Digital Tectonics:
the intersection of the physical and the virtual

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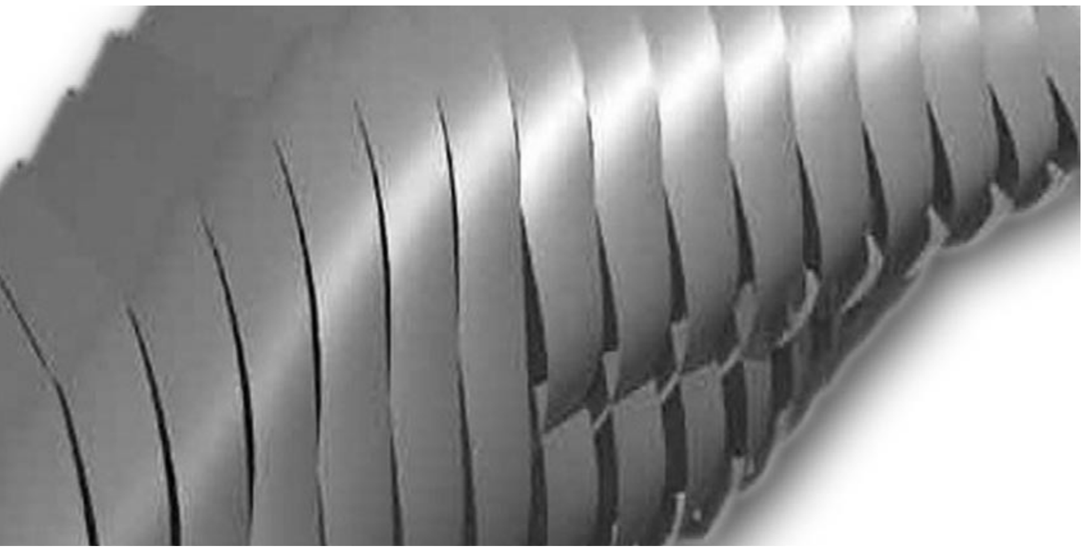


Abstract

The advent of automated manufacturing processes and the possibility of directly translating virtual creations into physical artifacts brought forth the possibility of exploring a digital tectonic: the poetics of digitally conceived, structurally clarified and directly manufactured architecture. CAD/CAM equipment is being rapidly installed in schools of architecture without much thought given to its effect on the tradition of tectonics. To investigate these effects, this paper includes discussions of the tradition of architectural tectonics and of more recent works that illustrate the possibilities of digital tectonics. This discussion is followed by a brief survey of some of the research in the area of analog/digital pedagogy. Additionally, two experiments were conducted in an academic course setting that explored analog, digital, and hybrid approaches to the creation of architectural artifacts. The physical and virtual artifacts from the two experiments were analyzed and commonalities and differences were discerned. The research project reported in this paper further clarifies the notion of digital tectonics as the poetics of digitally constructed assemblages, and points to possible pitfalls of using CAD/CAM equipment that disregard the materiality of components and their interconnectedness.

Introduction

Architecture has a long tradition of emphasizing *tectonics*, the poetics of an assemblage's structural clarity, materiality, and detail. The maturity of the field of digital fabrication opened up the possibility of exploring *digital tectonics*, the poetics of digitally conceived, structurally clarified and directly manufactured architecture. Schools of architecture in the U.S. are rapidly installing (or seeking funding to install) digital fabrication laboratories to expose students to methods of digital construction. Yet, not much thought is given to the effects of this technology on the tradition of tectonics. Does the equipment they are purchasing truly allow an investigation of a digital tectonic? Does it allow a better understanding of how buildings are assembled or will be assembled in the future? To attempt to answer these questions, this paper includes a discussion of the tradition of architectural tectonics and of some more recent works that illustrate the possibilities of digital tectonics. This discussion is followed by a brief survey of some of the research in the area of analog/digital pedagogy that points to the main characteristic of digital tectonics – mainly its *in-betweeness*. As the title of this paper indicates, digital tectonics is viewed as the intersection of the physical and the virtual. The interest in digital tectonics is derived from its hybrid nature in that it is concerned with digitally conceived assemblies that are then analyzed, manufactured and deployed. However, due to the capabilities and limitations of some of the manufacturing equipment that schools of architecture can afford, there exists the danger of using the equipment in a non-tectonic manner.

To expose this danger, a series of experimental student projects were issued over a period of eight months (two semesters) at the School of Architecture, New Jersey Institute of Technology. The two experiments were repeated over two consecutive semesters. In the first experiment students were asked to construct and collaboratively inter-connect physical objects without the aid of computers. Then, they were asked to re-create the same artifact using 3D modeling software, incorporate a new virtual component to it that is not meant to be manufactured, and transform the resulting composition into an interactive and dynamic virtual reality world. Again, the virtual composition was to contain virtual connections to the constructions of other students. The interfaces and linkages were collaboratively decided upon in a peer-to-peer fashion. In the second experiment, the students were asked to scan and model an existing physical object, isolate and abstract a portion of it, re-interpret it as an architectural surface, rationalize it, manufacture its components using a laser cutter, and assemble them to create a tectonic structure. The physical and virtual artifacts from the two experiments were analyzed and commonalities and differences were discerned. The research project reported in this paper further clarifies the notion of digital tectonics as the poetics of digitally constructed assemblages and points to possible pitfalls of using CAD/CAM equipment that disregards the materiality of components and their interconnectedness.

