SECTION 4:

SELECTED WRITTEN WORKS

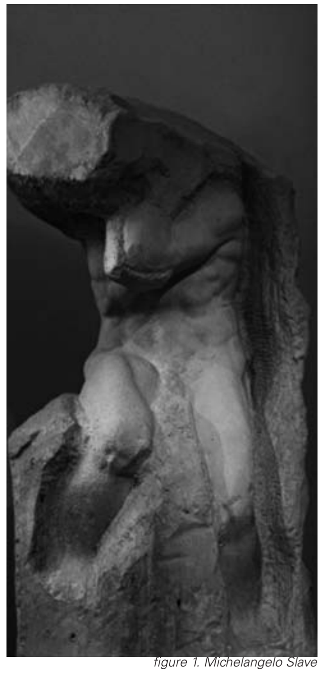
figure 1. Michelangelo Slave

"Resistances, those facts that stand in the way of the will"
– Richard Senet

In 1505 Michelangelo was summoned to Rome to design the Tomb of Pope Julius II. Originally intended for Saint Peter's Basilica and consisting of nearly 40 freestanding figures, the version completed in 1547 was a ghost of the original proposal. Following Julius' death in 1513, numerous funding reductions and competing demands of Michelangelo's time led him to permanently stop work in 1523 on what were to be a series of enslaved figures that would form the base of the tomb. As a result, six slave figures were left unfinished and stand as a physical record of Michelangelo's process. [figure 1] While the sculptures provide insight to the techniques of the day, perhaps more striking, is the resulting imagery. It is one in which the slaves struggle to break free from not only their torments, but also the very stones from which they are formed. The juxtaposition between identifiable human forms and rough hewn stone animate the figures in such a way to suggest the slaves coming into a state of existence out of the stone. Michelangelo speaks to this as he describes his process as one that does not sculpt figures into stone but rather liberates them.

Sculpting natural materials is an inherently precarious proposition. The material characteristics that enrich the object under formation are the very things that present challenges to those working the material. In the case of Michelangelo's enslaved figures, one must have the skill to read and navigate the veins and pockets within the stone to ensure material integrity is preserved and vision achieved. In his seminal book, The Nature and Art of Workmanship, David Pye refers to this negotiation as a workmanship of risk. In contrast to a workmanship of certainty, in which "the result is predetermined and unalterable once production has begun" [1] risk relies upon acquired knowledge to address problems as they are uncovered. The stone quite literally, presents resistance to the act of chiseling. The skill of the individual working the material is directly related to their ability to work through the material resistance. This is not the result of shear will, but rather an opportunistic response to those things uncovered. It is a form of enlightened improvisation. While, in the case of the enslaved figures, the risk is tethered to materiality, risk can also manifest through the tools and techniques employed. In essence, Pye's distinctions between certainty and risk speak to the very relationship between design and realization. This is inherently a negotiation between will and feasibility.

In the sphere of architecture, this relationship has, by necessity, typically been top down with design largely determined prior to fabrication or construction. This is understandable, as the act of building is often a unique, complex assembly of a multitude of components and materials. [2] In light of the inherent costs, those with a vested financial interest in the process must mitigate risks and keep surprises to a minimum. As a result, there is an implicit bias towards resolution prior to fabrication and often, reliance upon low risk conventions.

Increasingly advanced design, simulation and management tools such as a building information modeling software promise an even greater degree of design resolution and efficiency before the commencement of construction. In the context of practice, the benefits of such tools have been made clear.[3] Streamlined information sharing and the ability to "see" every piece of the building are changing the ways architects collaborate and the extent to which a building is understood prior to construction. While this process remains novel in the construction industry, it has been utilized for quite some time in the aerospace industry as an attempt to remove all uncertainties prior to the costly endeavor of fabrication. [4] While an airplane and a larger building may share complexity, most buildings are typically one off custom constructions with unique material conditions. As a result, the design processes are implicitly distinct. While the data may facilitate a streamlined process, and in the case of the airplane, lead to highly optimized engineering, it alone does not ensure a great or even good building by standards beyond measure. Ideally, in the case of architecture, the data of the virtual model is parsed through the expertise of the architect and a growing list of specialists. Here, the distance between virtual design data and material reality is compressed through an architect's material sensibility, borne out of observation and engagement of material conditions and their associated limits. A classic example is that of precision. While the 1:1 modeling environment of design software affords absolute dimensional precision, only the architect versed in material reality will transpose intrinsic material characteristics such as dimensional variability or material movement to the virtual simulation. As such, the virtual design data is most useful when understood in relationship to the physical conditions it represents. Otherwise the data is relegated to a graphic, devoid of any intelligence.

Digital fabrication technologies are increasingly utilized to realize novel form and to achieve greater efficiency within the construction process. They have been heralded as processes that redefine traditional systems of communication while empowering those with access to the virtual building information.[5] Herein lies the paradox of contemporary design and construction. While use of software in the design process may in the past have distanced the designer from the messiness of physical reality, emerging connections between software and hardware tools are increasingly extending the hand and intent of the designer deeper into the process of fabrication. Digital design and material processing have reinvigorated a material discourse and currently offer potent connections to architecture's physical presence. Within the academy, the promise of such processes is a material awakening or, as Richard Sennett refers to, a material consciousness [6] whereby one develops an interest in physical things one can change. This active engagement of materiality prompts a reassessment of virtual design data that, for the young architect, are often devoid of material characteristics. The result is a materiality infused with the characteristics of its digital processing. [7] Here the presence of the digital is evident through geometric complexity, control and fidelity rather than a singular formal or aesthetic representation of digitally derived form.

Since its inception, the architectural design process has relied upon various forms of representations, simulations or proxies.[8] The sheer size and complexity of buildings does not allow the degree of full-scale studies common in other design disciplines. The design of a product, such as a chair typically affords a degree of immediacy and direct material investigation not found in architecture. The evolution of the Eames shell chairs, beginning with plywood, evolving into sheet metal and culminating with fiberglass speak to the feedback loop afforded through direct material engagement and testing.

While mockups or material studies may be executed prior to construction, they generally have served as a test of prototypical conditions or occasionally a limited palette of options. Their execution is necessary to the process of construction but typically has not served as the catalyst for design advancement. As abstractions, material proxies may represent a limited range of material characteristics, but they often serve as a rendering of form rather than a tool to elicit fundamental material properties. As is the case with virtual design data, their utilization relies upon ones ability to project materiality into an otherwise inert form. This again, relies upon a sophisticated design process that is conscious of materiality.

Over the past decade, digital fabrication tools have grown exponentially in presence throughout the academy. The result has been a veritable arms race amongst institutions intent on projecting themselves as cutting edge. The transformative potential of these tools is clear and the opportunities to explore complex physical form have been well documented, however the material focus of such processes is very much emerging. The focus of our investigations resides in the pedagogical impact of the process, specifically the value of a student's understanding that materials and processes present resistance and limits that inform the design process. It is in this space between intent and actualization that the student discovers they must reconcile their will with what they can achieve. Limits are discovered rather than predefined within the software.

