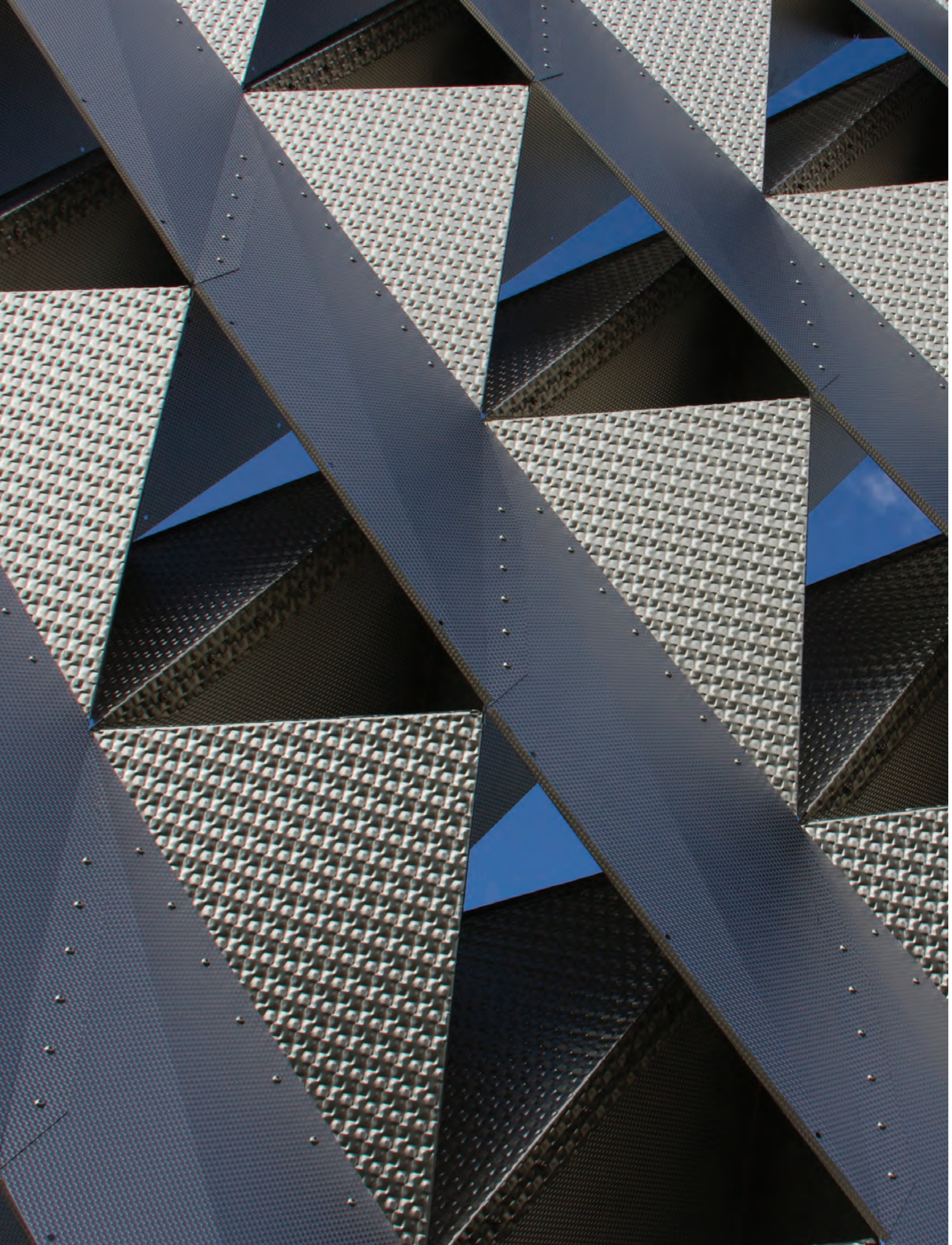

Collaborative Models between Academia and Industry: Experiments and Applicability

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INTRODUCTION

This paper will present strategies for forging collaborative architectural practices between universities and manufacturing industries. It will focus on current architectural research, its explicit impact on manufacturing processes, and the influence of these processes on design outputs. Specifically, the authors will discuss examples of collaboration between faculty and students at the University at Buffalo Department of Architecture, and, initially, manufacturing industries based in the Buffalo area, but more recently, a network of architects, manufacturers, and engineers spread across the globe. These include: 1) the initiation of a working relationship between the Department of Architecture and a local textured metals manufacturing company, Rigidized Metals Corporation (RMC), through the development of a student design competition and graduate design seminars; 2) the development of further research by faculty and students on the structural capacities of folding stainless steel, and the development of an experimental prototype, *project 2XmT*, that demonstrates the aesthetic potential of this research; 3) *project 3xLP*, the winning submission to the international TEX-FAB SKIN competition that coupled the authors and RMC with material and fabrication support from A. Zahner Company and engineering support from ARUP, thereby rapidly expanding the reach and momentum of an emerging research practice; and (4) forging new collaborations with manufacturing companies spread more broadly across the globe, specifically the Absolute Joint System (AJ) based in London, England, allowing our team to integrate a wider range of materials and digital technologies into our workflow, while moving our research toward a marketable product.

Using the framework outlined above, this paper has four thematic objectives: to describe the procedures by which two faculty developed, designed, and fabricated a prototype in collaboration with an industrial manufacturer, and utilized the described framework in developing a proposal for an intense collaboration; to identify how architects are utilizing digital tools to facilitate collaboration among diverse architecture, engineering, and construction (AEC) teams with the goal of merging design and construction into an integrated workflow; to catalog how new means of interfacing with information and an increased proximity to the production of products/objects through CNC machinery is radically reshaping a renewed material-centric practice in architecture and its related fields; and to assess the capacity of parametric design software and how this method of working/thinking has allowed architects to streamline drawing-to-production methods.

