# Making as a Form of Exploration

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## INTRODUCTION

It is widely recognized that architectural form-making processes have been profoundly revolutionized by the pervasive influx of computational design and digital fabrication technologies and techniques. At varying stages of acceptance or resistance, the integration of computer-aided design and manufacturing technologies in architectural academia and practices has produced a state of euphoria and great sense of recaptured empowerment, in some, and an entrenched form of skepticism and nostalgia in others. This paper focuses on how a cohort of faculty and students at the University of Virginia School of Architecture are working critically towards a synthesis of conventional tools and techniques and new digital technologies of representation and fabrication. This effort is driven by a desire to achieve a well balanced and constructive methodology in service of substantive, well-informed design processes. Pedagogical, curricular and professional frameworks are discussed in this paper as a way of critically reflecting on concurrent interrogations and experiments. Three projects, at varying stages of development, scale and scope, are used to reflect on an emerging set of interests and expertise while contemplating new ways of working that emphasize interdependency between conventional methods and tools – one could even say traditional – and advanced digital methods and technologies. The work described in this paper includes academic exercises and a project that combines the effort of students, faculty, practitioners and woodworkers. These projects were made possible through collaborations that supported mutually beneficial, constructive, and exploratory form-making enterprises.

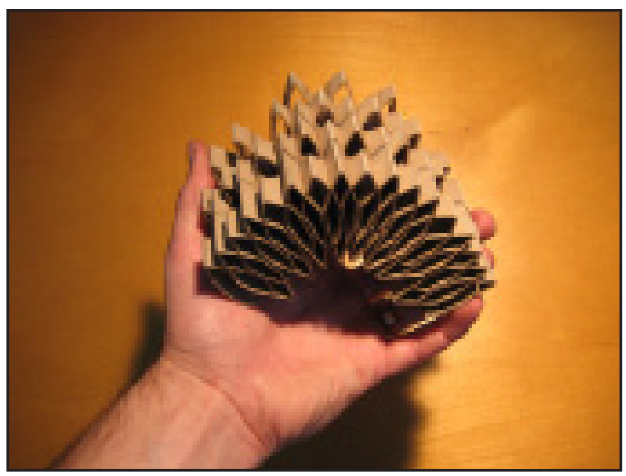

Figure 1: Compressive assembly studies

Much of the negative criticism directed toward the architectural avant-garde's use of „digital parametrics' largely focuses on what has been argued to be meaningless and gratuitous form- making, lacking in substance or rigor.

> "In some of the most academic applications, the intense focus on digital parametrics, with its virtually limitless capacity for innovation, runs the risk of pursuing a new type of form for form's sake, with the designer preoccupied with algorithms of design rather than the logic of making."[1]

Michael Weinstock, of the Emergence and Design Group, argues for "a more developed mathematical approach in current architecture"[2], and identifies a "lacuna in the theoretical body of architecture" in regard to process of design and form-making. In more recent times, the re-emergence of ornament in architecture, made possible by the prevalent use of digital technologies of parametric design and computer aided manufacturing, is being passionately debated. In their latest book M*anufacturing Material Effects: Rethinking Design and Making in Architecture*, Branko Kolarevic and Kevin Klinger make a strong argument that ornamentation is a "necessity." They write:

> "The human need to perceive, organize, and structure the world around us into patterns and rhythms is seen as intrinsic; decoration and ornament are recognized as neurological synergy of the eye and the brain."[3] Kolarevic and Klinger are careful to point out that "The challenge is to avoid creating a singular, outstanding image, pattern, or form (*the* effect), but a subtle, sensory, contextually responsive and responsible experience (*an* affect)."[4]

