a growing gap between the curriculums orientation and the realities of the manufacturing industry.

The preceding decades have seen increased emphasis on engineering science (both analytical and mathematical) and a bifurcation from and decreased emphasis on experience with physical artifacts. This has resulted in engineers who are essentially analysts, incapable of designing or building anything. Conversely, some programs have emphasized a shop culture. This has produced craftspeople, lacking the cognitive skills and scientific background to design the kind of high quality, complex products the marketplace demands. More generally, faculty in the Sibley School perceived a loss of the broad, cultured design sensibilities that characterized the best engineering of the past.

Concurrent with this educational dilemma, dramatic changes have occurred in the theory and practice of American manufacturing. Traditional approaches to design are being reexamined. Rigid organizational hierarchies and classical models are proving ill-suited to address the complexities that characterize the problems engineers face. These changes include: an unprecedented rate of technological innovation, the decay of monolithic manufacturing hierarchies with the breakdown of the logic of mass production (Piore and Sable); the related rise of niche markets and their new competitive demands of permanent innovation and quality improvement; increased pace for survival in the marketplace (Peters); emphasis on quality, particularly as seen in features and customization (Pine); and the globalization of marketplaces. In addition to traditional technical skills, such qualities as creativity, non-sequitur thinking, even unreason (Handy) - qualities that were once considered marginal or even detrimental for engineers - are now necessary and sought after survival skills. Taken together, this has caused a reconsideration of engineering education and a transformation of the conception of design. These problems require flexible, creative approaches; strategies that develop from the dynamics of the problem itself. The Cornell Project was initiated in response.

2 A review of fundamental design tenets that shape the Cornell Project

A design studio is introduced into the mechanical engineering curriculum because design is the quintessential engineering activity. All engineering is design or is in support of design. In addition to an understanding of engineering science, competent design requires experience working with one's hands in the actual fabrication of prototypes. This experience engages a type of thinking other than intellectual reflection. It is creative intuition. Like intellectual reflection, creative intuition generates knowledge. It is a nonverbal, visceral knowledge of things rather than of abstract ideas and concepts (Croce). Creative intuition, difficult as it is to quantify, is indispensable to design.

Studio education is validated by this idea that disciplined "making" generates knowledge about the nature and quality of stuff. This notion of making is broader than what is meant by visual composition in the arts or functional solution in engineering. It focuses on the dynamics of creation rather than on its final effects. Related to these dynamics is the interpersonal motivation encouraged by a collaborative and open setting.

Mechanical engineering has, to some critical measure, lost its direct link to the experience of creative making. This results in a degradation of quality and aesthetics in the design of mechanical systems. In part, this is caused by a past tendency to view engineering design as separate from and irreconcilable with aesthetic design. This view unnecessarily limits one's range of potential design solutions by casting a negative light on open ended, intuitive approaches. It fails to recognize that many engineering advances are initially unreasonable leaps of the imagination whose practical uses are only recognized in retrospect. The Cornell Project considers all serious design activities to exist on a spectrum. There is more to be gained by grasping the connections between various design types than by insisting on their differences.

The Cornell Synthesis Studio is modeled, in part, on the architecture design studio experience. It introduces a studio environment into an academic setting as a tool to teach synthetic skills. It is natural that mechanical engineering would look to architecture for inspiration. Both fields are firmly planted on the interface between intellectual activity (and applications of information science) and physical artifact. No other design domains are so intimately involved with geometry. Furthermore, the studio experience has remained central to the architecture educational process. It differs from an architecture studio in that students rotate use of the facility. It differs also from architecture and engineering CAAD laboratories by its inclusion of non-computing activities. In this new studio, however, computing is ubiquitous.

The electronic revolution has been one of the chief agents of change in design and manufacturing processes. Computers, once considered facilitators for existing design methods, have instead changed the conception of design. Beyond the impact of CAAD and CAM (which is considerable) computers have indirectly affected design by changing the nature of marketing, communications, finance and research. Given this, computers are introduced in the Cornell Synthesis Studio as components of a changing design consciousness.