MODEL 1: FACULTY AS ORGANIZER

The first collaborative model begins on campus under a loose pedagogical theme to explore architectural applications for RMC, a local textured metals manufacturer based in Buffalo, NY. The company is unique for its cold-rolling process of embedding geometric textures into thin gauge metals (fig. 1). The approach was strategically split between two graduate seminars, one, led by Nicholas Bruscia, which focused primarily on specular effect through subtle geometric variation (patterns and folds), and the other, led by Christopher Romano, which focused on self-structuring thin-gauge metal surfaces using similar methods. It was an extremely exploratory phase, with students testing a number of preliminary issues that were based on individual interests: unrolling geometric surfaces, folding metal, and mapping a range of specular qualities inherent in the metal. This semester-long process included a tour of the manufacturing facility, an introduction to the material and manufacturing process by Rick Smith, president of the company, and week-to-week feedback provided by the course instructors. This structure resulted in a series of student groups working collaboratively on small physical prototypes and using the tools and technology available to them within the university to simulate the effects of rigidized metal and the fabrication workflow of the manufacturer (fig. 2). As the large majority of the research was being conducted within the university, there were no monetary or logistical risks assumed by the manufacturer. At the conclusion of the semester, students presented their work to the president of the company and a small group of administrative staff at RMC.

To begin to unpack the benefits of this type of interaction, the manufacturer had a large group of students, who were near graduation and about to enter the workforce, touring its facilities and learning about its product, which alone is an enormous benefit to any manufacturer. In addition, students free from any economic or logistic constraints were able to ask questions, design freely, and introduce contemporary parametric software to the manufacturer, which we felt could be of potential use to the manufacturer in the future. As a model that is implemented in the initial phases of a manufacturing relationship, it is useful for the structure to be more traditional so as to allow the academy to engage with imaginative *thought experiments* based on *real-world material contingencies.* The advantages for both parties emerge naturally as the relationship moves away from students and faculty simply applying new information toward the completion of a single self-guided project, to the production of new knowledge whose ultimate goal is real-world applicability.

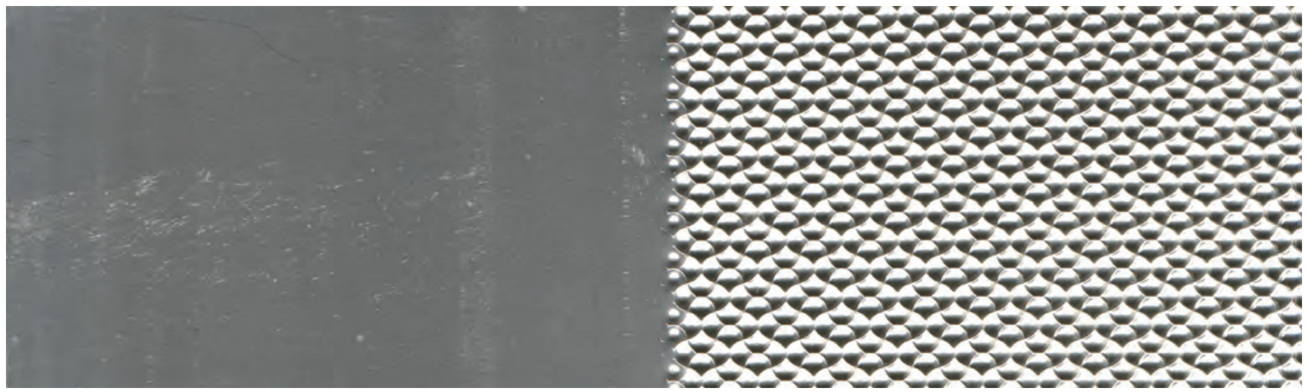

Figure 1: Comparison of 22GA (.029") plain stainless steel vs. rigidized metal 3ND texture

MODEL 2: FACULTY AS MATERIAL SCIENTIST

The second collaborative model proposes a faculty-directed research structure that allows the Department of Architecture and local and regional manufacturing to collaborate on the development and full-scale testing of architectural applications for their product line. This includes finding new potential in existing products, and the development of new techniques and optimization of existing processes through the use of digital tools for both design and fabrication. The research collaboration detailed below is used to explain how this model builds on prior collaborative work completed within two graduate technical methods seminars described in Model 1, while synthesizing these pedagogical approaches into a singular research proposal.

In this model, much of the effort is two-fold: material testing a manufacturer's existing product line, and attempting to extract the unwritten knowledge that collectively exists amongst the fabrication team. A challenging and crucial next step is attempting to document this data in some kind of quantifiable and measurable format that can be used to inform future design decisions. To that end, we conducted extensive testing: photographic documentation of the exterior light reflecting and diffusing qualities of textured metal under a range of weather conditions; strength comparisons of plain stainless vs. textured stainless; 3-point deflection testing of some of the more common patterns to pinpoint which patterns yielded the highest structural performance; and extensive metal folding studies to reveal to the academic team the fabrication limits of both the hydraulic turret punch and hydraulic press brake. This process yielded a decision-making process that was based on empirical data instead of relying on rule of thumb or repeated cycles of trial and error.