The Tradition of Tectonics in Architecture

The focus on the structural clarity, materiality, and attention to detail in the assemblage of buildings components in architecture is commonly termed *architectural tectonics*. The industrial age brought with it the realization that buildings can be thought of and assembled in similar ways to the industrial artifacts and machinery that were being manufactured. One of the earliest and largest examples of a building that was thought of and assembled as a kit-of-parts is Sir Joseph Paxton's 1851 Crystal Palace project in London (Fig. 1). Perhaps for the first time since the pyramids in Giza, building components were standardized, mass produced, and repetitively deployed to create architectural space. In sharp contrast to the pyramids, however, the Crystal Palace was meant to be a light and temporary structure that could be disassembled.

Early twentieth-century modern architects such as Mies van der Rohe have long advocated the poetics of tectonic architectural space that is bounded by, but often escapes, a highly streamlined, industrial, and detailed set of building elements that interconnect in a clear and expressive manner. A prime example of the symbiotic relationship of poetic space to its tectonic envelope can be found in Mies van der Rohe's

Figure 1. Crystal Palace, London, 1851; Sir Joseph Paxton; Interior of Great Exhibit Hall

Figure 2. German Pavilion, Barcelona, Spain, 1929; Mies van der Rohe; Exterior and Interior

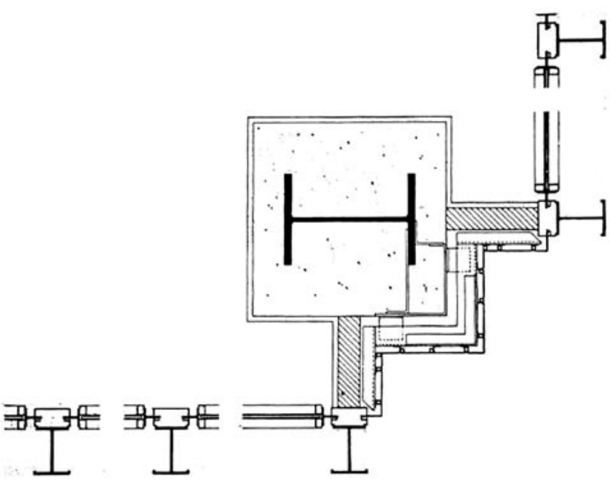


Figure 3. Seagram Building, New York, 1958, Mies van der Rohe, Corner Detail

1929 German Pavilion in Barcelona, Spain where solid and void, line, plane and volume, column, wall, and slab, fluid and static space are all exquisitely choreographed to complement and rationalize each other (Fig. 2). Other well-known examples of van der Rohe's explicit tectonic articulation include his 1951 apartment buildings project at 860-880 Lakeshore Drive in Chicago and his 1958 Seagram building in New York. In both instances the bounding envelope is explicitly tectonic and the joints (e.g. the corner column condition) are deliberately articulated (Fig. 3). A clear and concise comparison of the tectonics of both projects is offered by Beesley and Seebohm (2000).

More recently, architects such as Jean Nouvel have carried on the tradition of tectonic architecture in projects such as the 1987 *L'Institut du Monde Arabe* project, the 1994 *Fondation Cartier Pour l'Art Contemporain* project, and the 1999 *Kultur und Kongresszentrum Luzern* project (Fig. 4). These projects illustrate an almost jeweler-like attention to detail and a concern for the relationship of space to the elegant and evocative solids that bound it. More importantly, these projects emphasize a preoccupation with the materiality of architecture and its plethora of building components and the methods by which they assemble, layer, and interconnect.

The works cited above are not influenced by the contemporary digital revolution as it relates to architecture. Obviously, the work of van der Rohe pre-dates the advent of digital tools. However, even the work of Jean Nouvel is not most appropriately described in terms of its relation to the tools that translated the architect's ideas into the built form. Thus, the question becomes self-evident: What effect if any did the use of digital tools have on architecture as a whole and architectural tectonics in particular? While the scope of this paper is not adequate to answer these questions, one can examine a few illustrative examples.

Considering the work of Frank Gehry, one might come to the conclusion that digital tools allowed a more accurate translation of architectural ideas into built artifacts. More relevant, however, is an apparent transformation of architecture as a set of assembled components into a set of more homogenous and reductionist volumes, and surfaces. This transformation can be exemplified if one compares Frank Gehry's early projects that make use of digital tools such the *Fred and Ginger* building in Prague, Czech Republic to more recent projects such as the Disney Concert Hall in Los Angeles. The Fred and Ginger building, while bearing the mark of digital design in its deformed surfaces and non-repetitive paneling geometry, continues to evoke the tectonic in its materiality and assemblages (Fig. 5). In contrast, The Disney concert hall conceals its structural systems and building components to present to the viewer an abstract sculpture, as if made of a single sheet of metal that has been made to deform according to the will of the architect (Figure 6).

Figure 4. From the left: L'Institut du Monde Arab, Paris, 1987, Façade; Fondation Cartier Pour L'Art Contemporain, Paris, Exterior View, 1994; Kultur und Kongresszentrum, Luzern, Switzerland, 1999, Exterior View, Jean Nouvel

Frank Gehry's use of software and digital methods to rationalize and manufacture a highly physical and visible architecture, such as the Guggenheim Museum in Bilbao, launched an international debate about the relationship of digital tools to the artifacts they represent and – more recently – directly manufacture. While many applaud Gehry's work for its almost direct translation of his ideas into built artifacts through digitally controlled methods, some have found fault in his willingness to sacrifice structural clarity in order to entertain a postmodern desire to celebrate surface and create photogenic formal effects.