The objective of this new curricular activity is to give students skills that are relevant to the future of the engineering profession. Among them are effective skills for teamwork, decision making in the presence of uncertainty and conflict, and an appreciation 0f quality. These new topics are in addition to the well established need for modeling, mathematics, and characterization of physical processes. The aims of the studio have led to the unlikely wedding of sophisticated computing and communications equipment with workbenches and power tools in an effort to create a dynamic link between these activities. The studio sets up an orchestrated set of possible activity links, multiplying the potential design results. In a structured way, this encourages an open design search - at times through serendipity and accident - rather than a regimented set of predetermined outcomes.

3 Parenthetically: the nature of the collaboration

The creation of the Cornell Project puts into practice the ideals and philosophy of the curriculum. It serves as an instructional and inspirational legacy to future users of the lab and as a case study for design professionals. Its creation is an implementation of the curriculums objectives in two ways: first, the design process was conducted as a collaborative research effort; second, the architectural form evokes the spirit of the new curriculum by suggesting the flowing and intermingling structure of fluids in motion.

This project was initiated and undertaken at Cornell University's Sibley School of Mechanical and Aerospace Engineering in collaboration with faculty of the Department of Architecture and with students. Dean Taylor of the Sibley School is the creator and main organizing force behind the project which is an important component of the Realization Consortium. His is the pedagogic and technical vision of the project. Additionally, Dean Taylor served as engineer and design collaborator on the architecture of the studio. Andrew Zago of the Department of Architecture also performed several roles in the development of the project. Taken together, his role can be characterized as creative consultant to the project. He functioned as advisor on the curriculum, architect of the studio, and lecturer in the course. During the project, architecture and engineering students were involved in CAD model creation, physical model fabrication, furniture design, and investigation of fabrication technologies. The result was an unique structure of architect/client/user roles.

To develop the design, Andrew Zago established a temporary architecture studio inside the Sibley School. This allowed daily contact with Dean Taylor on all aspects of the designs development. While initially unnerving - permitting much closer scrutiny than in typical architect/ client relationships - it grew into a synergistic collaboration allowing the twin concerns of function and form to coexist and meld into a single vision of the project. The art of the room came to be considered essential to its proper functioning.

From its inception the project has been developed and documented in CAAD (FormZ) and models exclusively. This has allowed a seamless transition of the project from schematic design to construction documents.

As a case study problem, the creation of Cornell Project has a significance beyond academia. It demonstrates that a tangible new direction in design is not only theoretical speculation, it is a tangible possibility. The interlocking relationships and blurring of roles in its creation is an excellent example of concurrent or simultaneous engineering. For the architect, the design process presents an alternative to standard contractual relationships integrating, in part, concerns of architect, client, user and contractor. Also, the architect was brought in early in the project's conception. This allowed the architectural issues to evolve as an integral part of the project's vision and purpose, not as an afterthought.

4 The studio environment

As architecture schools have long understood, a design studio is a cumbersome and exotic creature to maintain in an academic environment. Nonetheless, an effective studio experience is unique in its ability to instill synthetic design skills by shaping perceptual sensibilities. As an entity, an effective studio is greater than the sum of its parts. o be effective, it must create an integrated experience from a heterogeneous set of activities, resources and individuals, giving them a cohesive sense and logic. In this way, a studio creates an experience that is both inspirational and challenging.

Unlike many academic experiences, an effective studio transforms its participants - student and teacher. It does so because it demands nothing less than a reorientation of one's perceptual framework. Achieving this complex goal requires more than simply combining the appropriate equipment, methods and participants; it needs an environment that fundamentally alters one's perceptual sensibilities. The term environment is used to suggest a totalizing spatial experience that, in this case, engages accelerates, and catalyzes creative production.