Figure 2: Graduate Technical Methods Seminars – full-scale prototyping of self-structuring metal surfaces using 22GA carbon steel

To understand how we framed the research, it is important to have a more detailed understanding of *rigidizing* as a manufacturing process—rolling geometric textures into ordinary sheet-metals to increase the cross-sectional depth of thin-gauges by distributing metal above and below the neutral axis, resulting in a much stiffer material that provides thinner and lighter gauges with increased structural capacity. At the same time, the process gives the material dynamic light diffusing qualities. To summarize, both specular quality and surface rigidity result from the same geometric conditioning of the metal, and we felt these material characteristics had not previously been studied or exploited. While a more typical use of the this material is for non-structural facade elements or interior panels backed by substrates, the intention of this research is to develop a self-supporting architectural system that reveals the existing but underutilized structural potential of the material while simultaneously exhibiting the specular quality of the texture. Our research culminated in an experimental prototype, *project 2XmT*, which uses a framework of arrayed octahedrons and thin-gauge textured metal to generate a self-structuring skin that

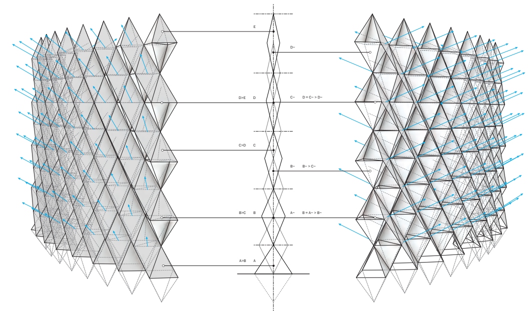

Figure 3: project 2XmT – rendering showing framework of arrayed octahedrons with thin-gauge metal panelization

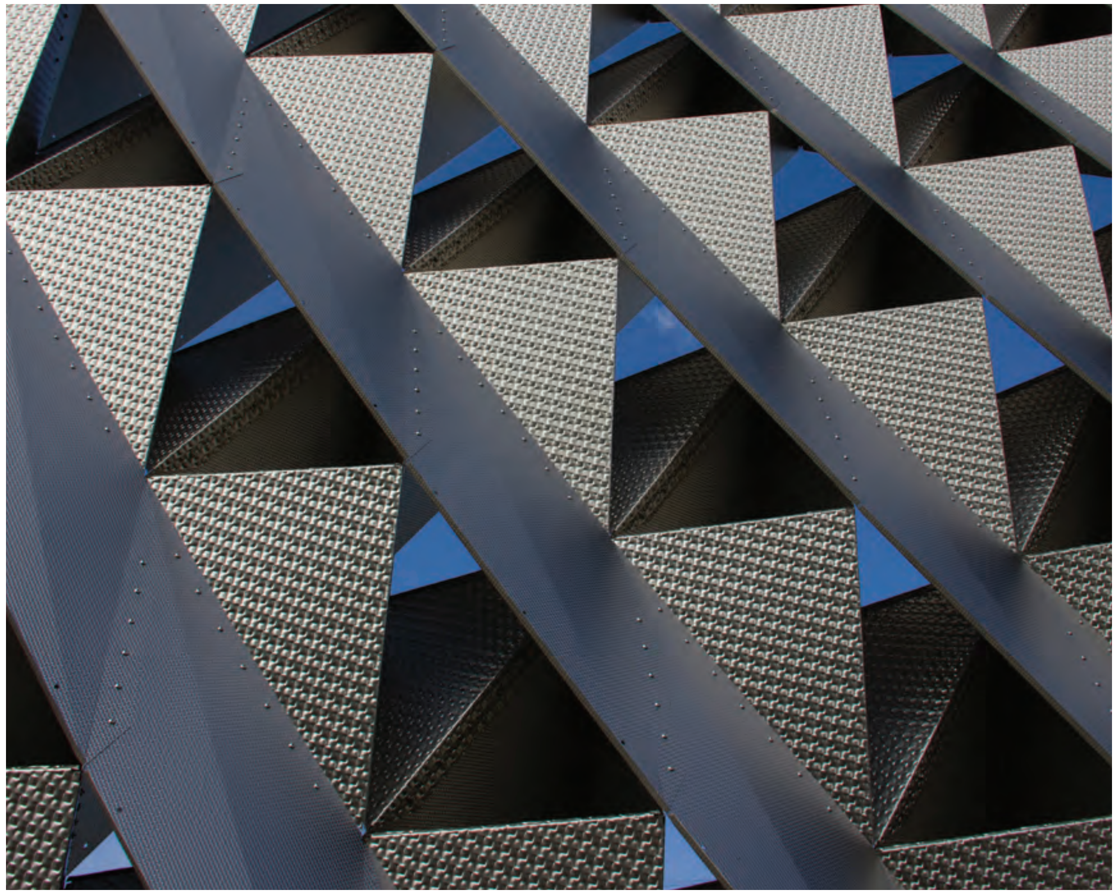

Figure 4: project 2XmT – detail view showing X-braced diagrid with panel-to-panel connection using 10-24 fasteners

exhibits extreme physical and visual lightness (fig. 3). Based on the textural qualities of the metal and the principle of triangulation, specifically through the use of an expanded diagrid, we invented an ultra-thin, woven "face-frame"—a space frame turned into surfaces where, instead of nodes, overlaps in the surfaces make the connection (fig. 4). What is made clear through this work is that the rigidizing process simultaneously creates a visual and structural potency, making large-scale thin-gauge assemblages possible (Picon 2003). At a height of 19'-6" (5.8m), it may be the world's-largest self-structuring surface, and we have speculated that we can use this framework to scale up infinitely (fig. 5).

As an approach, it can be compared to the Los Angeles County Museum of Art's original Art and Technology program, which ran from 1967 to 1971. Curator Maurice Tuchman invited artists to be matched with companies working in industry, pairing Tony Smith with the Container Corporation, a manufacturer of paperboard products including folding cartons, paper bags, and fiber cans. Up until that time, most of Smith's sculptures were generated from modular-based paperboard components, typically tetrahedrons or octahedrons, but the component nature of his work became invisible once the work was fabricated in steel at a much larger scale. Working with the Container Corporation, he could replicate his method of working at a monumental scale—resulting in a 2,500-unit cave-like exhibition for the U.S. Pavilion at Expo '70 in Osaka, Japan (King 2014). As in our case, the installation achieved a more precise level of clarity when artist and industry jointly collaborated on research.