Digital fabrication tools can be generally understood as task centric and loosely categorized as either subtractive or additive processes. Contrary to this condition, the industrial robot is not designed or biased toward a specific task or method of fabrication. Industrial robots are found in food processing, material handling and heavy manufacturing. They have a long history and significant presence in mass production settings such as automotive assembly lines and have typically been implemented as a measure to streamline production, increase productivity and improve safety. In this context, the robot has been principally utilized for highly repetitive tasks. Historically, the time and associated cost to program the robot was outweighed by the productivity gains once the machine was operating. Other than occasional maintenance, the robot could predictably cycle the predefined task into the foreseeable future. The articulating arm industrial robot differs from most other digital fabrication tools in that it, in and of itself, does not bias a particular method of fabrication. The tool on the end of robot dictates what the machine can or can't do. While industrial robots have grown in manufacturing sectors over the past 30 years, their use in the construction industry has been marginalized due to high implementation costs, operational complexity and labor concerns. While current utilization has been primarily limited to the academy, decreasing equipment costs and significant developments in human machine interaction suggest an untapped potential for industrial robots within the construction industry.

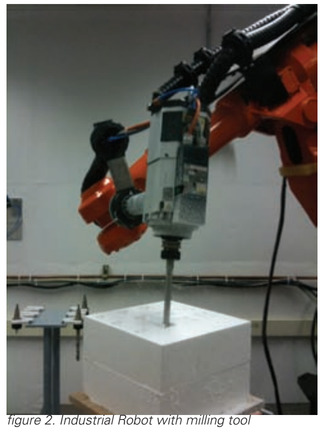
figure 2. Industrial Robot with milling tool

An ABB IRB 4400 industrial robot was acquired by the digital fabrication lab [dFAB] in the School of Architecture at Carnegie Mellon University as a supplement to existing task specific digital fabrication tools. The IRB 4400 is a six-axis articulating arm with a reach of approximately 2 meters and an end-of-arm load rating of 40kg [figure 2]. The robot work-cell was further outfitted with a rotary table that acts as a seventh axis, providing additional flexibility and reach for the robot. The first, of what will be a series of courses taught to undergraduate architecture students, focused on the utilization of industrial robots in the field of architecture. The intent being that each course will be structured around a specific type of fabrication and architectural condition. A guiding principle for the research is a focus on the material and tectonic potential through the process. Subtractive processes, specifically multi-axis milling served as the mechanical process, while the architectural screen served as the condition. To this end, the robot was configured as a multi-axis subtractive tool with a high-speed cutting spindle mounted on the end of the robot arm, allowing for the cutting of foams, plastics and woods.

Significant differences exist between a milling robot, such as the IRB 4400 and traditional subtractive CNC equipment. Whereas most subtractive CNC equipment operates about three axis and tends to limit milling to one surface at a time, the industrial robot

figure 3. material / process study

allows a substantially greater degree of carving options such as undercutting, where the axis angle of the cutting tool varies from what is traditionally fixed at ninety degrees on three-axis CNC equipment. While industrial robots offer a significant degree of task and motion flexibility, they do not have the same degree of stiffness found with traditional subtractive CNC equipment such as milling machines or routers. As a result, the palette of potential robot carved materials tends to be limited to softer materials such as foams and woods. While this limited material palette could be used to focus the material component of the initial experiments, the seemingly limitless milling flexibility found with the robot could easily become unproductive and an excuse for a lack of critical engagement with the process. As is the case with most educational pursuits and studio projects, increasing options does not ensure greater pedagogical effectiveness or project complexity. To the contrary, constraints are enabling devices that can serve as catalysts for the design process. The distinctions between opportunity and distraction are subtle, contextual and often challenging for undergraduate students to assess. Therefore, the methods and range of robot motion was focused to ensure a depth of engagement on the student's behalf.

The architectural screen both separates and connects the spaces and individuals on either side. As a surface, wall or object, the screen is defined by the relationships between material and void, across the screen and through its thickness. Here, one's attention vacillates between the screen, its implicit boundary and the resulting effects. Screening can be achieved through a permeable surface or object, or can be the result of a spatially loose assembly of components that leads to porosity at the joint. These distinctions speak to a geometric and tectonic logic that is potentially reliant upon subtractive or additive methods. The porous nature of the screen implies a degree of correlation between its two faces. This can be reciprocal or the resultant intersection between two distinct surface conditions and geometric systems. Initial investigations probed these conditions through the development of complimentary, yet non-intersecting geometric systems and surfaces. The translucent properties of Corian were exploited to reveal a superimposition of the two systems. [figure 3] While the surface denied a literal visual connection, the relationship between surface geometry and tool trace were revealed when backlit. Slight variations in the sheet thickness resulted in a broad range of translucency throughout the ½″ sheet thickness and spoken to the latent potential within a relatively thin piece of material.

As the investigation proceeded, the influence of materiality shifted in light of the necessity to work with distinctly different materials on the robot. The maximization of thinness, associated with the use of Corian shifted to the maximization of thickness offered through the use of foams. Furthermore, the affordability and speed with which the robot mills foam promoted an iterative design process. The additional thickness found with foam, allowed for the development of spatial transformations through the thickness of the material. A focus on surfaces that were previously reciprocal yet non-intersecting evolved into a focus on the relationship between surfaces and perforation.

While the industrial robot offers a higher degree of milling flexibility, the considerations for how the machine will remove the material are far greater than found with traditional three-axis machines. Industrial robots, such as the IRB4400 typically have more than one robot arm orientation for any given point in space. Robot orientation can be resolved by the robot controller software in real-time or planned in conjunction with the generation of robot instructions. If, robot orientation is resolved by the controller, unpredictable robot motion may occur, leading to collisions between the robot and the milled material or any supporting fixtures or jigs. In light of these added levels of planning, initial use of the robot began as relatively simple operations and grew in complexity to match the learning curve. This was manifest through subtractive studies based on distinct collections of points, lines and surfaces and began with drilling and ended with mult-aixs milling. [figure 4] In milling operations, material is typically carved through a progressive engagement of the bit tip with material. The added freedom of the robot offers alternative methods for subtractive milling. As robot milling progressed, attention focused on use of the length and edge of the bit as the cutting surface. This type of milling, referred to as swarfing, utilized the ability of the robot to tilt the bit about the z-axis and subsequently allowed for a substantial degree of geometric transformation along the z-axis. [figure 5] The axis of the bit acted as a rule line and could be traced through the material to develop a ruled surface. This method of material subtraction served as the framework for all subsequent student investigations. The thickened perforations of the surface were developed as lofted surfaces that consisted of two loft curves, ensuring a ruled surface. The relationship between bit tilt (about the z-axis) and resulting maximum achievable milling depth operated as a parameter to guide the development of surface geometry. Closed boundary curve geometry was created at minimum and maximum levels along the z-axis, corresponding to the thickness of foam stock. Tool-paths were calculated as straight lines between an equal number of points along both curves. Robot motion was calculated through each of the rule lines, resulting in a smooth surface. The geometry and resulting voids achieved through this method of milling could be transformative, allowing for spatially distinct or intertwined voids. [figure 6] While use of expanded styrene foam [EPS] in these investigations allowed for quick, rather inexpensive iterations of a thick material, it offered few compelling material properties beyond its insulation capacity and extreme light weight. Ironically, the closest form of resistance levied through the use of EPS was manifest through its fragility and relatively low resolution. Foam, in and of itself, was not sufficient as the final implemented material.