Creating a studio requires also an understanding of the creative process. While most attempts to quantify this process have proved dubious - with creative practice contradicting design theories as quickly as they can be formed - one can, from experience, describe some structural characteristics of design. In his landmark book The Shape of Time: Remarks on the History of Things, George Kubler effectively argues that the central perception in the creative process is the experience of actuality. It is an activity that engages one's sense of the moment. In this light, the art of "making", outlined above, is a vital process of give and take simultaneously generating a dynamic set of possible conclusions. It is analogous, perhaps, to the spontaneous structures achieved in jazz improvisation.

In addition to this general time sense, the computing activities of the Cornell Synthesis Studio introduce asynchronous and heterogeneous features. To foster creative work in the studio, these features are embraced and encouraged. The studio attempts to increase one's awareness of temporal dynamics and the opportunities for heterogeneous interfaces. The studio brings together disparate design media and places them - however uneasily - into mutual play. This is achieved by the composition of course assignments, by the mix of fabrication techniques, by team dynamics, and by the interaction with computing and telecommunication technology. Thus at any given time students may be sketching, working with hand tools, computer modeling, or interacting with other students in the room or through teleconference with another site.

5 Architecture

To create an environment, however, the Cornell Project provides more than a mix of equipment and course work. Borrowing the literal definition of event from physics - an entity occurring in three coordinates of place and one of time - the environment of the room is conceived of as a series of events. Environment becomes a conflation of media, movement and built form. Relationships take perceptual precedence over singular objects, functionalities and activities. Rather than making the "object" of the studio thematic, this project makes the environment thematic. The chief innovation of the Cornell Project is the orchestration of events as environment. This creates a coherent, if chaotic, medium out of the studio's various components and, through reorientation, allows new perceptions to

While the "object" nature of the studio is one factor among many, it is the architectural form that provides the crucial orienting tool. Over and above its potential for spatial problem solving, architecture's strength is its ability to synthesize (create) an environment. Unlike the electronic environment, architecture gives a sensuality to the space, engaging the body. The architectural goal was to make the medium of the environment perceptible. Both the functional planning and the form of the studio allow the various subsets of activities and their hybrids to function in unison. It provides a medium, evocative of flow and movement, that establishes participation in the studio as a spatial engagement.

The practical needs for the computing environment, its physical requirements, are relatively light and will decrease with improvements in computer flexibility and robustness. That fact, and the desire to provide heterogeneous experiences led the design away from the notion of a dedicated CAAD laboratory and the notion that a design studio should serve as a neutral backdrop. Rather, architecture functions as a dynamic agent for and exemplar of the studio's vision.

The spatial inspiration for the architecture of the Cornell Project came, in part, from the School's research in fluid mechanics. Faculty in the School have undertaken extensive visual documentation of turbulent systems. These images provided a striking and relevant model for an unusual structural condition, one that is not classically defined yet, like chaotic systems, has an intelligible order.

Through the use of geometry, this type of structure was given concrete form. It was then recorded, through incusion and projection onto a thick datum layer that envelops the room. (Figure 1) The design does not make an hierarchic or articulated differentiation between floor, wall, ceiling. The goal is to suspend the pre-existing orientation and create this alternative experience. The denial of a differentiated floor, wall, ceiling creates an interplay of elements rather than a construction. (Figures 2 and 3) The architecture of the studio makes a transformation of world, body, and their mutual engagement (space). This focus is to accentuate and even engender a vital four-dimensional sense.

6 Description of facilities

The design studio experience includes rapid physical prototyping and testing, computational prototyping, multi-media projects, long distance collaborations through video-teleconferencing, and presentations of student work. The studio serves as a student gateway to the information highway. Facilities to support these activities have been arranged in the room on a spectrum from dirty to relatively clean.

The room must accommodate a variety of group sizes. It will be used by up to 160 students per semester. This necessitates hot seating' by dividing the class into eight sections with twenty students per lab section. The students are further organized into project teams ranging from two to ten. Students have access to the studio during times other than scheduled section periods. The room will also accommodate student presentations lectures and critiques for up to 60 people. Gatherings of the entire class will be elsewhere.