Figure 5. National Nederlanden Insurance Company, a.k.a. Fred and Ginger/Tancinsky Dum (Dancing Building), Prague, Czech Republic, 1995; Frank O. Gehry and Vladimir Milunic; Exterior View

In the face of an increasingly digital architecture that is digitally conceived, simulated, and represented, a counter movement, which stresses the importance of tectonics in architecture, began to gain momentum. A manifesto of this movement can be found in Kenneth Frampton's book *Studies in Tectonic Culture* (Frampton 1996). However, once architects who have been trained in the use of digital tools graduated and started building, a shift occurred in which architectural tectonics evolved into what has been termed *digital tectonics*. Conventional wisdom would suggest that the digital is ephemeral, dynamic, virtual, and free from the constraints of physical reality, while the tectonic is grounded in the material, the structural, and the real. Yet, as discussed below, digital environments are increasingly used to investigate a new manufacturable tectonic that is tightly integrated with the digital tools and algorithms that produce it.

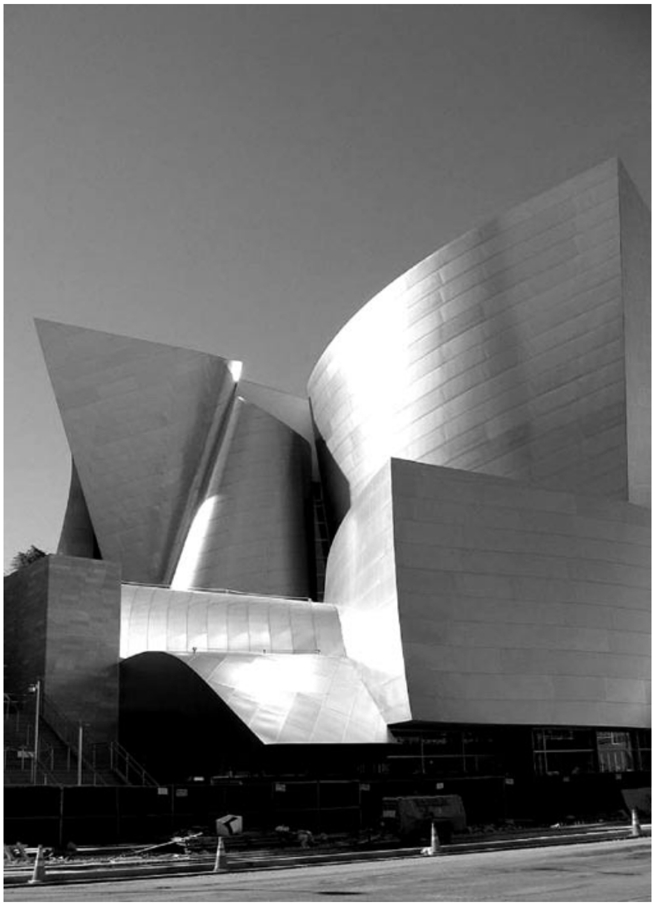


Figure 6. Disney Concert Hall, Los Angeles, 2004, Frank O. Gehry, Exterior View

The Shift to Digital Tectonics

Several researchers, educators, and architects have converged on the term *digital tectonics* to symbolize the poetics of digitally conceived, structurally and materially clarified and directly manufactured architecture (Beesley and Seebohm 2000; Leach et al. 2004). Some confusion occurs when one discussed the tectonics of the digital as illustrated in the work of Marcos Novak, as opposed to the tectonics possibilities afforded by digital tools as evidenced in the work of architects such as ABB Architekten/Bernard Franken (Fig. 7).

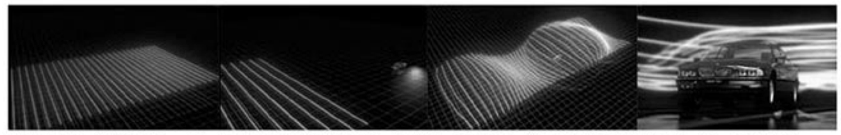
The shift to digital tectonics is a direct result of the ubiquity of digital tools. Until recently, those who were experts in the use of digital tools were not always the most innovative architects. Similarly, architects resisted the use of digital tools because they could not see their potential. Instead, they only saw either the experimental and sometimes awkward images of simulated spaces or the overly photo-realistic renderings of commercial and non-imaginative architecture. The shift to digital tectonics took place once students trained in the use of digital tools graduated and established their architectural firms. In an interview with George Rand at UCLA (Rand 2000), Greg Lynn puts it this way: "*The problem is that the technology has built-in biases. It often prevents the designer from asking the right kinds of questions…very little attention has been paid to the technical, economic, and cultural transformations of the creative process. Mine is the first generation to treat digital techniques as a given medium in a manner that transcends any built-in cultural paradigm*." In reflecting on the shift caused by digital tools and computer-controlled cutting machines, he replies: "*We now work in digital environments where dimensions are no longer sacred. In the past it was critical to work with whole and prime numbers to avoid the complexity of fractions. With new design and building techniques like robotic cutting machines and welders, we have been released from the constraints of 'numerical purity' and are free to design based on rhythmic patterns*." (Fig. 8). Branko Kolarevic also echoes the sentiment of being released from old constraints when he writes: "*The predictable relationships between the design and representations are abandoned … The topological, curvilinear geometries are produced with the same ease as Euclidean geometries of planar shapes and cylindrical, spherical, or conical forms*."

(Kolarevic 2001). Yet, Kolarevic's thinking about this issue evolves into an emphasis on the translation process: "*It is this newfound ability to generate construction information directly from design information, and not the complex curving forms, that defines the most profound aspect of much of the (sic) contemporary architecture.*" (Kolarevic 2003). Thus, one can see how the shift to digital tectonics is a direct result of the fusion of the architect and the CAD expert. It is not until the architects' level of comfort and expertise with the tools reached a critical threshold that digital environments and methods became a natural medium for the conception and manufacture of architecture, and allowed for a *letting go* of old methods of design and a freedom to explore new ways of exploring form, space, and structure.