A prevalent pedagogical direction in academia (and in new or newly rejuvenated architectural practices) is an emphasis on making and learning how to manage new modes of production. Making and experimenting using actual materials to produce prototypes, mockups and full-scale installations (temporary or permanent) is a common practice in all areas of architectural curricula. From required, beginning and advanced design studios and construction courses to optional seminars, to one degree or other, all have been affected by digital representation and fabrication technologies. Increased access and versatility of digital tools has also had a significant effect on the quality and complexity of design/build work produced in schools of architecture. Another important factor to take into account is the growing interdisciplinary cohort of architects, engineers, computer scientists and programmers, (and open-source online tutorials) that have made highly sophisticated analysis, simulation, scripting and parametric software more accessible to the design community writ large. A more direct and facile "command" of algorithmic functions and a seemingly effortless manipulation of geometric information is becoming a more integral part of iterative and exploratory design processes in a variety of design disciplines. Additionally, developments in post processing software have enabled designers to narrow the gaps between conceptualization, representation and manufacturing phases of design development. An underlying critical pedagogical issue remains; that is the comprehensive, sound, and anticipatory preparation of architecture students who will contribute to the discipline as well as question its commonly accepted practices for decades to come. It remains important for students to understand how theoretical principles may differ or share fundamental similarities between manual construction practices and automated manufacturing. A student should also come away from a rigorous program with a base knowledge of how fabrication methods and techniques, with different histories and cultural derivations, have evolved (or become obsolete) and influenced the construction process, whether off-site or in situ. Every generation is challenged by a transitional paradigm; the latest generation is faced with a paradigm profoundly influenced by systems thinking and the complex behaviors of hybridized frameworks. As Donella Meadows points out in her book *Thinking in Systems*, an exuberant effort associated with complexity could potentially result in a delusion:

> "People who are raised in the industrial world and who get enthused about systems thinking are likely to make a terrible mistake. They are likely to assume that here, in systems analysis, in interconnection and complication, in the power of the computer; here at last, is the key to prediction and control. This mistake is likely because the mind-set of the industrialized world assumes[5] that there is a key to prediction and control."

Kolarevic and Klinger point out that the "digital technological shift" has resulted in a distinct set of investigations.

> "One aimed at seamless materiality, in which fluid smoothness [is] a primary design consideration, a second trajectory [explores] the outcome of digitally crafted two- and three- dimensional non-uniform patterns and textures, and a third [seeks] out the unity of skin, structure and pattern."[6]

The three projects considered in this paper fall under the last form of investigation while acting as exploratory projects for an evolving digital design and fabrication research trajectory at the University of Virginia School of Architecture.

## RESEARCH: PERFORMATIVE CRAFT

A recent post-professional design research project explored the integration of digital design and fabrication methodologies into existing practices of construction and assembly. This work took a performance- based approach to digital fabrication: structural, tectonic, optical, photometric, acoustic and thermal performances were all used to develop and evaluate the work generated by the research. While acknowledging the importance of what Elizabeth Meyer terms "the performance of appearance," the work sought to avoid the "appearance of performance," where the constructed work becomes a diagram of existing or desired conditions, without actually impacting or creating them.[7] The critical use of traditional and emerging tools, materials, and processes – what could be thought of as craft – was a central means to controlling these performances: playing the resistance of a given tool off the resistance of a given material often yielded new possibilities for how a material behaved at the scale of a joint, a module, and an assembly.

These ideas were tested through the design and fabrication of performative assembly systems. The assembly systems were developed iteratively through an alternation of hand modeling, digital modeling, and digitally- driven physical modeling. This back-and-forth process was critical to developing these systems as interwoven explorations of material, geometry and joinery. Physical modeling was found to be most useful as a method of understanding basic advantages and limitations of materials as they related to geometry, often manipulating and recombining geometric configurations to repurpose them as new subassemblies and modules. Digital fabrication was found to be most useful for quickly developing and testing a range of more sophisticated variations on the hand-made models to test their relative performance. Often these two modes of production were combined: digitally fabricated models were often intuitively modified and manipulated by hand to attempt alternative systems of joinery or assembly. In this way, digitally fabricated models often served as incomplete templates to be layered with additional explorative processes. Over the course of the research project, this collection of iterations yielded two subsets of assembly systems: one using compressive forces, and the other relying on tensile forces. Each of these assemblies employs digital design and fabrication processes to introduce performative, geometric variation into a standardized framework of joinery that effectively integrates material and formal properties of the module, eliminating the need for adhesives or fasteners. This approach maximizes the precision and prescriptive potential of mass-customized components and allows for on-site customization of the overall installation.