Most of the studio space is devoted to team work area. (Figure 4) A key feature of this area is the ten work tables (3 ft x 6 ft) which serve the teams as workbenches (in the traditional shop sense), computer stations, and conference tables. Some worktables have high quality Silicon Graphics UNIX workstations (with 'video on the net" capabilities). Plans are to include a number of notebook computers with wireless networking to achieve truly ubiquitous computing.

The remainder of the room provides infrastructure. There is a workshop for light fabrication (drill press, scroll saw, band saw, hot-wire). Heavy fabrication (lathes, mills, welding) is provided by a machine shop 75 feet along the same hallway. Student projects are fabricated of metal, plastic and fibers. There will be no significant use of wood in this studio.

To further the appreciation of quality in design, a display area is included in the room and adjacent corridor. The display will house pieces from the Sibley School's historic Reuleaux collection of mechanisms and a changing exhibition of student work. This display gives the studio a physical presence in the school by extending out, past the entry into the adjacent corridor. Also, fenestration in the entry wall gives the corridor some natural light and provides views into the studio.

Part of the studio's extensive storage capacity is a set of five large (4' x 4' x7') rolling racks holding 100 storage bins for student projects and one for material storage near the workshop area.

The studio supports a variety of information processing equipment sited peripherally in the studio. These include scanners, various printers and plotters, electronic storage, Macintosh and 486 computers, large screen displays, and video teleconferencing. Networking within the room is both 10baseT and wireless Ethernet. The large screen displays (Xerox Liveboards) are for group presentation, group teleconferencing (via PictureTel equipment), and shared whiteboard sessions with remote sites.

Students have the ability to scan geometry, scan images, create three dimensional geometry, render geometry through a variety of programs including photo-realistic imaging, transfer geometry to stereolithography facilities and/or numberical controlled machining facilities (CAM), analyze systems using finite element methods, optimization techniques, and create sophisticated dynamic simulations, prepare data visualizations, and prepare high quality presentations including digital video imaging of physical prototypes.

The lab uses Internet and WWW protocols, but also ISDN phone lines are used for video teleconferencing and CODEX switched video lines are being added. AC power and 10baseT networking are provided along the perimeter of the room. In the center AC is provided through recessed floor outlets, and battery powered notebook computers with radio frequency wireless networking are planned.

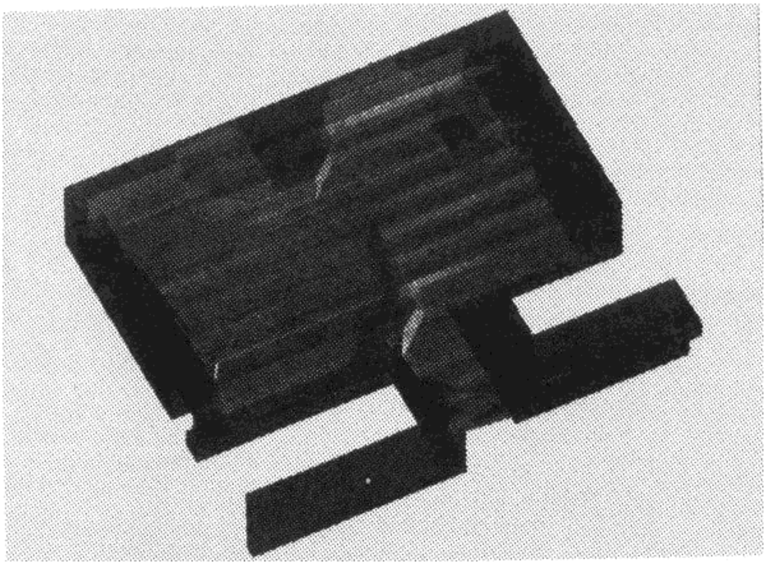

Figure 1. Diagram of turbulance model with datum envelope.