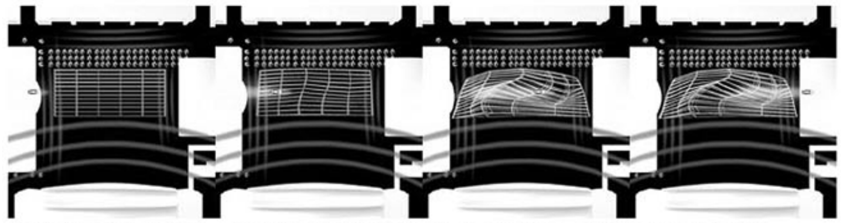
The emphasis on structure is crucial to this shift. In the introduction to their book, titled *Digital Tectonics* (Leach et al. 2004), the editors describe the term digital tectonics as "*a new paradigm of thinking in architectural culture … facilitated by – but not totally dependent upon – the technological possibilities afforded by the digital realm*." They describe the shift to digital tectonics as a 'structural turn' due to a renewed focus on the structural integrity of buildings and new dialogues and collaborations between architects and engineers. They even see the emergence of a hybrid practitioner: "*a kind of architect-engineer of the digital age*."

The Role of Education

As noted above, the digital revolution is firmly rooted in the educational process. So it is slightly ironic that educational institutions are increasingly feeling the pressure to maintain their relevance in this new digital era and prepare students for a career that is heavily influenced by digital tools and methods. This pressure is due to the fact that exposing students to digital fabrication processes requires the purchase of expensive CAD-CAM machines that budget-strapped schools of architecture can ill-afford. Yet many schools, especially the better endowed ones, are rapidly investing in manufacturing laboratories in a manner similar to their earlier investment in computer-aided design and visualization equipment. As CAD-CAM machinery becomes more common, less expensive, less dangerous, and smaller, fabrication labs will become as ubiquitous in schools of architecture as computers are today.



Doppler Effect: We accelerated the space around the automobiles to conjure up the feeling of motion.



Form follows force: By overlapping the environmental forces and Doppler effect, we created the Dynaform.

Figure 7. BMW Dynaform Hall, 2001 Frankfurt International Motor Show, ABB Architekten/Bernard Franken

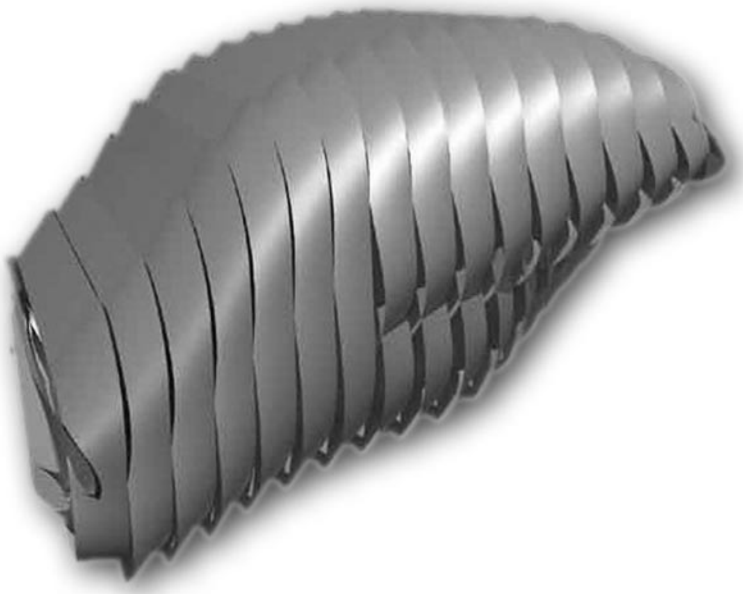


Figure 8. A computer study for the Embryonic House, Greg Lynn

Figure 9. Students' constructions that illustrate an interest in assembly, materiality, opacity, and connection

Apart from the machinery, researchers and educators in schools of architecture are at the intellectual forefront when it comes to considering the issue of digital tectonics. The overall research pattern seems to focus on the middle-ground of the digital and the material. One of the earliest and most prominent advocates of a hybrid approach to creating architectural space was Peter Anders, who coined the term *cybrid* to signify the amalgamation of physical and informational space. Anders writes: "*Cyberspace is not a place of escape. We found many similarities to the physical world … Issues of territoriality, dominance and various behavior modes are among the many things we encountered.*" Bennet Neiman and Julio Bermudez have also been investigating and comparing digital and analog constructions (Neiman and Bermudez 1997). In their spatial manipulation media workshops, they explore how architectural space is informed and transformed by media. They use a 3-day intensive workshop format to explore the effect of digital systems of production (scanning, video capture, modeling, rendering) to fundamentally alter the production of architectural space. Theoretically, Neiman and Bermudez are concerned with the realization that moving forward and away from old analog design methods requires that architecture finds an innovative in-between location that maximizes the strengths of both analog and digital methods: "*For it is in this space of between-ness where the dialectic processes unfold and therefore new techniques, knowledge, and ideas first arise. The future is not ahead, in the digital, but between the analog and the digital.*"

Neiman and Bermudez's pioneering work has been replicated, verified, and expanded through the work of Thomas Fowler and Brook Muller at the California State Polytechnic University in San Luis Obispo (Fowler and Muller 2002). Fowler and Muller trace the roots of their methodology to the Bauhaus tradition, but add to it the new medium of digital technology: "*The success of developing these Bauhaus methods into an analog-digital framework is that it introduces the students to a pedagogy of play and interpretation … which focuses more on the poetics of representation.*"