This model of collaboration is closely aligned with a privately sponsored research project, and in the planning stages, it requires a great deal of time to frame the research in a manner that is mutually beneficial to both parties. Working agreements are signed outlining the scope of the research, project expectations are agreed upon, and monies exchange hands to execute the research. From the start, it was clear that it would entail far more oversight from the manufacturer and regular meetings with the fabrication team, and that we would be integrated into their monthly production cycle as if we were a paying customer. As a model, it requires financial support, larger quantities of raw material, and higher demands on machine time and human labor, but if successful, the research would dramatically increase the visibility and marketability of their product line. In addition to the potential marketing benefits, we felt it was equally as beneficial from a technical perspective. The digital tools we were introducing were not part of the day-to-day workflow of the manufacturer, which has since changed as a result of our work and our attempt to demonstrate its relevance in advanced manufacturing. Furthermore, by discussing the project in a parametrically controlled digital model, architects and fabricators are able to speak the same language and clearly visualize information. This three-dimensional conversation allows the fabricators to work off a more accurate base file, reduce mistakes, and thus minimize risk. It also results in better coordination amongst team members and in a faster fabrication schedule than projects of a similar scale/scope. For our team, this digitally-based workflow reinforces our appreciation for mathematics, allowing us to be more creative and explore more complex geometries that were not familiar to the fabricator, thus spending additional time, which would have otherwise been dedicated to project coordination, on design. More importantly, this collaboration allows us access to cutting-edge machinery and the ability to test ideas at a much larger scale than previously possible, re-centering the material mockup as a crucial and necessary part of the architectural design process.

MODEL 3: FACULTY AS CONDUIT

The third collaborative model was a two-day specialized workshop that was part of the 2013 International ACADIA Adaptive Architecture Conference. The workshop covered topics ranging from scripting to simulation of complex systems, to digital fabrication with advanced manufacturers. As workshop directors, we were interested in getting students and professionals to directly interact with the fabrication team, with the primary goal of getting participants on the factory floor with the people who make things, observing the process of how their drawings are translated to generate CNC code that can be read by the machinery available within the facility (fig. 6). For many participants, this is their first time on a factory floor exploring a type of making that is unfamiliar to them: making with machines. At a minimum, we wanted participants to understand how to effectively communicate with fabricators.

Throughout the two-day workshop "Rigidized Metal Forming," we were tasked with consolidating what we had learned in one year into a 48-hour period, taking students through the entire design-to-fabrication process. Participants were consistently moving between analog and parametric ways of thinking/making, trying to live in both of these worlds simultaneously and realizing a very small but critical lesson, as stated by the French engineer Robert Le Ricolais: "The art of structure is about where to place the holes." Even in a very brief period of time, the opportunity to speak directly with fabricators, tacitly handle the metal, and assemble a prototype of their own design changed the way participants thought about material and fabrication (fig. 7). In addition, the manufacturer's affiliation with the ACADIA community gave its product wide exposure both domestically and internationally by supporting students, academics, and professionals from around the world. The workshop model is an effective method for closing the gap between the academy and the profession, and perhaps more importantly, breaks from the traditional university model that is comprised of 15-week academic semesters with classes meeting once or twice weekly. From our experience, the workshop model, based on brief but uninterrupted periods of intense learning, is able to produce similar results in terms of output and quality when compared to typical university coursework, such as described in Model 1.

MODEL 4: FACULTY AS TACTICIAN

The fourth model of collaboration was a repeat of the latter half of Model 2 (Faculty as Material Scientist), except that it was now a long-distance collaboration amongst many parties involving a commissioning agent serving in the role of client, a number of universities that make up the TEX-FAB Digital Fabrication Alliance, A. Zahner Co. as fabrication sponsor, and an additional engineer. The project needed to be completed in a matter of weeks, not months; thus, we saw ourselves in a new role—that of tactician, with a large majority of our time and energy dedicated to managing the relationships between a greatly expanded team of stakeholders. An added challenge was that this research would have to be conducted remotely with very little face-to-face communication, which was vital to the success of previous models.

As part of our TEX-FAB SKIN competition winning entry, *project 3xLP*, we were granted the opportunity to build a second iteration of our SKIN prototype, refining and experimenting with our self-structuring system to introduce visual porosity while maintaining structural stability (fig. 8). Our first assignment was to negotiate bringing Rigidized Metals on-board as both a co-material and co-fabrication sponsor. This strategy allowed us to continue to work with a material that we felt was central to the research, and not knowingly, more than double the funding available to execute the second prototype—thereby increasing the scale/scope of the second prototype. With little time to build physical prototypes, we opted to digitally simulate the effect of physical forces with the assistance of Maria Mingallon, a structural engineer at ARUP, performing an initial round of FEA analysis on the second prototype, creating a feedback loop between digital model, our first physical prototype, and stress-based FEA analysis (fig. 9). Stated Mingallon, "The results of the digital analysis demonstrated that the origami-like strategy would make the wall strong enough to deal with the typical design loads applied to medium-height buildings" (Mingallon 2014). This feedback provided a level of confidence that we could apply our system at a much larger scale and as a contemporary facade solution.