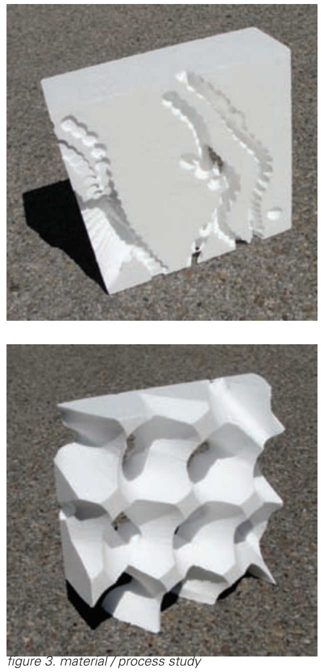

figure 3. material / process study


figure 6. multi-axis milling detail

As work proceeded, there was a shared sense that materiality and the methods for processing material be explicitly addressed and expressed. This ambition moved the conversation of materiality beyond that of a proxy or simulation in which the immediacy of material characteristics may be sacrificed, into the realm of specific material properties and limitations. The pedagogical potential of the project lie in the ability to serve as a counterpoint to design studios in which the proxy is an abstraction device. In the context of this project, a meaningful process must provide students with the immediacy of material engagement, stripped bare of the proxy. The understanding of material and process transformed from a single step subtractive workflow in which foam served as the proxy, into a multi-step process in which foam was utilized as a negative mold for subsequent casting. [figure 7] The distinctions between casting and carving, particularly in the context of Pye's negotiation of risk are significant. The 'unknown' variables embedded deep within Michelangelo's marble block are displaced in casting processes. When executed properly, the material is quite consistent, even with the use of aggregates. Resistance is manifest first and foremost through the constraints found within the process.

The potential for a thick, spatially varied screen was retained while the completed screen could be manifest through a range of cast materials. Casting materials were limited to those that were readily available and cost effective. High strength cement and fast setting plaster were deemed most appropriate for casting plasticity and structural viability. Initial, tube-like castings relied upon simple one-part molds and consisted of a ¾" thick ruled surface as the spatial envelope and structural component wall. The trace of the bit was inverted and now as solid, was manifest through the cast component wall. Each casting contained a single void that was an offset of a perimeter hexagon and could be nested as a cellular system of components. [figure 8 and 9] While the physical strength of the initial castings was promising, they were deemed unsatisfactory due to the fact reliable stacking and nesting could not be achieved without the use of an adhesive or mechanical fastener. Ideally, the system of components should be dry stackable, yet capable of producing a broad array of internal voids in response to particular performance criteria such as light transmission and airflow. By addressing exterior and interior surface geometry independently, rather than as offsets of the same surface, component nesting (exterior surface) and performative potential (interior surface) could be refined simultaneously under distinct criteria. A system of "ridges" and "valleys" along the outer surface allowed components to reliably stack and nest without a secondary means of attachment, [figure 10] Furthermore, two-part molds allowed a greater degree of geometric transformation and facilitated a significantly thicker screen. An extruded hexagonal tiling system acted as the geometric basis for screen geometry and provided a substantial degree of rigidity through the packed nature of the pattern. [figure 11] Transformation points were subsequently placed across both sides of the surface and served as the basis for algorithmic transformations between outer and inner surfaces. [figure 12] As these transformations diffused across the tiled geometry, size, shape and directionality of openings adjusted in conjunction with a change in distance from the transformation points. The result is a dynamic range of spatial conditions that shift as one moves along the wall. [figure 13]

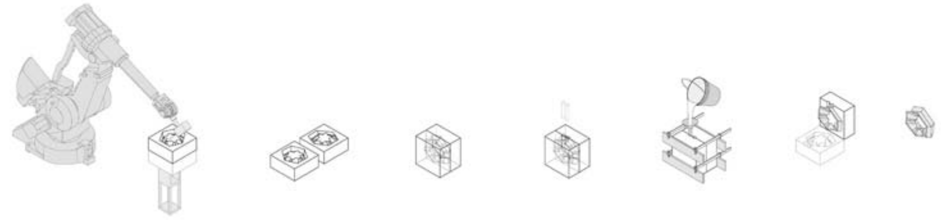
figure 7. robot milling / casting workflow


figure 8 and 9. cast components

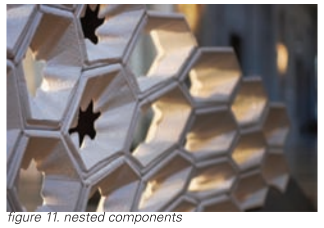
figure 11. nested components


figure 13. assembled component wall

The physical manifestation of the screen resists simple associations and stands in contrast to typical perforated conditions. The screen is at once materially substantial and rigid yet highly porous. The pattern of openings abides by a strict set of interrelated geometric transformations but is comprised of over 150 unique components. While the geometries are controlled and speak to their digital origins, the surfaces are decidedly textured and evocative of the multiple processes undertaken. The smoothness and seamlessness of digitally generated and fabricated surfaces is subverted, resulting in a material logic that evokes both the machine and the hand. As such, materiality is a manifestation of both analog and digital processes. The resistance presented by processes and materials necessitated recalibrations of intent and resulted in a complex set of translations between geometric systems, digital and analog processes and material characteristics. The resulting construction offers a material and tectonic language that is both reliant upon and evocative of emerging fabrication processes, while also referencing longstanding methods of material use and construction.

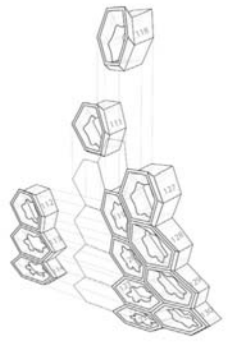
figure 10. nested components

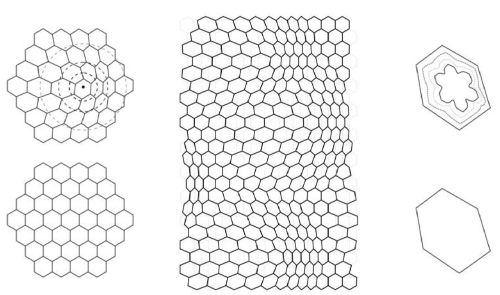
figure 12. geometric principles

Endnotes

1. David Pye, The Nature and Art of Workmanship, (Cambridge University Press, 1988), 4-8
2. Stephen Kieran James Timberlake, Refabricating Architecture, (McGraw-Hill, 2004),
3. Ibid, 25-27
4. Ibid, 79-84
5. Branko Kolarevic, Architecture in the Digital Age: Design and Manufacturing, (Spon Press, 2003), 29-54
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figure 1. Jean Prouve factory


figure 2. Gropius / Waschmann panelized house

Abstract:
This paper documents the possibilities of variation within serialized manufacturing, facilitated through the use of advanced computer controlled manufacturing tools. Specifically, it speculates upon the potential for architects to acutely affect the design of a particular building component through the use of digital equipment. In this investigation, a common architectural element, the interior wall surface and partition, was addressed as a building component that is ubiquitous to many buildings but particular to the specific needs of each application.

Standards?