Researchers have also been predicting the current interest in digital tectonics and software's ability to model and simulate material properties. In 1998, David Matthews and Stephen Temple published a paper titled *A Pedagogy of Interdependent Technologies: An Experimental Studio for Synthesizing Digital and Mechanical Processes*. In their paper they question how future processes will incorporate a concern for the material properties of designed components and offer an insightful suggestion that is relevant to today's concern with digital tectonics: "*If digital technologies are replacing and expanding a system of existing abstract representation, how will ideas and experiences of material essences be explored? Will the design processes of the future incorporate material essences as directly as we seem to be currently embracing digital representations? The proposed model links digital and mechanical technologies in such a way that they cannot be separated.*"

The main procedural and intellectual difference between analog and digital processes is outlined by Kevin Klinger (Klinger 2001). He writes that while manual craft requires eye/hand coordination, digital processes require "*eye/mind coordination of thinking through the design process and exploring potentials by considering the particularities of [digital manufacturing processes].*"

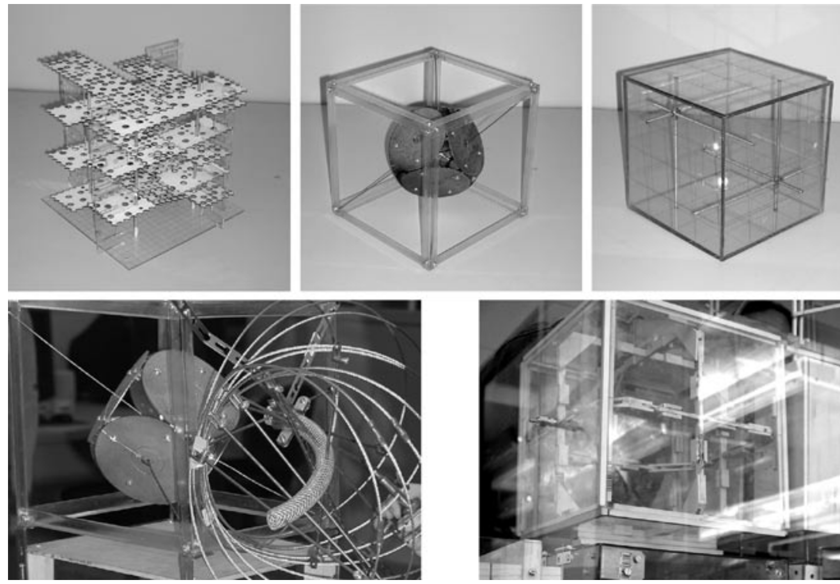


Figure 10. Example cube constructions from the first project

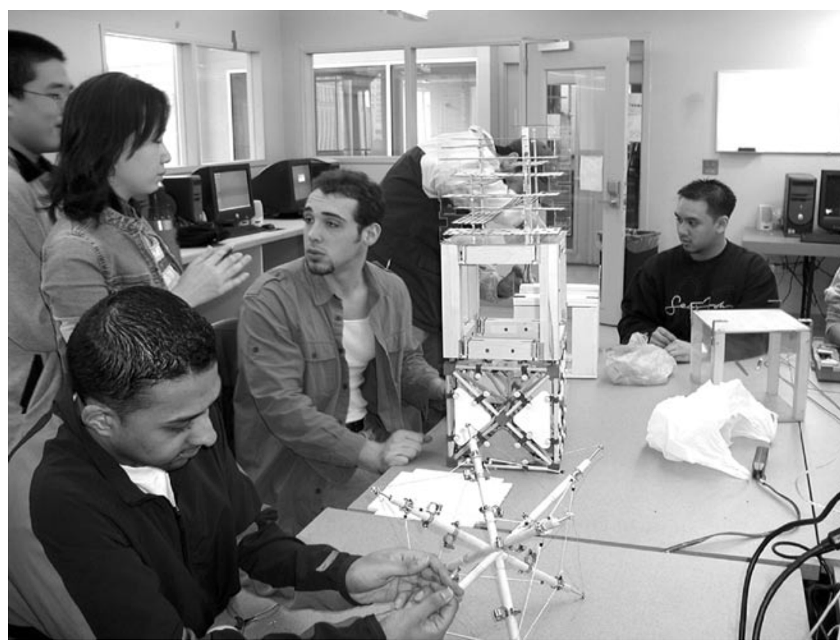


Figure 11. Synchronous collaboration, negotiations, and assembly of the matrix of cubes

The intersection of the Physical and the Virtual

Two experiments were conducted in an academic course setting with approximately fifteen students. The two experiments were repeated over two consecutive semesters. In the first experiment students were asked to construct and collaboratively interconnect physical objects without the aid of computers. Then, they were asked to recreate the same artifact using 3D modeling software, incorporate a new virtual component to it that is not meant to be manufactured, and transform the resulting composition into an interactive and dynamic virtual reality world. Again, the virtual composition was to contain virtual connections to the constructions of other students. The interfaces and linkages were collaboratively decided upon in a peer-to-peer fashion. In the second experiment, the students were asked to scan and model an existing physical object, isolate and abstract a portion of it, re-interpret it as an architectural surface, rationalize it, manufacture its components using a laser cutter, and assemble them to create a tectonic structure.