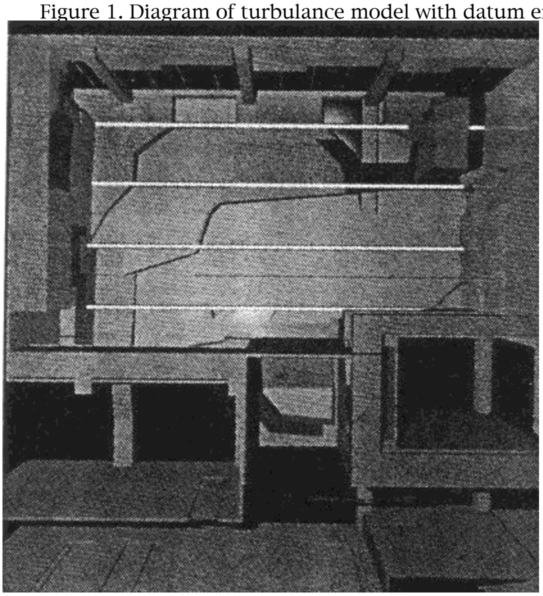

Figure 2. Ceiling geometry, worms-eye perspective.

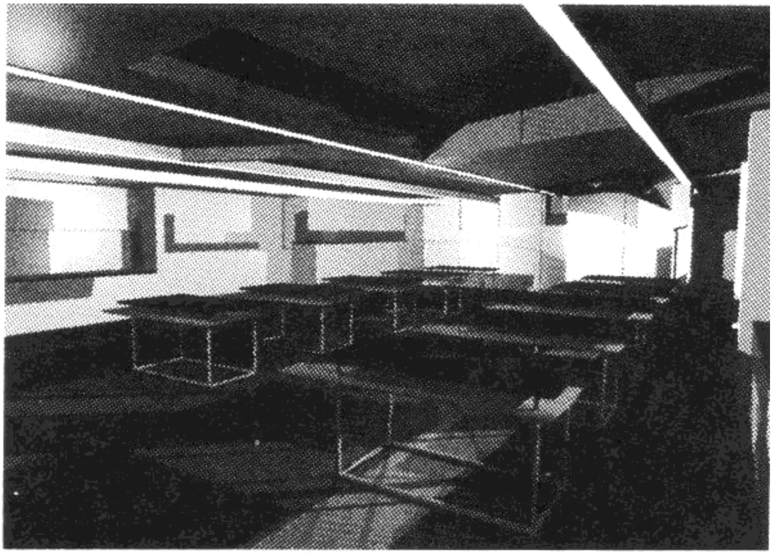

Figure 3. Perspective rendering of design studio

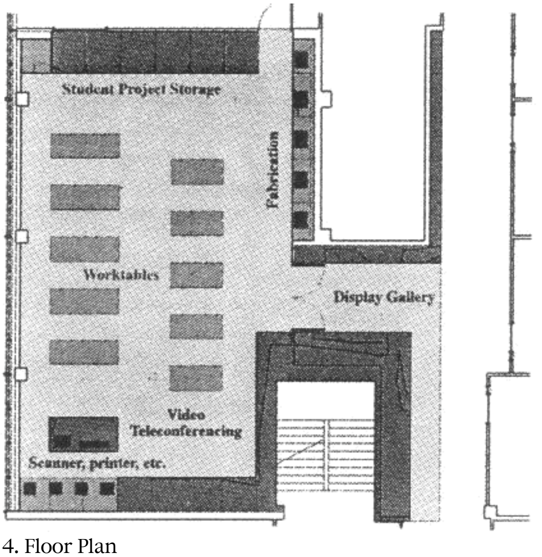

Figure 4. Floor Plan

Along the window wall, tandem roll-down shades are provided, blackout and translucent. The shades are to darken the room for presentations and to reduce solar glare and heat gain. The climate is further maintained with fan-coil heating and cooling units along the window wall. Prototyping activities have required a light duty hood and exhaust vent for processes such as hot wire cutting of blue foam, painting, and use of adhesives. The studio measures 2,000 square feet with a construction cost of $130/square foot.