## COMPRESSIVE ASSEMBLIES

The performance and material nuances of a cardboard coffee sleeve served as an early point of departure for this portion of the research project. While rarely thought of as a designed object, the coffee sleeve is remarkable for its efficiency and utility: it is economically mass-produced with minimum use of material and can be assembled simply; reusable, and made of recycled material; ships flat; and expands to create an adjustable volumetric enclosure. These material and geometric attributes enable the sleeve's immaterial performance as an energy threshold that captures and redistributes heat to create micro-environmental comfort. This interest in the performative aspects of manufactured packaging spurred a process of experimentation with lightweight, collapsible paper structures that began with the repurposing of the coffee sleeve itself as part of a modular system: it was cut, folded, perforated, joined to other sleeves, and used as formwork.

Figure 2: Compressive module and assembly

Through a series of subsequent full-scale mockups that expanded upon these early investigations of relationships between material, geometry and joinery, a structural system of folded, slotted, and perforated paper modules was developed.[8] The system is assembled in offset courses, with each course enmeshed with those above and below to create a network of paper that is vertically rigid and laterally flexible. This network is set into compression and

Figure 3: Compressive assembly

laterally stabilized by a frame of CNC-milled plates and stainless steel rods that establishes the geometry of the overall assembly on-site. The network is perforated to reveal a series of layered interstitial cavities where light and views are captured and redirected. Multiple perforation patterns are applied to this network of surfaces, established and customized as larger field conditions using parametric modeling; each operates at a different scale, under its own logic, to control the weight, strength, transparency, and view through the assembly at a given location.

This assembly system was implemented for a pair of screens in the reception space for a university research office, where the client desired a spatial and visual separation between public and private areas that also filtered the direct natural light entering the space. Smaller perforation fields compress at eye level for a standing visitor and expand at eye level for someone sitting to give simultaneous privacy and visibility; larger fields expand towards the top of the screen to reduce weight and maximize daylight. Similar to the way a coffee sleeve captures and redistributes heat, these screens were used to capture and selectively transmit light, dematerializing and rematerializing to differentiate experiences of entrance and egress, and visitor and occupant.

**TENSILE ASSEMBLIES**

A second trajectory of the research began to develop as an assembly system utilizing tensile forces; this time the wishbone was a source of inspiration for its simultaneous rigidity and flexibility, enabled by its geometry and varying material thickness. The wishbone was geometrically emulated with paper models that were scored, folded, and joined to establish an overall diagrid geometric structure. These studies spurred a rapid prototyping process that experimented with the scale, geometry, and joinery of the modules, using scripting software and laser cut modules to test the scale and geometry of the modules. Within a standardized framework that controlled the scale and assembly of the modules, a script was used to customize the geometry of each module to create zones of transparency at the scale of the overall assembly.

Figure 4: Tensile assembly

A system of primary and secondary joints was conceived that connected each module to four adjacent modules as well as two peripheral modules, bending each module into the desired form. When combined with the variable geometry of the modules, this system of joinery is alternately concealed or revealed by adjacent modules depending on the local transparency and directionality of the assembly system. The assembly system was further developed by experimenting with the material properties of wood veneers; while a single veneer was easily pulled apart by the multi- directional tensile forces created within the system, laminating two veneers with perpendicularly oriented grains created a "micro-plywood" that could effectively resists and redistribute these forces.

Rather than scoring and folding the material, a scripted perforation system was laser cut into each module to allow it to bend into place when joined to other modules, with the secondary purpose of filtering light through the module. This bending, similar to the stringing of a bow, causes a pre-tensioned force in each module that is in turn distributed to adjacent modules, forming an aggregate pre-tensioned effect. The accumulation of these forces gradually creates a concave structural form over the entire assembly, demonstrating a self-similar relation between the individuated module and the overall assembly. Selectively alternating the concavity and convexity of the individual modules neutralizes this curvature at desired points and creates an inflection point between larger concave and convex zones. The tensile assembly system is seen as a prototype for self-structured and self-forming wall and ceiling systems that can define spatial zones while controlling and directing environmental qualities such as light, visibility, and airflow.