As mentioned above, this collaborative model was

about speed, expanding outreach, and relying on external expertise to complete the project. There was little time to meet in person, to design, to prototype, and most importantly to make a mistake. In doing so, our three-dimensional modeling got tighter, containing more precise data regarding part numbers, geometric families, patterns, gauges, grain, finishes, and assembly sequence (fig. 10). Our need for traditional drawings was dramatically reduced (not eliminated), resulting in labor being spent on iteratively testing design solutions and resolving details to achieve tighter fabrication tolerances. We also began to optimize design parameters to find a suitable balance between geometric variation, machine time, and human labor (fig. 11). The competition platform provided a showcase to demonstrate the fabrication capacity of two expert manufacturing companies. Repeating the process strengthened and solidified our working relationship with RMC, a world leader in deep textured metals, and also allowed us the rare opportunity to collaborate with A. Zahner Co., a world leader in metal facade manufacturing. From a marketing perspective, the benefits were noticeable, as the results were included in various print/online publications and numerous contacts were made within Texas.

Figure 5: project 2XmT – elevation view of 19'-6" tall, 152-panel self-structuring prototype using 4LB and 1RL rigidized metal

MODEL 5: FACULTY AS PROCESS ENGINEER

The fifth model of collaboration is a joint-venture partnership forged between a public research institution and a privately held company—one focused primarily on the development of large-scale, modular building structures and the other, primarily on the development of innovative building skins—whose collaboration attempts to further develop a more marketable product that could be more widely distributed in global architectural contexts. In early conversations, both parties were interested in forming an interdisciplinary partnership that would merge the two threads of research together to form a more holistic system that could deliver architectural solutions for both structure and skin.

The authors teamed up with Bartolomeo Mongiardino and Alessandro Traverso, mechanical engineers based in London, England, and inventors of the Absolute Joint System (AJ), one of two non-welded, round pipe, stainless steel structural systems in the world. More specifically, AJ is a dismountable and reusable space frame system with members connected by means of custom spherical joints (fig. 12). Targeting reusability in lieu of recyclability, the AJ system is a highly durable kit-of-parts for small to large scale space frames that can adapt to a wide range of spatial configurations to reduce waste and minimize the embodied energy required to create building structures (Brescia et al. 2013). Our collaborators examined that there is an increase in the production of temporal programs that require large expanses of column-free space, such as temporary shelters, storage/transportation facilities, and large stadiums,

Figure 6: Rigidized Metal Forming workshop – participants observing drawing-fabrication process at Rigidized Metals Corporation as part of the 2013 ACADIA Adaptive Architecture Conference

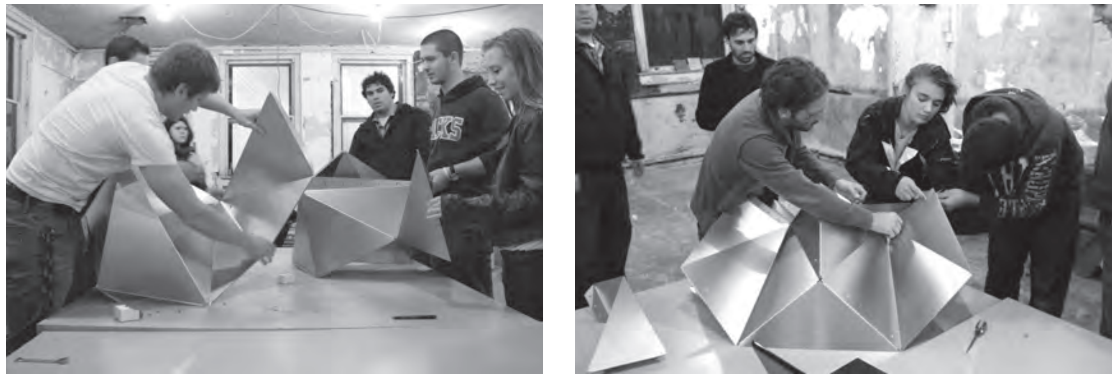

Figure 7: Rigidized Metal Forming workshop – participants assembling their 5-7 panel prototypes using 3ND rigidized metal as part of the 2013 ACADIA Adaptive Architecture Conference

whose intended lifespan may be shorter than traditional buildings. In contrast to the costly maintenance and (oftentimes) inaccessibility of these permanent structures, the dismountable AJ system proposes an alternative.

In response to the agenda set forth above, we summarized our work very broadly, working simultaneously in three areas to increase the feasibility of the AJ system, troubleshoot the existing web-based product offering, and testing its structural system against a range of geometries, enclosure systems, and panelization options. Currently, we are focusing on the development of surface optimization and efficient panelization using rigidized metal that can adapt to multiple configurations (fig. 13). Similar to the concept of the AJ system, we are attempting to develop a series of identical panel families that can be applied to formally distinct free-form surfaces. By designing a kit-of-panels, we are attempting to construct a full-scale mock-up that explores reusability in large-scale architecture: a reconfigurable kit-of-parts, structure and skin, that can be mounted and dismounted, packed in a shipping container, shipped across the globe, and reconstructed in a range of configurations.

For our team, this work has many benefits. It is research that directly engages in the construction industry and develops solutions that find efficiencies in problems that have existed within the discipline for decades. In addition, it allows our work to move toward a marketable product that could very quickly reach a global audience, doing so at a large-scale. For RMC, it is an ideal application for its deep-textured products: lightweight, durable, and highly resistant to visible scratching, they become ideal for structures that are repeatedly assembled and disassembled. For the AJ team, our collaboration gives them a base of operations in the United States, a manufacturing partner in RMC, and the ability to test their system on a range of complex geometries prior to entering into the highly competitive material manufacturing market.