1. Building and interconnecting analog constructions

To expose issues of tectonics, it was deemed necessary to initially expose students to issues of construction and connection on a small scale without the aid of computers. Thus, students were asked to design and construct a 10"X10"X10" physical cube that satisfied several requirements:

- The cube must clearly define the corners as joints, the edges as linear elements, the surfaces as cladding.
- The cube should be capable of assembly and disassembly.
- The cube should aspire to the purity and perfection of an ideal cube.
- The cube should take into account craftsmanship and the requirements of mass-production.
- The cube should allow the definition of inside, skin, and outside.
- The cube design should be adaptable such that it can be connected to other cubes in the future.

To evaluate the cubes, four criteria were measured:

- The time it consumed to assemble the cube (at the end of the project, students were asked to bring their cubes in a disassembled state to class and assemble them during class time; they thoroughly enjoyed the synchronous race to finish the assembly of their cubes).
- The proportion and size of the components of the projects.
- The degree of disassembly (to balance the needed time for assembly).
- The overall quality and design of the cube.

The resulting physical cubes illustrate an interest in geometry, assemblies of material, opacity, and connections (Fig. 9). The cubes varied in fit and trim quality due to the varying degrees of student skills and familiarity with the chosen material (Fig. 10).

Given that the cubes will be interconnected at a later time in an orthogonal matrix, the students were asked to collaboratively pick their neighbors to the north, south, east, west, as well as above and below them. Without the aid of a visualized matrix that specifically locates the cubes in a three-dimensional space, the students picked their neighbors in an abstract and informational manner by filling in names next to the six directions. What is of interest here is that this method of hyper-linking works flawlessly in a virtual world, but fails miserably if face-to-face adjacency is to be maintained in an orthogonal matrix. Once the students discovered the flaw in picking neighbors using an informational strategy, they constructed mock-cubes out of chip board and assembled them into a matrix and wrote on the faces of the cubes the names of their respective neighbors. To maintain connectivity to distant neighbors, students were asked to create tubular connections that acted as physical metaphors to hyperlinks. Finally, knowing the position of the cube in the matrix dictated the chosen material and required structural strength. The group collectively decided on the overall shape of the matrix and in a few instances decided that some cubes will be cantilevered and thus needed to be constructed of a light material. Cubes at the bottom needed to be structurally capable of carrying the weight of all the cubes above them. The students maintained informal contact during class time and e-mail contact after hours throughout the project to discuss the chosen materials and design of their respective cubes (Fig. 11). Additionally, they constructed a shared computer-model of the cube matrix as a reminder and a locater of the position of each student's cube. While the computer-aided design of the cube was prohibited, it was deemed acceptable that computers be used to aid the collaborative process.

2. Building and interconnecting digital constructions

For the second project, students were asked to create an accurate model of their physical cube (Fig. 12). As Fowler and Mueller write: "*Going back and forth between digital and analog media has the advantage of revealing more quickly and more clearly weaknesses in a project as well as inconsistencies*" (Fowler and Muller 2002). Students were allowed to modify the design as to incorporate lessons learned from constructing the physical cube. Once the digital model was constructed, it was converted to a VRML file that contained animation triggers and hyperlinks to the models of other students and other web sites. That is, the original tectonic cube was transformed into a digital, three-dimensional, and dynamic gateway to a virtual world. The transformation allowed the students to consider architectural and tectonic methods of presenting and navigating through information. In that sense, the students investigated the tectonic of the digital as opposed to the digitization of the tectonic.

The geometry and methods of connection were generally improved. Additionally, the computer models facilitated a better understanding of the qualities of materials, especially their visual qualities (texture, color, reflectivity and opacity). The main advantage, however, of creating a virtual model is the ability to analyze the cube. Students created analytical drawings and animation sequences that explained the assembly and logic of the cube (Fig. 13).

Additionally, they were asked to add a virtual non-manufacturable component. This requirement opened up the creative potential of the student and allowed for a dialogue of the relationship of the virtual to the physical. Based on the qualities of the cube, a new virtual entity was created that was in most cases an interpolation among the various physical components (Fig. 14). The virtual component, perhaps predictably, was almost always smooth, dynamic, rhythmic, translucent, and organic in character. This is not surprising given the digital architecture mass culture the students are exposed to. The resulting artifact almost always created an interesting dialogue between the tectonic qualities of the original construction and the rhythmic qualities of the digitally conceived entity. The hybrid (or cybrid) whole could point to what Bennett and Bermudez describe as a "*middle response*" that investigates and is informed by the nature of architectural making. The experiments corroborate their position that the dialectic process between the digital and the tectonic unfolds in the "*messy production space where the digital and the analog meet*" (Bennet and Bermudez 1997).

Figure 12. Physical and digital counterparts of a tectonic cube.

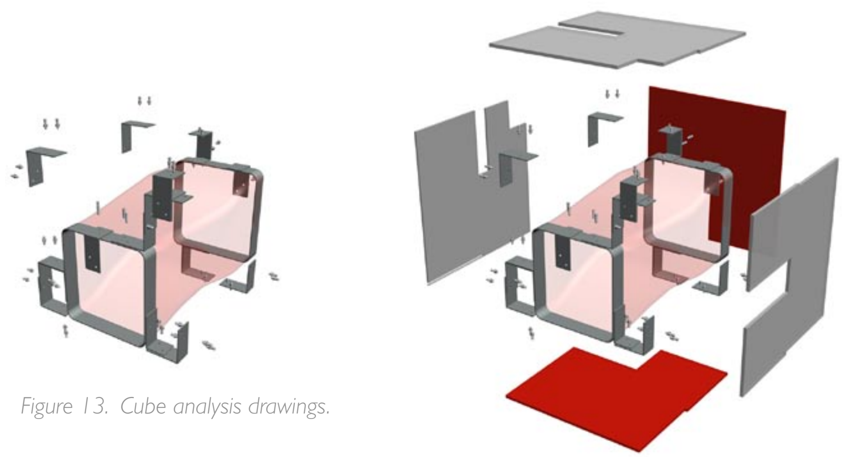


Figure 13. Cube analysis drawings.