7 The curriculum: description of projects and activities

Traditionally, engineering curricula are dominated by math and science during the first two years, with engineering science during the second and third year, and specific application areas during the fourth year. During the fourth year students are required to undertake major design projects, but without the experience of having faced open-ended problems and without having developed visualization skills and fabrication experience. Under the new curriculum, students have a hands-on introductory course during the first year. The major studio activity occurs during the second year simultaneous with the beginning of the engineering science courses. One of the objectives of the studio course is to provide the need to know" for the engineering discipline courses which will follow. Also, the course is to provide experience with collaborative work and with fabrication, experience which will be valuable in the major fourth year design project. Finally, the studio course is intended to help set a level of expectation for the quality of work during the more advanced part of the program.

The studio course was taught in temporary quarters during the spring of 1995, and can be best described by the sequence of projects undertaken. In addition to the projects described students received a coordinated sequence of lectures on sketching, form and shape, ergonomics, design methodologies, quality function deployment, concept generation matrices, Pugh decision matrix method, Meyers-Briggs characterizations of personalities, group dynamics and organization dynamics.

The first project (one week) was design of a motorcycle shelter and fabrication of a mock-up for the kinematics of the door mechanism. The primary objective was introduction to the studio process and beginning to keep a design notebook.

The second project (two weeks, groups of two) was design and machining of a hinge. Students were asked to observe and sketch a variety of hinges (Figure 5), to design the hinge in CAD (form •Z) and then to machine the hinge. (Figure 6) The two key objectives were an appreciation of variety in an artifact as simple as a "hinge" and experience with fabrication by material removal.

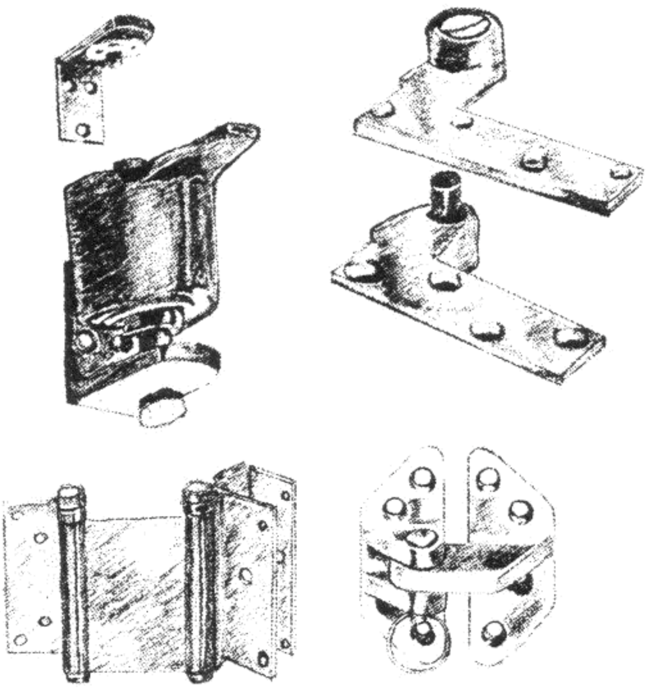

Figure 5. Hinge sketches from student design notebooks.

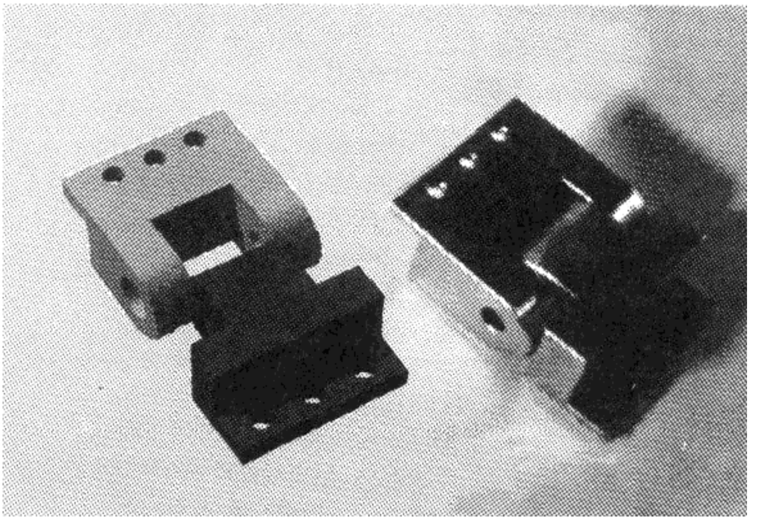

Figure 6. An aluminium hinge and the associated form•Z model.