MODEL 6: UNIVERSITY AS INCUBATOR

In this last model of collaboration, our role shifts from faculty-directed research to that of architectural consultant with workflow moving through the manufacturer. In the contemporary AEC industry, there is a reoccurring pattern where clients are looking for the manufacturer to provide in-house expertise to solve technical and logistical issues that arise throughout the design and implementation process. As the research moves from sponsored to for-profit commissions and consultations, we have found a usefulness for a young design practice that can move fluidly between a design-assist and a design-led format depending on the scale, scope, and scheduling of an incoming project. When not acting in a traditional architectural role, we operate as an alternative mode of practice, hovering between academia and industry and able to provide a number of alternative benefits: mediating between architects and manufacturing throughout all phases of the design process; teaching sales and marketing teams about emerging trends in architecture; and focusing on commissioned work that exists somewhere between the scale of furniture and architecture. This newfound capacity allows RMC to take on work it would have otherwise turned away, thereby increasing internal capacity and allowing a greater audience access to its product offerings. In this scenario, both university and industry-supported work generates an incubator where young design practices can balance their intellectual curiosity with 75 years of industry expertise.

CONCLUSION

This paper has focused on relationships that faculty within the University at Buffalo Department of Architecture have been forging with local industries, and how this is leading to practice models that hinge on developing material and data-driven research in the academy, testing and applying these developments in industry, and forming feedback loops between the two. From this categorization process, we have come to understand our work within the various models of research and practice listed below:

Model 1: A description of faculty as project initiators or organizers—instigating curiosity among students, encouraging a curriculum that engages students in a deeper knowledge of material, and facilitating student/professional relationships—not only with other architects but also with manufacturers and fabricators.

Model 2: A description of faculty as material scientists—engaging in research through making that attempts to teach new technologies to manufacturers and test the latent potential of materials by building prototypes that maximize material performance, exploit structural and specular qualities of textured metals, and push the limits of manufacturing tolerance.

Model 3: A description of faculty as a conduit between students and manufacturers—leading to an academic environment where acquiring a "deep knowledge" of materials through hands-on work is more of a norm than an exception.

Figure 8: project 3xLP – interior rendering prepared for TEX-FAB SKIN Competition showing application of our geometric system as a building skin with increased visual porosity

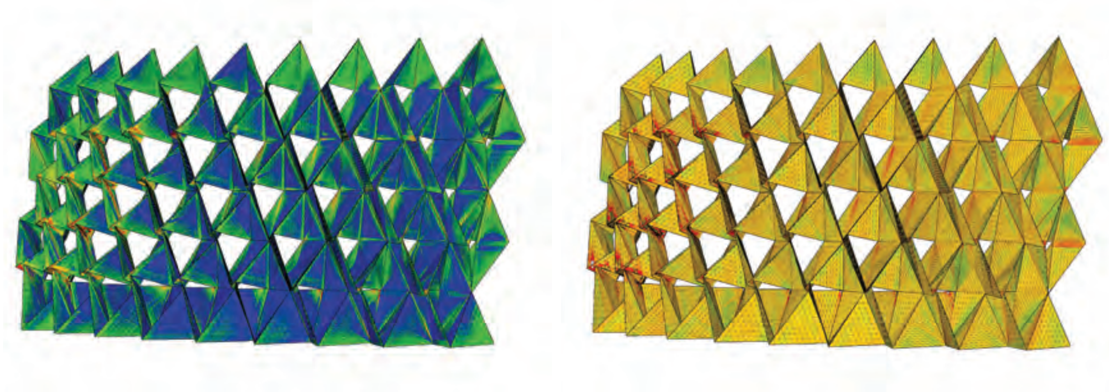

Figure 9: project 3xLP – FEA analysis (wind load and permanent load) of SKIN prototype using ARUP's structural analysis software Oasys GSA

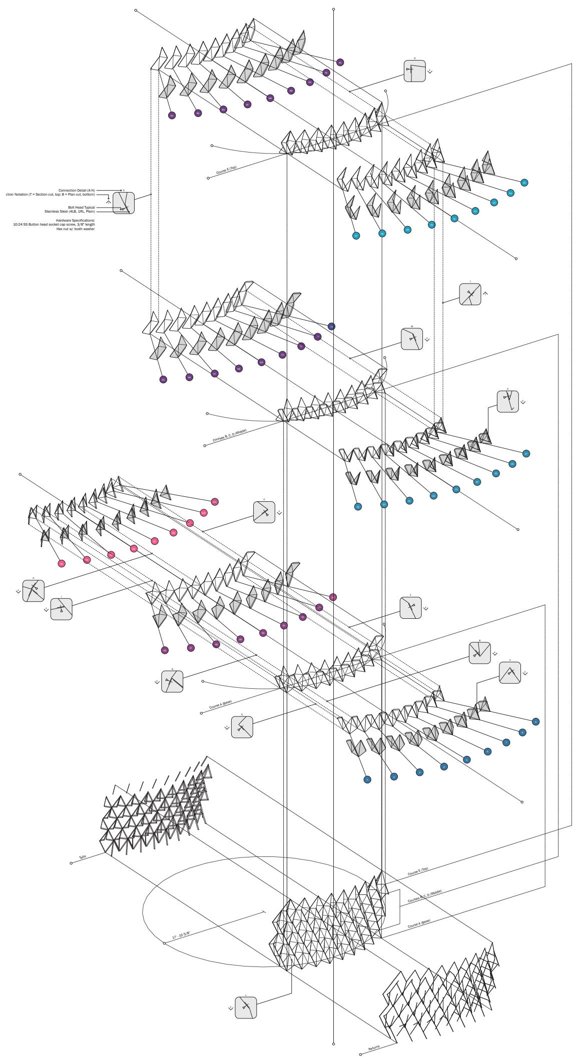

Figure 10: project 3xLP – exploded axonometric of 10'-6" tall, 137-panel self-structuring prototype showing course-by-course system coordination/optimization

Model 4: A description of faculty as liaison or tactician between businesses to implement a project—focusing on managing the multiplicity of relationships amongst an expanding group of stakeholders.