The design and ensuing fabrication of architecture is tied to and influenced by materials and related manufacturing processes. Historically, increased automation prompted standardization in these areas and severed traditional working relationships between architect and craftsman. There were some notable exceptions in which architects sought to exert control over manufacturing. This is probably best exemplified in the practice of Jean Prouve in which, for a span of time, studio and factory effectively merged [figure 1] or the prefabricated panel house collaborations of Walter Gropius and Konrad Waschmann [figure 2] where design of process paralleled product. Both utopian pursuits ended in failure as the qualitative demands of the architect met the quantitative and economic demands of mass production in which standards increasingly catered to the lowest common denominator. Many of these standards evolved from time-tested systems in which significant set-up and tooling costs were mitigated by high productivity and increased volume. A manufacturer's equipment performed specific tasks to produce a finite product. In most instances, these rigid manufacturing processes limited material and product variation, resulting in increasingly narrow choices for consumers to draw upon. Typically, deviation from these standards became increasingly prohibitive due to cost and time. For architects, this resulted in a dilemma in which, the particular and often unique necessities of a design project had to be addressed with a narrow palate of standardized products targeting broad audiences and necessities.

"We used to live in an era in which most things had to be made to be the same, but we are about to enter a new era where, if we want it many things or perhaps all things can be different."

In contrast to the past, today's manufacturing processes are increasingly elastic and prompt considerations for the possibilities beyond mass production. Manufacturing tools can be utilized for what they perform, not necessarily what they produce, redefining the traditional notion of a Fordist assembly line. Recent architectural projects illustrate such technological advances in which digitally driven equipment enable modes of production where software and hardware provide the medium for collaboration between architect and manufacturer. Here, typical conventions of information exchange found within practice evolve as design document becomes a literal set of digital manufacturing instructions, providing a virtual extension of the hand of the architect into the fabrication process. The translation is not seamless, requiring a familiarity with emerging techniques and a willing collaborator. This does, however, increasingly present the potential for customization, variation and standardization to co-exist. Ironically, the equipment that limited production variation and manufacturer – architect collaboration has evolved to a level of agility that reintroduces the very features it marginalized.

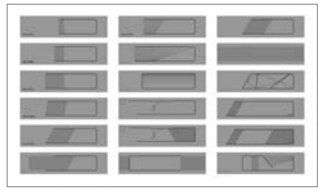
figure 3. bending kerfs

Process

Plywood and Medium Density Fiber Board are affordable, widely available building materials utilized by the construction and furniture industry alike. Although they are quite similar dimensionally, their structural, aesthetic and machining attributes vary significantly. These two off-the-shelf materials provided a palate for the investigation of digital fabrication techniques; specifically 2-1/2 axis computer numeric controlled routing (CNC) in which two-dimensional vector CAD drawings determined tool paths.[figure 3] Process and product shared importance and provided opportunities to test how one moves from digital model to physical artifact while encouraging speculations on alternative implementations of both materials. To begin with, functional associations with architectural conventions were loosely defined as interior wall surfaces. The generality of context fostered unpredicted results, while providing a basic frame of reference. The general premise was to allow for the product to evolve through material specific process investigations. It was not however, merely the result of technique. Form responded to, not followed, process. As research ensued, functional opportunities emerged. A reciprocal relationship between process and product emerged in which action on a material adjusted in response to refined goals. Together, the MDF and plywood investigations sought to produce surfaces that could respond to changing programmatic or environmental requirements of a given space, either through material mutability or built-in flexibility for future adjustment.

Performance

Generally, performance has had two distinct definitions, the effectiveness of something to fulfill its intended purpose or the execution of a series of actions. The architectural virtues of firmness, commodity and delight defined by Vitruvius point towards to the former and continue to represent a common interpretation of performance relative to architecture in which efficiencies rather than actions are the qualifying criteria. Although buildings are often a stage for performance, they rarely become the object of performance. One


figure 4. bending kerfs


figure 5. pull


figure 6. wall panels


figure 7. back lighting at panel


figure 8. back lighting at panel

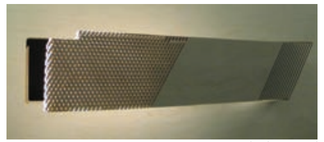
figure 9. lattice panel

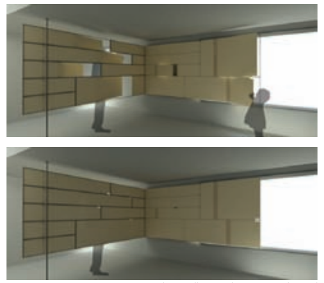
figure 10a,10b. wall panels open, closed

can consider an alternate, less static definition in which performance can be seen as a dynamic responsiveness to various complex relations. This suggests the potential for an architecture that is agile and capable of multiple identities, resulting in a form of detached determinism in which change primarily occurs within pre-defined limits. For the MDF and plywood investigations, these limits were largely dictated by the material itself, such as its dimension and strength. Although this is related to how the materials were machined and fabricated, the limits do not necessarily prevent accidental or intentional mis-use. They are more guide than barrier.

Performance relative to this investigation can be considered as both effectiveness and action, whereby the action of the panels is reliant upon the body. In the case of the plywood panels, action becomes bending. [figure 4] The operation of the panels is facilitated through the milling of visual clues into to the panels, informing the user as to their operation. [figure 5] The amount of action upon the panels is determined by the user. Here, performance becomes participatory as panels are adjusted to achieve a desired effect.

Product

Both branches of research, related to Plywood and MDF occurred in tandem. Although similar techniques were employed, intrinsic differences between the materials led to quite different results. In the case of plywood, 7 ply Baltic Birch was chosen for strength and finish quality. Initial routing was primarily 2-dimensional, producing kerfs and cuts which allowed bending in response to push and pull, effectively transforming a rigid sheet into a pliable surface. [figure 6] A subtle change in the depth or spacing of kerfs dramatically affected ease of bending and general stability. Milling too deep resulted in precarious sheets that were easily broken. Milling to shallow effectively left sheet rigidity unchanged. Additionally, it became clear that locating the bending element as a figure within or extension of a larger sheet, provided area for mounting.[figure 7] As these investigations progressed, milling moved to both faces of the plywood sheet. Here, the registration and intentional mis-registration between cuts on both faces provided tabs for hardware, which held panels open or closed [figure 8], while in the instance of multiple superimposed cuts of opposing angles, offered a lattice like condition.[figure 9] At the scale of a room, a series of operable panels encourage a modulation of view and light through adjustments of the surface by inhabitants. The panels can be installed on top of existing walls or glazing, effectively re-skinning it, or as free-standing partitions. In both scenarios, plywood panels are attached to a steel frame, providing structural rigidity while allowing for panels to be held off of ceiling and floor. Depending upon the number of bendable panels installed, the ratio of bendable surface to fixed surface and the degree of opened or closed panels, the ability for the surface to bracket view and light change significantly. [figures 10a,b]

Due to its fiber size and lack of grain, many of the outcomes of the plywood inquiry, such as pliability and translucency are unachievable with MDF. The homogeneity and strength of Medium Density Fiber board offered milling consistency throughout its section while allowing for relatively simple surface finishing. Here, the sheet contains multiple types of cuts, resulting in a vocabulary of tracks, screens and anchors. [figure 11] Tracks allow for objects to be hung and moved across the sheet; screens allow the transmission of light, air or view; while anchors allow for fixed fastening. The inscription of these cuts across sheets is driven by current and anticipated requirements of a space, such as lighting, storage, air circulation and view to mention but a few. The resulting panels blur the distinction between wall surface and furniture and by doing so; reconfigure the relationship between room, content and inhabitant. [figure 12]