The third project (two weeks, groups of two) was design and assembly of a cantilevered support from a limited selection of material cross sections. This project had an analytical component (estimate of stress for sizing components) and performance specifications (1000# load, 16 inch overhang). The design was scored by a cost function which included weight, number of pieces, number of cuts, and number of welds. The objectives were introduction to parametric design and fabrication by assembly and joining (welding).

The fourth project (two weeks, groups of five) was creation of a maquette for a kitchen appliance; an electrical jar opener. Students also created CAD models, gaining experience with sculptured surfaces and with rendering techniques. The objectives were hands-on experience with shape and form and the opportunity to experiment aesthetically. A wide variety of shapes, textures, colors and human factors were produced.

The fifth project (simultaneous with the fourth, groups of five) was a configuration design problem. Students were to design a powered hoist using components from a specified set of catalogs. The objective was further experience with satisfying performance specifications and product scoring by cost estimates.

The capstone project (six weeks, groups of five) was design, prototype fabrication, and test of a motor powered by compressed air. (Figure 7) Students worked in groups with significant task decomposition and specialization. An important attribute of the capstone project is to be multi-disciplinary. It spanned the disciplines of mechanical structure, motion, thermal energy, and fluids. It involved machining, welding, and parametric design specification. Projects were evaluated by performance (power production). Next year, the capstone project will be the air-motor again but will likely include electromechanical systems.

The curricular use of the room is being documented as a model for other institutions who will create similar studios. The innovations in the curricular activities are funded by the Realization Consortium (part of the Technology Reinvestment Program). This consortium - composed of the Worchester Polytechnic Institute, Cornell University, Massachusetts Institute of Technology, Tuskegee University, and North Carolina Agricultural and Technical University - is focused on the product realization process. A key component of its activity is the creation of the Design Studio of the Future. This studio will use computing technology to bridge the various institutions, and will be the sum of the facilities at all institutions, rather than a set of independent locations.

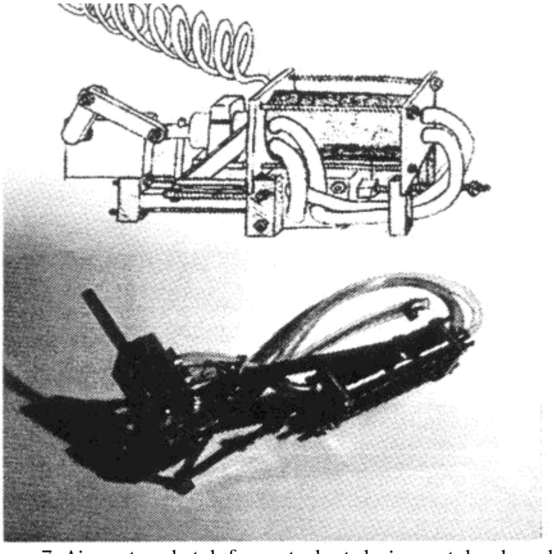

Figure 7. Air-motor sketch from student design notebook and the final air-motor.

8 Conclusion

The Cornell Project presents a constructive response to dynamic and challenging professional changes. It is an aggressive response. It does not adapt past models to new situations but actively seeks its own form. For the design community, it is valuable experimentally and, hopefully, inspirationally though its ultimate success or failure will not be known for several years. For architects, it sketches a possible scenario in which the profession's creative aspirations become an integral and valued part of a project's conception.

9 Endnotes

The Design Studio home page is http://cthulhu.mae.comell.edu.

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