Model 5: A description of faculty as process engineer—serving as a design-laboratory to test-drive new technologies and new tectonic solutions prior to entering into a competitive market.

Model 6: Thinking more broadly about the university as an incubator of young practices whose design professionals can act as a mediator between manufacturers and architects.

In conclusion, these are models that we are exploring as alternative modes to traditional architectural practice. The models suggest that these are not idiosyncratic moments/relationships, but rather, educational, research, and practice models that can be replicable in other locations and with other companies, and sustained for the long-term. Although each of these is capable of being a standalone model, they can be performed in succession as a relationship-building strategy, or they can simultaneously overlap, where one model can serve as a test-bed for the other. Nonetheless, it is through initiating a conversation about computation-tied-to-making that we are able to directly engage in the supply chain, allowing architects and manufacturers to develop a collective intelligence and a highly collaborative workflow. Through the use of these organizational models, parametrically controlled three-dimensional modeling, and an extreme attention to detail in the manufacturing process, we argue that we are increasing the scope of architecture—taking control back into the realm of the architect and re-constituting the legacy of the master-builder. It is this confluence of interest in both digital technology and contemporary industry that has offered us a way to push forward an alternative trajectory of architectural research and practice.

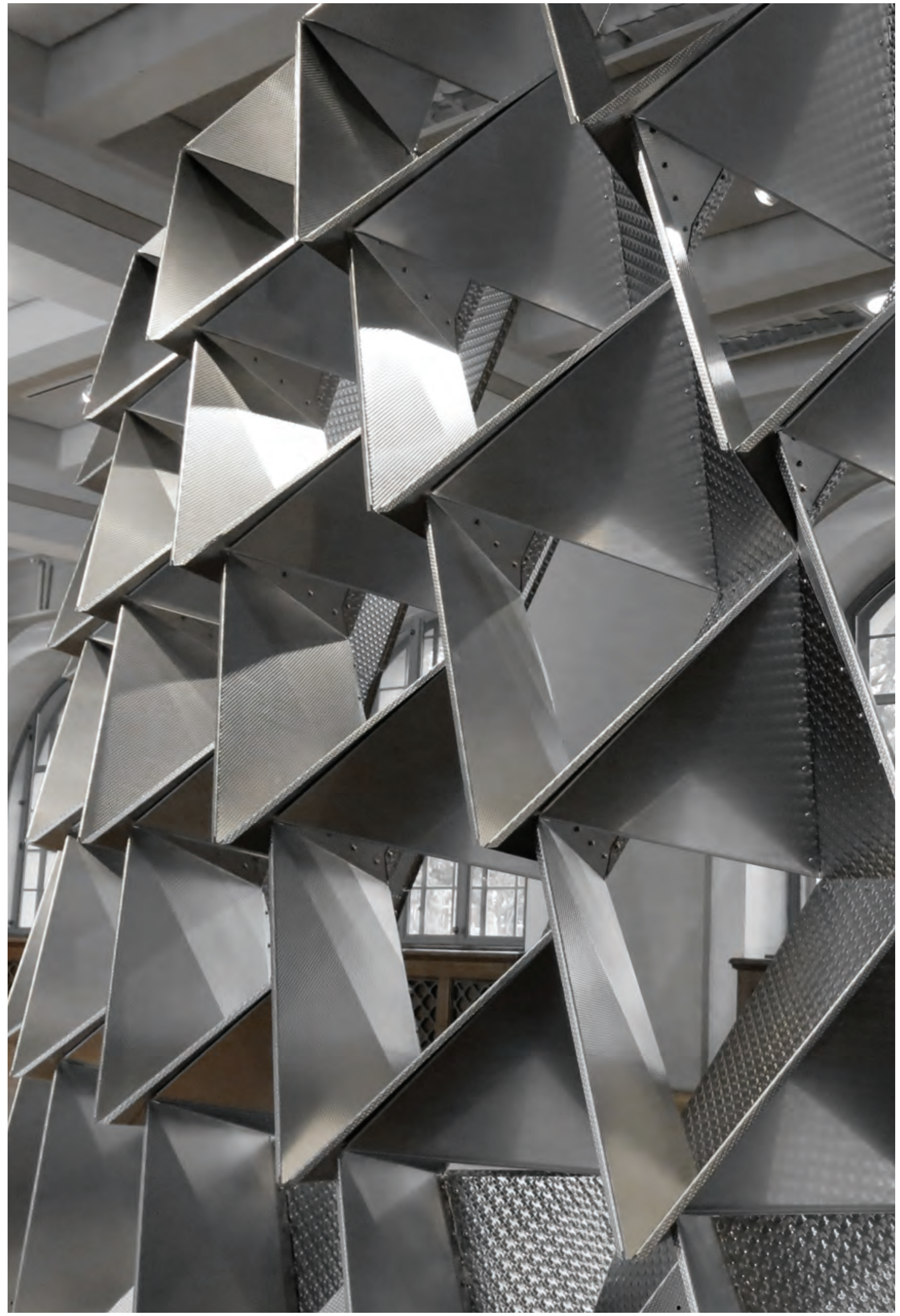

Figure 11: project 3xLP – detail view of SKIN prototype showing geometric variation, visual porosity, and specular qualities using 4LB and 1RL rigidized metal along with angel hair stainless steel manufactured by A. Zahner Co.