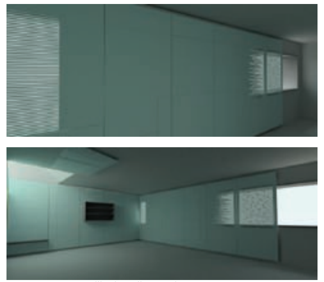
figure 11,12. milled wall panels

Both instances suggest a multiplicity of conditions within a finite system of panels. The processes employed and the resulting forms establish a formal language capable of fulfilling various needs. Cuts for a handle may also double as a light diffuser. Although they may attach onto existing walls or ceilings, both the plywood and MDF panel systems are effectively portable and provide the potential for installation in multiple locations. As user moves, so can the interior surfaces of the rooms which enclose them. The resulting reconfiguration of the panels recalls previous installations while adapting to current needs.

ENDNOTES:

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2 Tim Crayton "The Design Implications of Mass Customization" , in Architecture and Animation ed. Bob Fear (Architectural Design 2001)

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4 Bruce Gitlin, "Working with Designers: A Fabricator's Perspective" in New Technologies in Architecture, Digital Design and Manufacturing Techniques ed. Bechtold, Griggs, Schodek, Steinberg (Harvard University 2000)

5 Christopher Mercier, Alberto de Gobbi, Fred Adickes "The Conde Nast Project: A Case Study" in New Technologies in Architecture, Digital Design and Manufacturing Techniques ed. Bechtold, Griggs, Schodek, Steinberg (Harvard University) 2000

6 Vitruvius Pollio, in D. Rowland, translator, The Ten Books of Architecture (New York: Cambridge University Press 1999)

7 Ali Rahim, "Potential Performative Effects" in Contemporary Techniques in Architecture ed. Ali Rahim (Wiley Academy 2002)

Abstract:
With any representational course, the produced artifact is reliant upon the content chosen for study and presentation. Its associated scale, complexity and materiality affect the range of techniques employed as well as the general interpretation associated with each exercise. For this course, each student was assigned a noteworthy recently completed building. They proceeded by selecting a segment of their assigned building. Size and complexity of segments varied with the scale of each building. This segment served as the focus of all subsequent exercises throughout the semester. As media and techniques varied, the object of presentation remained constant. With this, students focused exclusively on what and how to represent rather than simultaneously designing content and deciding how to represent it. The media affected message.

This paper seeks to prompt a discussion concerning the introduction of representational techniques to the beginning design student. The growing number of digital techniques and yet the value of traditional techniques has dramatically increased the architect's repertoire. The learning curve, however, associated with many of these new digital tools is significant and the resulting work produced by students is often tethered to the computer and difficult for others to observe and learn from. How does one respond to these increased pressures? Does this require an increased level of specialization within a student's curriculum or is it essential for students to develop a facility with all these tools? The implementation of the representation course at North Carolina State University was intended to explore these new pressures through the use of alternative teaching methods. The content of this paper discusses in depth many of the issues that prompted the creation of such a forum and speculates upon the potential for alternative methods to enhance the effectiveness of an increasingly complex set of techniques and their implications upon the creation and representation of architecture.

Introduction:
The influence of digital media upon the practice of architecture, albeit still in its relative infancy has affected all facets of design and production. We as architects have been prompted to reevaluate if not adjust the way we operate on a daily basis. The fact remains that for the majority of practice, the computer and it's associated digital media has largely been relegated to two roles; an instrument for the efficient production of drawings and an instrument of representation. The relative timid use of digital media can be traced to many factors, unfamiliarity and subsequent skepticism of its benefits; a long-standing method of working and conventions based on hand drawing and cost, time and anxiety to mention but a few. Over the past decade a generational gap became evident between those new to the profession, equipped with emerging skills related to the use of digital media and those well positioned within the profession with limited understanding of the potential of this new media, let alone the skills to operate it. As is the case of many technological advances throughout history, the resulting application has widely conformed to existing conventions and preconceptions. The academy and a select group of practices linked closely to it have in some cases embraced the discipline and unanticipated behavior this new media brings to the design process (1). In both cases, the academic environment affords the opportunity for a critical engagement of an instrument that is another tool in an architect's repertoire, but also a medium with evolving influence. The pedagogical dialog related to the infusion of digital media within the academic environment is broad and well documented and suggests alternative studio models such as paperless studios (2). Where and how digital media is introduced to the student requires consideration.

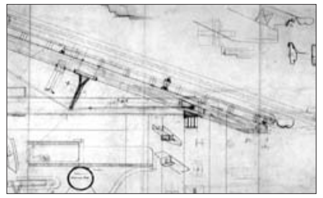
figure 1. Carlo Scarpa drawing

This paper reflects upon the integration of digital media within the curriculum as implemented through the creation of a course addressing both analog and digital media. It seeks to propose alternative models of instructional forums in which education and evaluation respond to the opportunities and constraints associated with the learning and application of these new tools. Furthermore it prompts a reconsideration of the position of digital media instruction within the curriculum and its impact on the culture of studio and the curriculum in general.

Analog Osmosis, Digital Dismay:
The dissemination of analog representational techniques, specifically drawing, has occurred across a wide range of forums, including but not limited to self-instruction, workshops and formal drawing classes. Typically these are tethered to the design studio either in the utilization of its physical space or in association with a particular studio design project. In the design studio the object of representation usually is the object of design. Exceptions, such as precedent studies or found object documentations are typically limited in content or duration. The reciprocal relationship between design and representation promotes a design process integrally related to the media, allowing for the coexistence of multiple forms of representation. This is evident in the drawings of Carlo Scarpa where the drawing sheet seamlessly blends sketches and technical drawings at multiple scales. (see Figure 1) Historically, the relatively shallow learning curve of many of these techniques promoted dissemination down through the ranks in which students taught each other, resulting in a general culture of resourcefulness. Simply stated, students are inspired and compelled by the work of their peers. Conversely, digital media often involves a steep learning curve and requires pointed instruction. Additionally, the intrinsic tether between hardware and software results in design artifacts that are often exclusively virtual. This results in a selective display of work, often inaccessible to one's peers other than

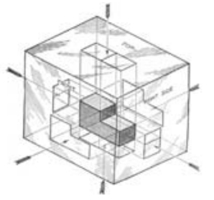

Fig. 2. The Glass Box, from Technical Drawing Giesecke, Mitchell and Spencer, 1958

at the time of review or jury. Compounded by each other, these two factors potentially contribute to a studio environment in which the development of technical and design skill is compromised by a lack of dexterity with the tools. Although the design studio is the forum for the infusion and application of digital media, it must not be degraded into a lab for software instruction. (3) For these evolving sets of techniques to become truly integrated into the studio sequence the foundation of skills and awareness of potential must be laid elsewhere.