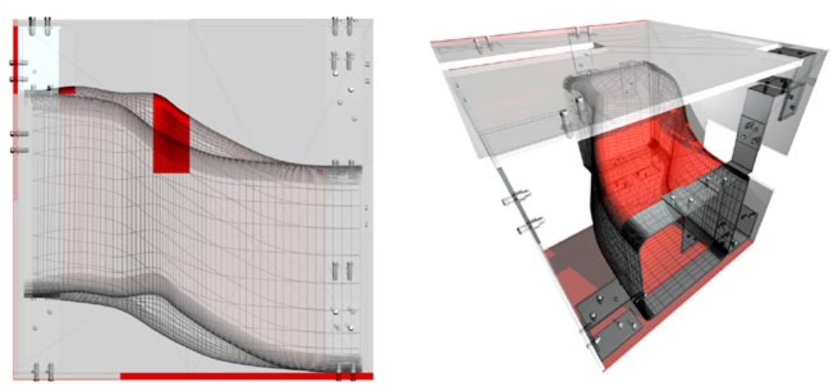


Figure 14. The addition of a virtual component.

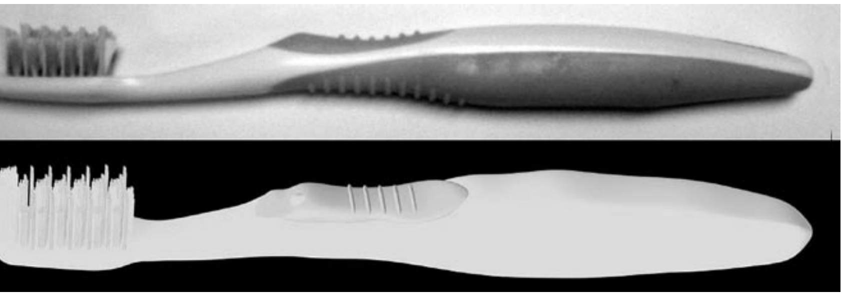


Figure 15. The modeling of a household object

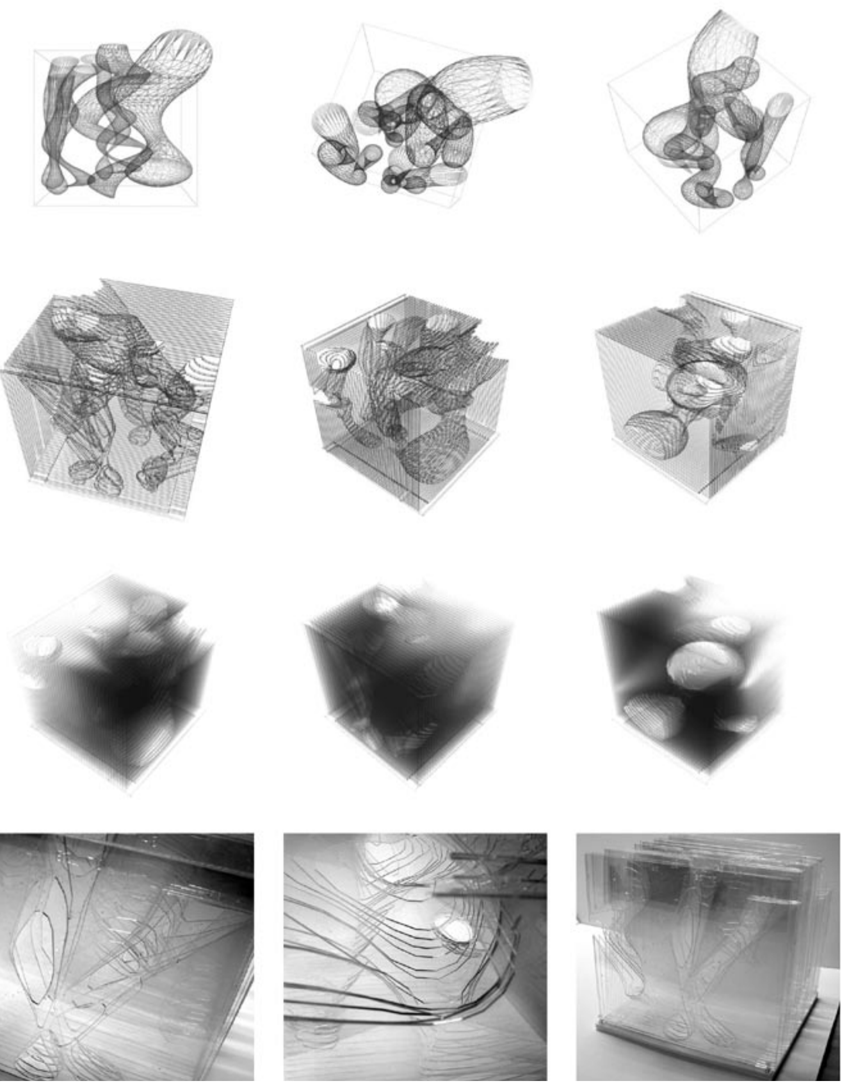


Figure 16. A process of deformation, rationalization, fabrication, and assembly

3. Physical-Virtual-Physical: Scanning, modeling, rationalizing, and fabricating.

The third project asked the students to find a household or similar object that is the result of modern computer-aided design software and digital manufacturing processes (Fig. 15). They were asked to choose a portion of the object that they find intriguing and look for repetition, pattern, and rhythm. They were then asked to invent a method to scan this object or trace its dimensions, create a 3D model of the object, and reinterpret this object as a rhythmic entity that can perhaps be understood as architecture. Finally, they were asked to rationalize the 3D object through segmentation, triangulation, slicing, or other similar processes, subdivide the object into multiple 2D surfaces that can later be re-assembled, and use the laser cutter to cut those surfaces (Fig. 16).