## PRE-FABRICATED FORM

A second research project focuses on the development of a transitional disaster recovery housing (TDRH) prototype. The TDRH prototype project serves four important objectives. First, as an ongoing research and development enterprise, the development of the prototype provides a set of instructive, full- scale design/build exercises for architecture and engineering students. Lessons in conventional constructional methods and emerging digital fabrication techniques are synthesized to teach students sound foundational construction principles and skill sets. Second, the TDRH prototype is an ideal instrument for testing innovative improvements in the manufacturing of highly integrated, light-weight, prefabricated, building components. The incorporation of CAD/CAM technologies in this process helps further improve the overall quality, strength, weatherization, and ease of on-site assembly. Third, in collaboration with the engineering department, the use of integrated sensing systems will be used to test and evaluate the effectiveness of the TDRH passive environmental design strategies and renewable energy systems performance. This testing will enable us to make significant improvements from prototyping to production. And fourth, as a form of hybridized transitional housing, the TDRH combines the effectiveness and high construction tolerances of off-site, prefabrication processes and an open building system approach to manufacturing, deployment, on-site assembly, and reuse. The group's design research emerges out of an interest in the fabrication processes and performance of prefabricated, composite building components. Digital manufacturing technologies are mined for the potential beneficial influences on sustainable building practices and consideration is placed on the significant history, traditions, and customs of building; new and emerging building methods are an extension of these histories, not substitutions. The project has developed through several vertically integrated graduate and undergraduate seminars, a summer research studio as well as two undergraduate architectural design studios. The project's framework allows various groups to contribute to various aspects of the TDRH system while focusing on an overall design goal.

Figure 5: TDRH frame design development

The focus on a lightweight system for ease of transport requires an innovative approach to deployment and assembly of building components to sites with unpredictable conditions and inexperienced building personnel. If the conventional construction process

Figure 6: TDRH structural frame fabrication

relies primarily on drawings and specifications as instructions for assembly, the TDRH strategy attempts to work on a more intuitively-driven process whereby the "instructions" for assembly are conveyed through the logic of the prefabricated building components. The sub-flooring structure is designed as a pre-assembled component to contract for packaging and transporting, and expand for installation. Performance criteria related to joinery and hardware challenged the design team to consider multiple methods of fabrication and assembly sequencing. The role of digital modeling played a key role in simulating and producing mockups to test the efficacy of the assembly. Nested and foiled geometries were developed digitally and then quickly tried at full-scale with actual materials to determine whether the on-site staging and deployment strategies were working reasonably. A weekly design-build approach of immediate translations (and interpretations) from digitally modeled iterations into physically fabricated mockups profoundly influenced the design teams' overall form-making and tectonic strategy. Basic, affordable materials (i.e. honeycombed 1" cardboard, oriented strand board, and bendable-grade plywood) were used frequently to investigate the effectiveness of the digital modeling studies.

## TRANSLATION TO FULL-SCALE EXPERIMENTATION

The initial study models were largely laser cut, chipboard constructs. This "conventional" start was in part used to take advantage of students' familiarity with this method of CNC fabrication. These ideas directly translated into an understanding of efficient uses of flat stock materials (foam, cardboard, OSB, and plywood) as the basis for the design and fabrication process. Following a series of formal explorations driven primarily by interests in assembly and structural integrity, students moved to full-scale mockups. This process, as is often the case, proved to be highly productive and challenging. Each week different teams would prepare and process materials in preparation for fabrication and installation. Forms achieved in the digital model were tested physically, and each week a new "failure" would lead to a new iteration for the following week. This material engagement yielded significant new understandings of the limits of various materials, effectiveness of the joinery, and user-friendliness of the assembly process.

## FEEDBACK LOOPS AND LEARNING THROUGH MAKING

At each mockup stage, lessons from making led to new expectations. Computer aided manufacturing functions such as "unroll" did not necessarily perform as expected. Conventional hand tools also proved to be less reliable in the case of tolerances and the precision of the subassemblies, leading to a compounding error effect. Different procedures revealed calculation inaccuracies as well as out-of-order construction steps - materials shattered under stress. While these challenges were initially frustrating, the project team soon accepted and critically reflected on these failures to gather important "feedback" and better inform the design and fabrication of the next iteration. This process was influenced by the pedagogical framework of the seminar as priority was placed on exploration and experimentation and not the resolution of the final product.