Becoming Digital

The position of digital media instruction within the curriculum determines its utilization by the students and affects its subsequent utilization within the profession. If it is to be utilized as a tool for design inquiry, not merely an instrument for efficiency, students must begin the process of experimentation early in their education. They need not achieve mastery, but rather become familiar enough with the technology so as to be able to strip away its mythological veneer. (4) This requires time for experimentation with each of the various studio topics within a curriculum. The utilization of digital media in the creation of form is quite different than the study of site and context. By providing foundational skills early in the curriculum confidence and familiarity are fostered. This promotes a skillful and thoughtful engagement of the tools later in their education and eventually in the office.

At North Carolina State University a required digital media course and digital studio sequence aim to promote this engagement. The lecture course occurs in the semester preceding the digital studio, allowing students to develop a repertoire apart from the typical demands of studio. The College of Design at North Carolina State University has a rich tradition of making in which, the value of analog techniques, as a tool for representation and a cornerstone of visual education, remain significant. Indeed, digital media should not supplant this heritage. It's use within the studio however is inevitable and requires consideration in light of current teaching pedagogies. Analog and digital media reveal noticeably different issues and biases.

With hand drawing, the drawing describes a three dimensional object or building that does not yet exist. (see Figure 2) Notions of abstraction, process, scale and context are tied to the drawing surface and the process of hand drawing. (5) Scale, paper size and orientation are all considered at the onset. Process is recorded through each sheet of paper or layer of trace and readily available for reference. Replacing hand drawing with digital media in the entry studio undermines the ability for students to recognize these issues. The computer allows one to work directly on the three-dimensional object, effectively eliminating the abstraction of hand drawing and flattening the distance between designer and object. As a consequence of this, the effect of working on the computer is cumulative. Nothing is lost. The designer moves from detail to ensemble and back again, potentially inverting traditional design hierarchies. (6) Although it is feasible to address some of these issues through digital media, such as saving unique files for each iteration, their latent value within the process is best conveyed to the entering student through analog techniques.

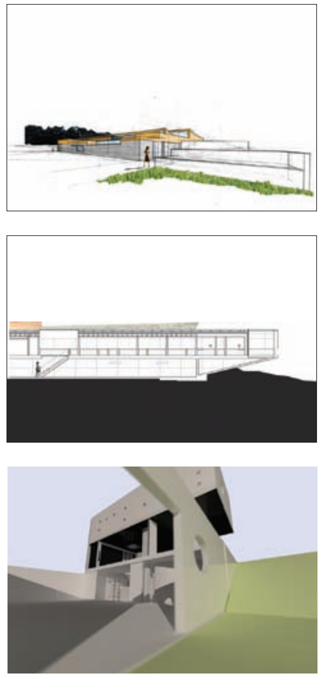

Fig. 3,4,5. Selected Student Work

Implementation

To encourage the infusion of digital media within the architecture curriculum an analog and digital representation course was implemented. Currently this consists of undergraduate and graduate students and occurs in the third semester for undergraduates and first semester for graduate students. Due to the relatively large class size, approximately 65 students, a workshop or studio model would prove ineffective for instruction. This was compounded by the objective to address both analog and digital techniques over the course of one semester. As a result, work would be completed at desks, on laptops and in computer labs, fragmenting and limiting individual consciousness of peer work. If such a course is to be effective at fostering an infusion of digital media into the foundation of design inquiry, beyond instilling the necessary skills, it must present the discourse associated with the media and promote a culture of shared knowledge. As a result, a hybrid format was adopted, providing lectures regarding topics related to the application of digital media within the discipline of architecture and tutorials for the software utilized. This was supplemented by a course web site which provided all course related material and functioned as a portal to online galleries of student work. At the commencement of the semester, students were instructed on the basics of web site creation. Following this, they were required to post individual web sites that functioned as a medium to display completed assignments. With the completion of each assignment, gallery size increased and a catalog of student work was established. Hand drawn assignments, such as planemetric and projected drawings were scanned and posted, eliminating the necessity to submit originals. The course web site permitted a public perusal of all student web sites while providing a means for assignment evaluation by instructor and teaching assistant. This promoted familiarity with peer work from other studios or programs (graduate student studios are located in a separate building than undergraduates) and encouraged a dialog outside of class.

As with representation in general, the final product is reliant upon the content chosen for study and presentation. Its associated scale, complexity and materiality affect the type of techniques employed as well as the general interpretation associated with each exercise. The techniques addressed; analog planemetric and projected drawing; raster and vector manipulation; web site creation; two-dimensional digital drawing and three-dimensional digital modeling, rendering and animating were numerous and for some, relatively complex. (see Figures 3,4,5) Assignments therefore, focused exclusively on representation. Utilization of this media as a design tool would occur in the following semester's digital studio. Students were each assigned a unique noteworthy building, from which they chose a segment of reasonable size and complexity. This provided the content for each of the ensuing exercises. With the object of inquiry given, students could focus exclusively upon utilizing the tools to assist in representation. Although the end goal is to foster a critical utilization of digital media across all facets of design inquiry, to start, students must develop a reasonable dexterity with the tools. Considering this, design and representation would prove burdensome and divert student focus. For efficiency, assignments often combined more than one technique. Perspective hand drawing assignments for example required students to draw, scan, digitally manipulate and post online. This promoted a hybridization of techniques while allowing students to develop analog and digital skills simultaneously. As a result the course addressed a number of techniques.

As the area of influence of digital media upon the design and construction of buildings expands, the knowledge and skill required to navigate this terrain steadily increases. The emergence of digital manufacturing tools such as CNC milling machines and stereolithography within architecture programs expand potential techniques and provide a means to physically manifest, information previously limited to the virtual realm. This however, adds to a growing list of techniques utilized by students and prompts consideration of how best to equip students with the skills required in the context of existing curricular demands. Although there are many tools, their interrelation points to a common thread, the three-dimensional digital model. From this, emerge most digital representation techniques, suggesting a primacy of the medium. Plans, sections, animations and physical models can all spring from this source. As a result, digital media instruction should center on the process of three-dimensional modeling and survey other techniques to expose the connections. This provides time for focused instruction while promoting a design process that utilizes emerging tools. Conversely, a cursory survey of all methods, including modeling, would leave students ill equip to fully utilize the medium in their subsequent studios.

The dynamic of studio will continue to change as digital media becomes more transparent to the process of design. Through this, the instruments for the exchange of ideas and displaying of work will take on new forms. Web based galleries and student hosted web sites suggest compelling extensions to the space of studio and offer tremendous potential for new forms of collaboration. The interface of digital media, however is not neutral and simultaneously draws us closer yet further apart. It is through this paradox that we should consider alternative methods of education in which the media is not only a tool for design but also a medium for the collective exchange of ideas.