Figure 12: AJ Pavilion – concept rendering of AJ structural system showing non-welded custom node

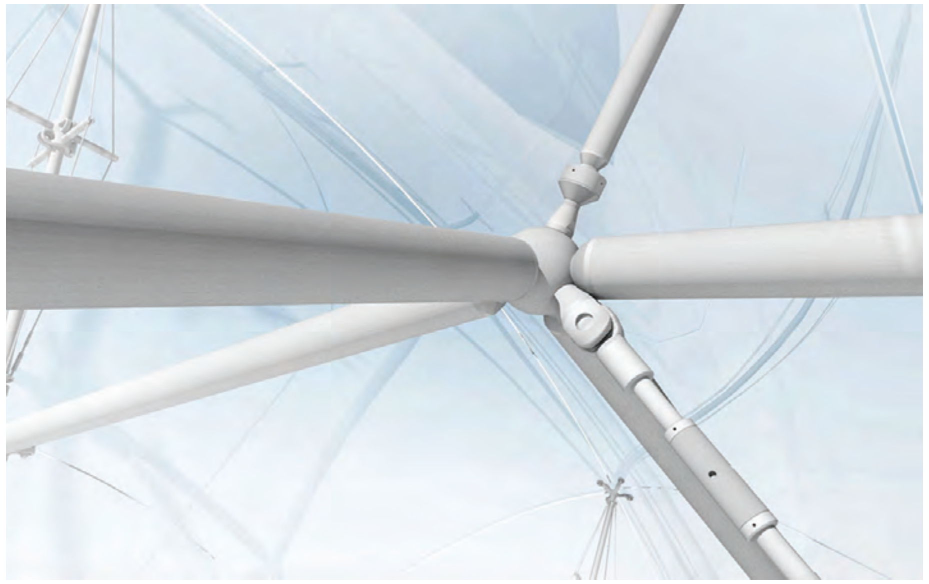

Figure 13: AJ Pavilion – screenshot of preliminary free-form surface showing optimized panel clusters

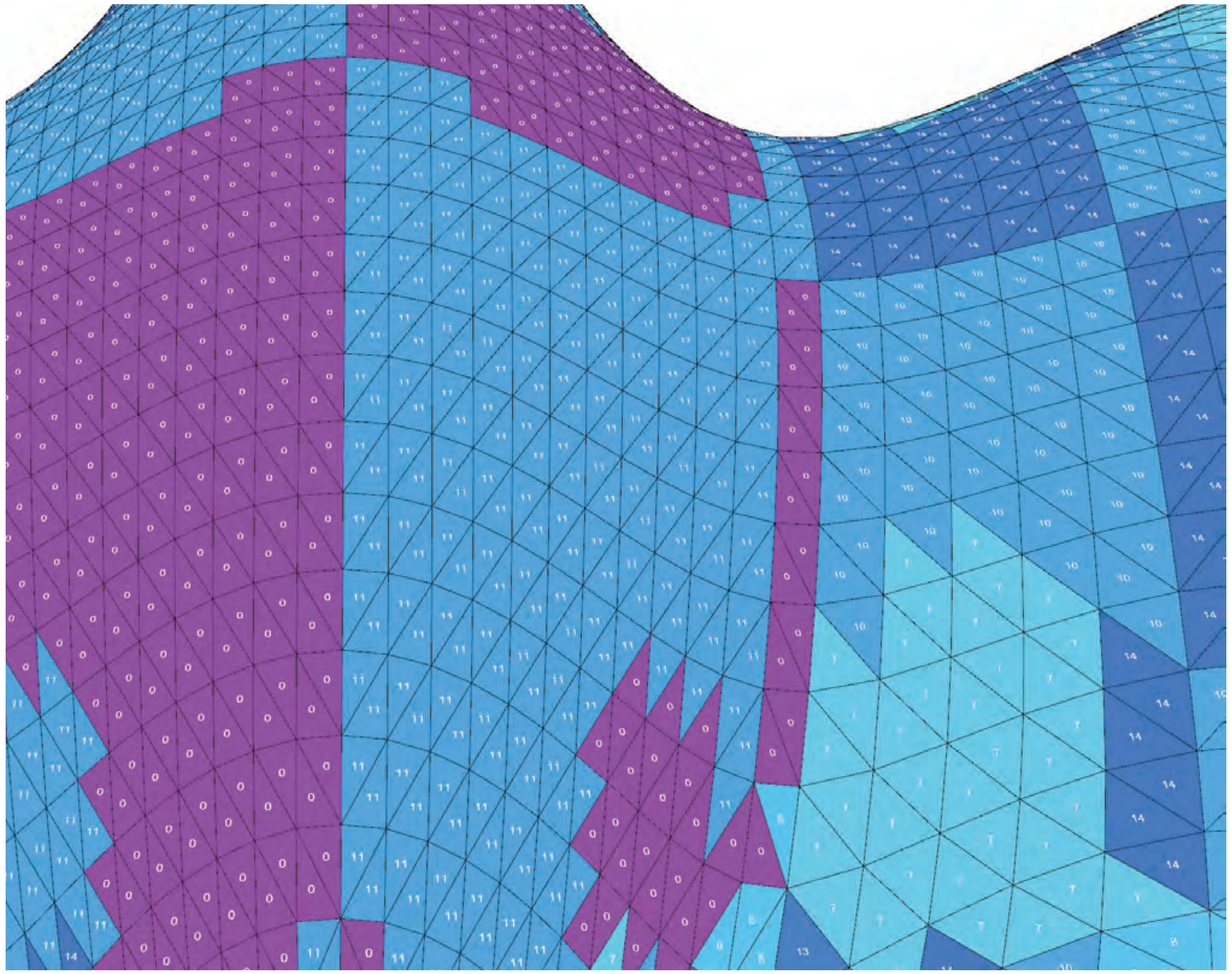

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IMAGE CREDITS

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