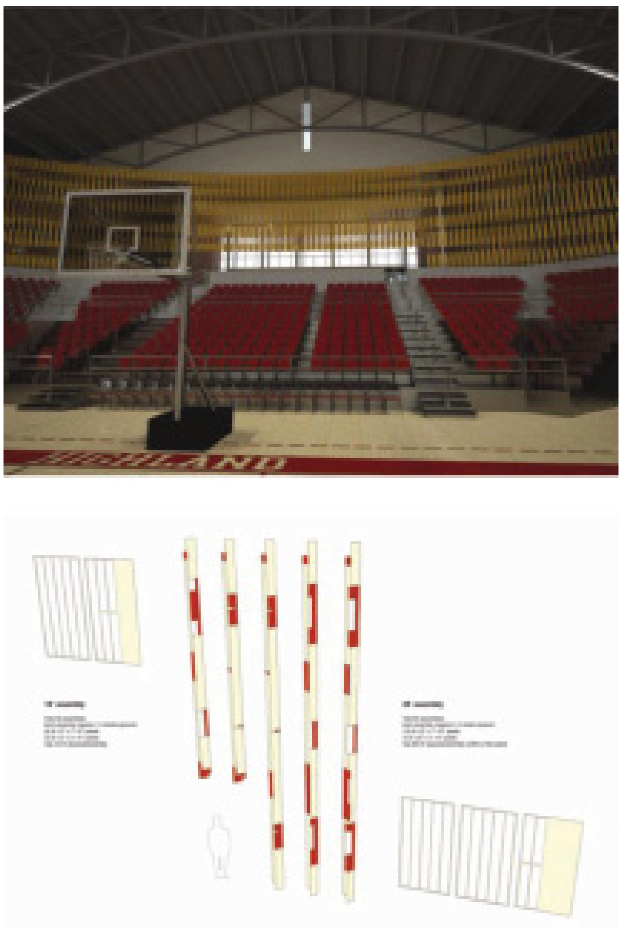

Figure 7: Multi-purpose arena screen wall rendering

## MULTI-PURPOSED SCREEN

The third research project has the largest scale, scope, and logistical complexity of the three projects described in this paper and is currently under development. Working with VMDO, a local professional architecture firm (architect of record), and an architectural mill shop, Gaston & Wyatt, Inc., with extensive experience in custom architectural millwork, the design and fabrication team is developing a screen wall system for a new, 3,000-seat, multi-purpose arena currently under construction at the Wise campus of the University of Virginia. The screen wall will act as the entry portal into the main concourse of the arena which leads down to the seating and main floor of the facility. The screen wall will also work as a backdrop to all events held in this facility – from basketball games, to music concerts and theater productions. The overall size of the screen

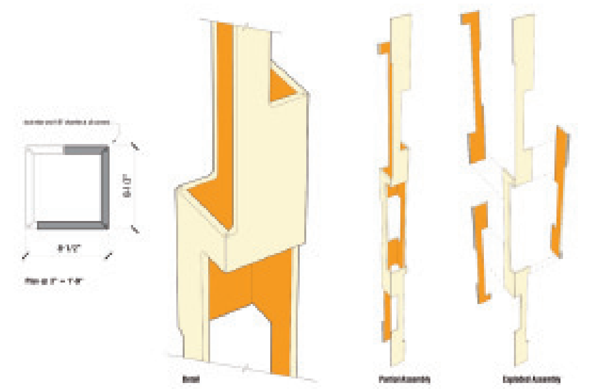

Figure 8: Screen wall component assembly

Figure 9: Multi-purpose arena wall prototyping

wall measures approximately 100 feet in length, 28 feet in height, and one foot in depth while curving in plan to match the predetermined form of the arena.