ENDNOTES:

1. Gregg Lynn, Animate Form (New York: Princeton Architectural Press, 1999)
2. Muir, E. and O'Neill, R.: 1994, The paperless design studio, GSAP, News Line Statement, http://www.arch.columbia.edu/DDL/paperless/NEWSLINE.html.
3. Frederick Norman, "Towards a Paperless Studio," 2001 ARCC Spring Research Conference Proceedings: pg. 89
4. Stan Allen, "Terminal Velocities: The Computer in the Design Studio," essay in The Virtual Dimension, John Beckman, editor (New York: Princeton Architectural Press, 1998) pg. 246
5. James S. Ackerman, "Introduction, The Conventions and Rhetoric of Architectural Drawing," essay in Conventions of Architectural Drawing: Representation and Misrepresentation, James S. Ackerman and Wolfgang Jung, editor (Cambridge, MA: Harvard University Press, 2001) pg. 9
6. Stan Allen, "Terminal Velocities: The Computer in the Design Studio," pg. 248

Abstract:

Gypsum panel, a material ubiquitous in modern construction is typically employed for durability, fire-protection and economy. The composite paper and gypsum sandwich is ordinarily hidden behind a homogenous finished surface. The section of the panel is lost to an appearance of uniformity that is all but skin-deep. The material research conducted sought to exploit the composite sandwich and reveal the inherent qualities of gypsum and paper. Focus remained on the potential across the section of the material. Two distinct yet overlapping areas of investigation were explored, both intent on revealing the depth of the material through simple alterations during the manufacturing process.

The first area of research inserted a transparent material, such as resin, within the field of gypsum and between the outer sheets of paper (image 1). These translucent objects are placed into the wet gypsum prior to the application of paper. Once the paper is applied and the panels are cured, the translucent objects are permanently embedded. Material dimensions remain the same, however assumptions of 'front' and 'back' are challenged through the light transmission of the inserted resin. Depending upon the location and intensity of either natural or artificial light 'behind' the sheet, the surface vacillates between homogenous (no light) and mottled (light). With this simple alteration, the material begins to engage the conditions on either side and provokes applications beyond those traditionally found.

The second area of research focused on formal alterations to the flat panel (image 2). Investigations sought to develop complex surfaces through exploiting attributes found in gypsum and paper. In a standard panel, gypsum provides substance while paper supplies rigidity. Adhering the two produces a universal thin rigid sheet. A series of prototypes explored precision routing as a method to produce a surface capable of achieving compound curves. The two dimensional pattern and routing depth correlates to the desired final surface geometry through the creation of creases in the material. Once routed, the panel can be (de)formed and adhered to a final sheet of paper. The resulting surface is rigid and ready for installation.

Both areas of research sought to develop unconventional implementations of a conventional material through manufacturing alterations. The introduction of a material in the first research area and a process in the second, provide opportunity for a significant degree of customization within the system of mass production. The results challenge standard applications of gypsum panel and elicit a dialog between both sides of the sheet.

Introduction:

Utilized for interior wall coatings, frescos and carvings, gypsum existed early on as a truly global material. The Egyptians coated the interior of their pyramids with it; the Greeks called it gypsos, which translates as "earth" and "to cook;" and, the Romans used it to preserve their dead during their occupation of Britain. A variation of the material known as plaster of paris has been commonly used since the sixteenth century. It was in 1890 that Augustine Sackett and Fred Kane of the New York Coal Tar Chemical Company created the first plasterboard using manila paper and plaster of paris as substitutes for their preferred materials of straw paper and pitch. Reluctant at first, builders and architects gradually embraced the new material for its stiffness, strength, and convenience (i.e., rapid instillation). By 1909, hollow wall construction was forever changed American factory lines produced nearly 423 million square feet of material. Today, the number has soared to 30 billion and the material constitutes an estimated 90 percent of interior building finishes.

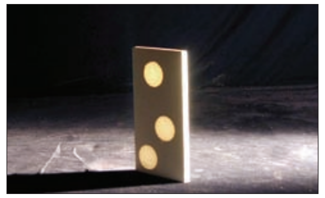

figure 1. plug wallboard

figure 2. crease wallboard

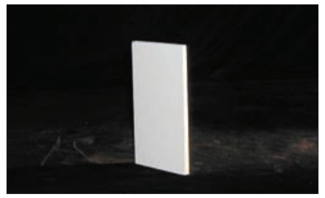

figure 3. typical gypsum board

Gypsum wallboard has become the thin surface of modernity, cheap, quick, durable, and low tech. Typically utilized to hide the spaces of the cavity wall, the material ubiquitously spreads over walls and ceilings homogenizing most interior surfaces. Referred to by Rem Koolhaus, it is one of the common constituents of "junk space" the unending, undifferentiated space of post modernity. The gypsum panel cladding assembly process in contrast to plaster on lath, distinguishes skin from structure and more clearly frames the hollow space of the cavity.

Value resides in the smooth seamless false solidity defined by its application. The universal de facto application of gypsum wallboard provided a context to work within and upon. The inherent properties of the material, in conjunction with their composite manufacturing and cladding instillation, reveal multiple opportunities with which to exploit or subvert the material and assembly. In referring to the viability of building material research, Sheila Kennedy states,

> *Materials are no longer finishes that provide closure to a building. Instead, they are critical starting points that open new possibilities for structuring the experience of space, for re-thinking the seemingly banal surfaces of partition, curtain wall, chase space and hung ceiling that characterize the familiar landscape of building types.1*

This investigation sought to exploit a common construction material utilized throughout the industry. It focused on the potential across the section of the material and aimed to investigate the viability of increased qualitative attributes in the context of a mass produced material. Gypsum wallboard was chosen for its ubiquity, conventional application, low cost and, most importantly, its seemingly uncritical application. The ongoing investigation seeks to:

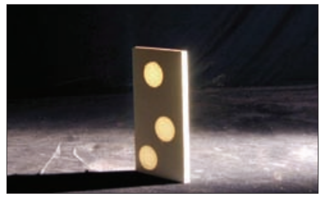

figure 4. gypsum board with resin pucks

- Reveal missed opportunities through slight alterations to the material;
- Reveal the inherent qualities of gypsum and paper traditionally lost to an appearance of uniformity that is all but skin deep;
- Seek out opportunities to alter the plaster component and change how the wallboard as a whole is perceived;
- Consider the back of the surface as a visible component and finally;
- Base the investigation on a cheap common material.

Two distinct yet overlapping areas of investigation were explored, both intent on exploiting the material's sectional composition through slight alterations during the manufacturing process and on-site installation. These are loosely termed "plug" and "crease" (see Figures 1 and 2). Plug allows for the transmission of light through the material, while crease allows the composite to bend to a (pre)scribed shape. Although the alterations may appear simple, in actuality they require varying degrees of material and manufacturing resources. Specialized equipment is needed, as well as support for the complex processes necessary to achieve the specific results. These requirements, however, should not undermine the validity of such investigations as their roots and critical checks were not strictly process driven. The homogenous surface of wallboard, or at least the hypothetical homogeneity, often broken by nail pops and settling cracks, among other things, surpasses its predecessors in that the time required to achieve a surface is greatly reduced. Ironically, gypsum wallboard is often plastered over when budgets afford the luxury. It is reduced to a substrate that seemingly has little visual potential.

A closer look at the sheet reveals a complimentary relationship between paper and gypsum, effectively a composite (see Figure 3). While both face and back papers are flexible, relatively translucent, smooth and generally strong in tension, the re-hydrated and cured gypsum is stiff, plastic, opaque but fragile when un-reinforced. The bond established through manufacturing yields strength greater than each of the individual components. A mask-upon mask finishing conceals joints between sheets and disguises any visual reference to modularity. That which is contained within or positioned on the other side is all but hidden. Material thickness does not affect appearance so much as pliability.