The results of the experiment indicate that thinking about architecture as a surface inherently excludes an investigation and a consideration of assembly and tectonics. Given that the assignment did not mention using various materials, the students intuitively restricted their investigation to the modeling, rationalization and fabrication methods. Plexiglass was by far the most popular choice, since one student informed the group of a store where they could get remnants for free. Additionally, plexiglass provided the layered translucency the students found visually seductive (Figure 17). Regardless, some joinery had to be considered and designed into the cut pieces in order to assemble the sections. In most cases, a threaded rod and nuts were used.

The most fundamental decision the students had to make during the fabrication process was the interpretation of what is solid and what is void. Since the computer model provided a zero-thickness surface, the students had to create a closed polygon in order for the laser cutting to work. The decision as to how to read the surface offered the students an opportunity to study how rhythms and continuity can be designed and experienced through repetition, evolution, and distribution in space. It is in these investigations that students start to appreciate the notion of digital tectonics. Conversely, the first experiment that emphasized material investigations and physical connections conveyed the importance of understanding the manufactured product and incorporating that understanding into the digital process. Essentially, the experiments were designed to allow the students to investigate the bi-directional pathways that connect the physical to the virtual.

Conclusions

Based on a strong architectural tradition of buildings being conceived as assemblages of components, tectonics in architecture celebrate the poetics of an assemblage's structural clarity, materiality, and detail. The advent of automated manufacturing processes and the possibility of directly translating virtual creations into physical artifacts has brought forth the possibility of exploring a digital tectonic: the poetics of digitally conceived, structurally clarified, and directly manufactured architecture. Digital tectonics challenge architects to explore new ways of conceiving, analyzing, and manufacturing structures that remain true to the tectonic tradition while addressing the shifts in culture and media towards the digital. Educational institutions were at the source of the fundamental shift to digital tectonics that we are witnessing today, yet they need to be aware of some possible pitfalls and biases that are built into the tools they are deploying. CAD/CAM equipment that produces complete so-called *appearance models* does not readily provide the students with ability to critically investigate issues of assembly and tectonics. What is perhaps ironic is that the incorporation of digital manufacturing in architecture was in part a reaction against the use of computers for purely representational purposes. Yet, for the most part, CAD/CAM techniques such as stereolithography can only use one material for the 3D plotting of an object. The material, in most cases, does not match the physical, visual, and structural properties of the modeled material. Thus, the same way that a color plotter usually adds little if anything to the design investigation and process, a 3-D plotter, if not questioned and used critically, will add little or nothing to the investigation of digital tectonics. The use of a laser cutter, which some might consider outdated, was actually advantageous because it allowed students to rationalize and segment their design into components that needed to be manufactured and assembled. The experiments were limited in that most students narrowed the rationalization process to sectioning their models in parallel slices. Future experiments

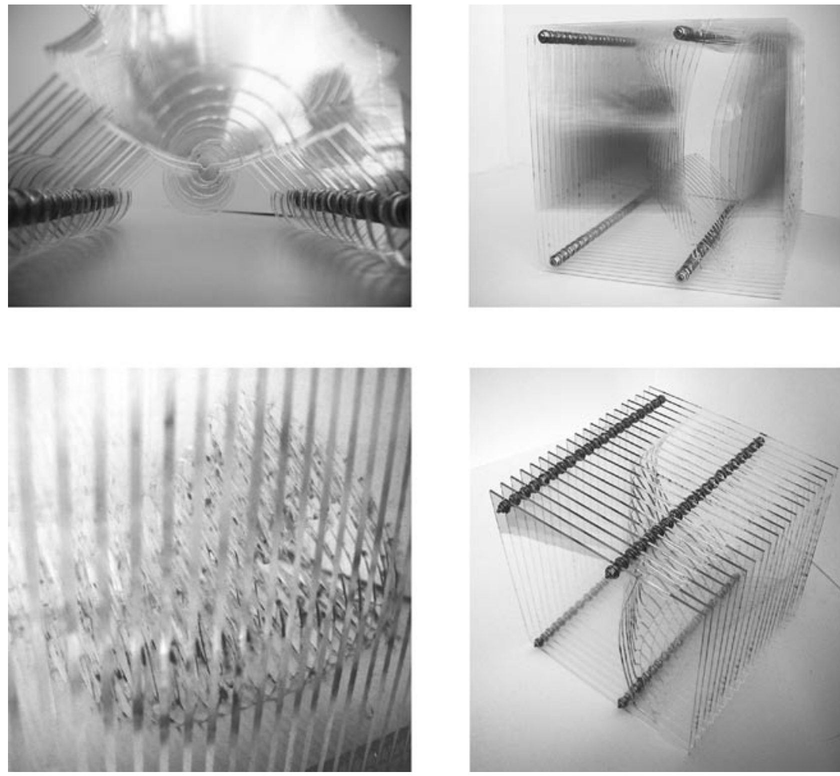


Figure 17. Examples of final assembly of laser cut sections

will emphasize the variety of possible rationalization and manufacturing strategies and critically match those to any new CAD/CAM equipment that might be available. In particular, future experiments will emphasize the investigation of tectonic and structural surfaces that interconnect without the aid of an underlying armature.

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