The design of the screen wall integrates three essential systems of frame, surface modulation and pattern while assigning specific performance criteria to each. The overall geometry is comprised of concave and convex surfaces superimposed in section to create perceptual and physical depth of the screen wall. The structural system for the wall combines compressive and tensile members to account for a 50 foot span over the main entry to the arena. The concept for the screen wall emerged out of a set of performance-based spatial and formal criteria. The surface modulation and articulation is driven by a set of critical optical and acoustical requirements. Comprised of a compound faceted and radial framework, a system of horizontal and vertical elements creates reflective and absorptive, transparent and opaque, compressive and tensile zones of the wall. As the outer most surface of the wall curves in plan and in section, it reveals or conceals the inner most edge of the frame creating a variegated effect as one walks along the wall or sees it from various elevations in the main space of the arena. A combination of reflective wood surfaces (species and veneer core type currently being studied in the prototyping phase) and sound absorptive surfaces (fabric and acoustic panel types currently being developed in consultation with an acoustician) will be integrated into the overall installation.

This project represents an opportunity to expand the traditional roles normally held separately by architects and fabricators. The design and fabrication team includes members from academia, the architecture profession and woodworking industry; students, faculty, architects and woodworkers with over 30 years of experience are working together to develop this project from conceptualization to final installation. The scope of the project has challenged everyone to step outside of their familiar comfort zone and to rely on each other to address the technically demanding parameters. From academia, students and faculty have an opportunity to work on a project that would otherwise be inaccessible due to scope; from practice, the architects benefit from the innovative and experimental use of new digital design and parametric modeling software normally prohibitive due to project budgets and timelines; and from the woodworking industry, millworkers benefit from a new process of manufacturing and assembly not normally associated with traditional millwork projects. In turn, students, faculty and architects benefit from the extensive woodworking expertise accrued by millworkers with remarkable experience.

## CONCLUSION

The projects described in this paper are considered sites of investigation used to explore new modes of form-making and methods of fabrication. Material and tectonic virtues are used to gage the barometric pressures of an emergent form-finding process that is "anexact yet rigorous."[9] As collaborators with different experiences and expertise, we share a common value in the quality of craftsmanship and have embraced new ways of thinking that strive to integrate old and new methods of making. This is the case for the full range of projects from speculative academic exercises to professional installations. With one foot in the world of "formal imagination" and one foot in the world of "material imagination,"[10] we are in the midst of trying to reach a state of equilibrium – if only momentarily.

Figure 10: Fabrication and working design meetings[11]

## ENDNOTES

1 Barry Bergdoll, "Home delivery: Viscidities of a Modernist Dream from Taylorized Serial Production to Digital Customization," in *Home delivery: Fabricating the Modern Dwelling*, (New York: The Museum of Modern Art, 2008), 25.

2 Michael Weinstock, "Morphogenesis and the Mathematics of Emergence," in *AD, Emergence: Morphogenetic Design Strategies*, (London: Wiley- Academy, 2004), 12.
3 Branko Kolarevic and Kevin Klinger, M*anufacturing Material Effects: Rethinking Design and Making in Architecture*, (New York: Routledge, 2008) p.20, This assertion is made based on E.H. Gombrich's research in *The Sense of Order: A Study in the Psychology of Decorative Art.*
4 Ibid., 20.
5 Donella Meadows, *Thinking in Systems*, (White River Junction: Chelsea Green Publishing, 2008) p. 166
6 Klinger Kolarevic, op. cit., 12.
7 Elizabeth Meyer, "Sustaining beauty - the performance of appearance: can landscape architects insert aesthetics into our discussions of sustainability?," *Landscape Architecture*, (Oct. 2008), 92-131.
8 The distinction made by Sheila Kennedy between "building materials" and "building products" in her essay "Material Presence: The Return of the Real" in *Material Misuse* (London: AA Publications, 2004) was particularly instructive for thinking about paper as a finished material for the compressive assembly.
9 Gilles Deleuze and Félix Guattari, *A Thousand Plateaus – Capitalism and Schizophrenia*, (Minneapolis, University of Minnesota Press, 1987), 483.
10 Gaston Bachelard, *The Poetics of Space*, (Boston, Beacon Press, 1958).
11 In addition to the authors of this paper, to date, the project has involved Daniel Mowery (4th year architecture student), Joe Celentano (VMDO architect and principal), Drew Fleming (VMDO architect), Kirk Jansen (VMDO architect), Rick Wyatt (Gaston & Wyatt, Inc. president) and Wes Leach (Gaston & Wyatt, Inc. woodworker and fabricator).