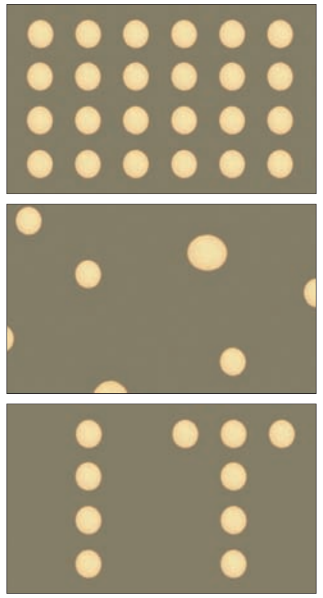

figure 5,6,7. random and planned alignmebt

figure 8. pliability of scored wallboard

The plug research sought to re-evaluate the homogeneity of the surface by allowing light transmission across the section of the material. Sheet size and form are unchanged as alterations occur entirely beneath the paper surface, within the thickness of the gypsum. The flatness of the sheet remains constant; however, the inherent single-sided nature is brought into question. The translucent resin "pucks" are a mediator within the sheet, undermining assumptions of front and back by allowing the light conditions on one face to affect the perceived homogeneity of the other face (see Figure 4).

The pucks are embedded into the wet gypsum during assembly line production, but before the application of the top sheet of paper. Once applied, paper permanently encapsulates the pucks and retains the homogeneity of the paper surface. The size and ratio of translucent objects to gypsum affects the rigidity and weight of the sheet. The structural integrity of the sheet is achieved through the continuity of the gypsum; therefore, too many pucks lead to an unstable sheet. Here, the board begins to engage the conditions found on either side, provoking applications beyond convention. Depending upon the location and intensity of either natural or artificial light "behind" the sheet, the surface vacillates between homogenous (without light) and mottled (with light). The composite is exploited such that puck presence is only revealed through the presence of light. In this, the environmental conditions on either side of the sheet affect the perception of the surface itself. The relationship between spaces on either side of the sheet can be hierarchal, where the conditions of one side automatically reveal their presence on the other, or subservient in which the affect is prioritized to one face and therefore regulated from the other. Either prompts a re-evaluation of assumptions towards both the cavity and the window. Can the cavity become a plenum for light? Can the wallboard skin run independent of the window openings themselves yet still transmit light?

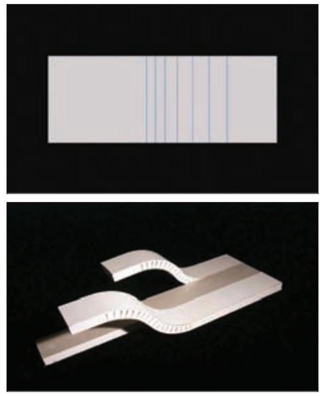

figure 9,10. single-axis cut

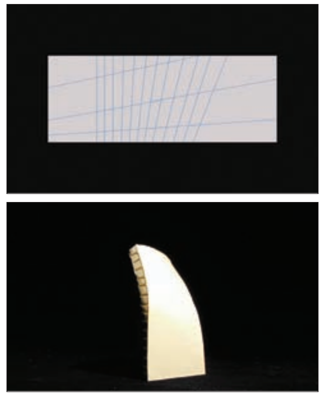

figure 11,12. dual-axis cut

The position of the pucks within the sheet can be random, arbitrarily embedded during sheet production; standardized, achieving the appropriate structural ratio of gypsum to resin; or precisely located, aligning to the position of a light source behind, may it be natural or artificial. The size, shape, and frequency of pucks yield multiple iterations, with varying degrees of light transmission and surface articulation (see Figures 5, 6, 7). The finishing, spackling, and painting, of the wallboard surface at the location of the puck reduces light transmission and questions the use of traditional finishing techniques in conjunction with this material implementation. An alternate to the plug investigation is a sheet drilled entirely through and covered with a new layer of paper. Through reducing gypsum, the sheet is significantly lighter and porous, allowing light and sound transmission.

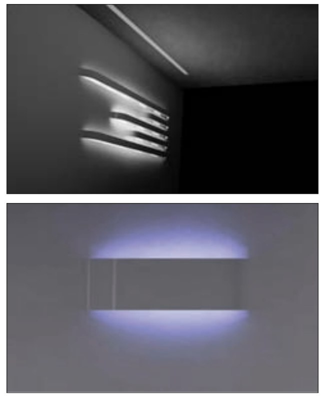

figure 13,14. light diffusing

The crease research focused on formal alterations to the standard flat wallboard. Within a standard panel, gypsum provides substance and rigidity, while paper adds stability through its bond with gypsum. Alone, each is a relatively delicate material, susceptible to cracking, breaking, or tearing; however, together their strength is compounded. Investigations sought to deform the board through the removal of material and subsequent creation of crease lines. In scouring the boards, that is the routing away of face paper and gypsum along precise lines, the crease becomes an axis of folding, along which the panel deforms. When amplified in number, creases facilitate sheet flexibility. Their orientation and grain determines size and amplitude of deformation.

A series of prototypes explored precision routing as a method to produce creases. The post routed sheet's pliability and cohesiveness is dependent on the remaining paper sheet, whether front or back. This wallboard, however, has limited self-supporting integrity. A high resolution of creases yields fabric like pliability (see Figure 8). The specific form of the sheet is achieved through a supporting mold, either over, which the pliable sheet is placed, or a form specific framing system, onto which the sheet is attached. Due to the pliability of the sheet, either system requires adhering an additional paper sheet to "lock-in" the deformation.

There are two branches of the crease investigation: single axis and double axis. The single-axis creases occur along one axis and run parallel (see Figures 9 and 10). This results in a "de-lamination" of the sheet, where the deformation is localized and appears to peel away from the adjacent sheets. A gap results, revealing the section of the material. The double axis produces a compound curved surface in which the sheet bulges or de-laminates along a non-orthogonal path. In the context of a standard cavity wall, both iterations increase the cavity width, locally at the point of deformation (see Figures 11 and 12). This can support objects embedded within the wall or allow for the transmission of light, air, or sound through the wall (see Figures 13 and 14).

The results of both investigations suggest multiple applications, but recognize the technical difficulties implicit to each implementation. Existing manufacturing processes require adjustments to achieve the proposed results. Depending on the severity of the adjustments, the proposed material alteration itself becomes suspect. These studies; however, centered first on the material and not the manufacturing. Traces of manufacturing are inevitably embedded in the material and subsequently informed the investigation. The approach however alleviated some of the predeterminancy potentially resulting from an investigation that came exclusively out of the manufacturing process. The traditional uses and properties of drywall are broken or distorted. In the case of the crease investigation, specifically the delaminated panel, the wall cavity is open to the "finished" space. Along the cut line, the paper and gypsum are revealed. Issues of durability and practicality inevitably call into question the direct application of these techniques. They are however a vehicle through which to investigate reinterpretations and alternative applications of a widely accepted and assumed material. The introduction of a material in the plug investigation and a process or action onto the material in the crease investigation begins to reveal possibilities for customization within a system of mass production. The subsequent findings reveal latent potential within the ordinary and ideally prompt inquis tiveness towards materials often discounted as banal.

ENDNOTES:

1. Sheila Kennedy, KVA: Material Misuse. London: The Architectural Association, 2001.
2. See "Surface" in Immaterial / Ultramaterial: Architecture, Design, and Materials. New York: George Braziller, 2002.