THINNESS is a 10’x10’x10’ lightweight modular concrete pavilion (fig. 1) showcasing concrete fabrication and design research as a collaboration between Julie Larsen and Roger Hubeli, partners of APTUM who are also Syracuse University School of Architecture professors, and the CEMEX Global R&D, the research arm of CEMEX, a global cement manufacturer. The mobile pavilion is made of 16 prefabricated elements of only 2-centimeter-thick walls (fig. 2). The design hybridizes surface and structure with high-performance, lightweight concrete to create a new approach to being “thin” yet volumetric.

To achieve a new perception of concrete and to amplify the spatial potential of the material, the design uses optimization of structure, surface, and materiality to influence the formal exploration of a cross-vault. Cross-vaults are typically not modular and made of stone, masonry, thin grid-shell steel-reinforced concrete, lattice steel, or timber frames, which are typically made with heavy, solid materials that don’t challenge the structural potential of what a system can do in contemporary construction. But with the use of high-performance, lightweight concrete, the pavilion aims to change the
perception of thick and heavy concrete vaulted systems through rethinking the construction of the vault with a thin and hollow surface that becomes structural. A focus on architectural topologies, such as the cross-vault, offers an inherent possibility to scale up due to its inherent structural logic. By focusing on a structural type, rather than strictly performance-driven design, the design field is expanded beyond our perception of a material and its limited applications. Farshid Moussavi refers to this as an expanded understanding of materiality, or “supra-materiality,” which should “liberate built form from [approaches] that separate ideas from substance...[that] do not allow the design process to respond effectively to urgent problems.” With typological objects defined through “supra-materiality,” new formal exploration has the potential for further societal reach if they can be used performatively, such as for structural capacity, infrastructural applications, lighter facade methods, or new systematic needs.

INDUSTRY COLLABORATION
In order to change the perception of concrete, the team of APTUM and CEMEX aimed to create a new type of collaboration between architects, engineers, and material scientists that worked together at the molecular scale of the material. Most advanced areas of the concrete industry, in particular research and development, have ambitions that far surpass the general use of their materials in the market. But the application of new materials is often prevented by either code or inertia of their own industry. Therefore, as academics and practicing architects, more recently we began seeking input from the material industry to facilitate new methods of architectural production and form-making.

Throughout the design and fabrication process of the pavilion, two questions formed the foundation for the collaboration. First, for the concrete industry, there is an interest in understanding how digital form finding can be integral to finding new applications for concrete that go beyond purely technical and performative measures. In other words, CEMEX aimed to explore the potential of design methodologies to reverse the typical design process that emphasizes form over material and fabrication. Second, as architects, the aim was to redefine architectural form and spatial potential through the study of a new material. These two approaches resulted in the team recalibrating a mix by CEMEX early in the design process, which led to new design methods that shifted material science beyond
the purely technical and re-envisioned the potential of fundamental architectural elements.

**TYPOLOGIES**

Structural typologies, in combination with the study of materials and advanced construction methods, have seen a re-emergence in contemporary discourse to make a broader argument for design intentions. A focus on architectural elements, such as the cross-vault, offers an inherent possibility to scale up. Typically, materials are argued through availability and performance, such as their structural capacity, profitability, environmental concerns, and/or creating comfort. This project aimed to use typology and material as a way to make an argument for design. Such is the case with Sigfried Giedion’s proclamation in his seminal 1928 publication, *Building in France, Building in Iron, Building in Ferroconcrete*, where Giedion sees new materials as the key ingredient for a new architecture. Despite Giedion’s assertion, it was not so much a modern design vision that proliferated concrete and made cement one of the most-used building materials on the planet, but rather the material’s capacity, with its technical advantages, to create larger spans and faster construction processes. This led to new types of architectural applications only achieved through rethinking the structure and the material. This is similar in scope to Farshid Moussavi. By focusing on the material and spatial quality of architectural elements, rather than strictly performance-driven design, the design field is expanded beyond limited applications and combines ecological goals, such as lighter structures with less material, or low carbon concrete with new formal and spatial opportunities.

The cross-vault was chosen to introduce curves that give each hollow column more stability (fig. 3). The opportunity was to test how vaulted forms could become thin cavities with hollow and curved walls when comprised of high-performance concrete. The study of the cross-vault was not only a way to speculate on the material’s potential to make lighter structural wall systems, but also to imagine how one could embed other systems within a cavity wall to truly make the vault a primary spatial project for a building. Another technique of testing the concrete’s capacity to become seemingly transparent was to thin out the surface with voids by creating a punctured surface. The combination of three-dimensional scripting and structural programming dramatically altered the surface according to the load capacity and, in turn, optimized the material’s capability to perform not as a thin and decorative veneer, but as a thin and structural surface (fig. 4).

**VEILING CONCRETE**

Challenging the structural and surface quality of the cross-vaulted form, there was an opportunity to think of the concrete as a thin “veil” while still maintaining structural strength and integrity in the form. This study made it possible to speculate on the potential of much lighter wall systems with embedded building system services within a cavity wall and create a thin veil or transparent expression for the form. By rethinking the archetype of the cross-vault, the complex geometry and modular construction system, in turn, altered the typical matrix and density of high-performance concrete without losing its strength or workability. The hollowed out, vaulted modules made of thin, 1/2”-thick walls was only achievable because of the high strength of the concrete surfaces to perform at a higher capacity than typical concrete (fig. 5). As seen in the elevation, the material’s capacity to be thinned out created a more ephemeral lightness to the surface and spaces inside (fig. 6). This quality wouldn’t have been imagined with traditional concrete because of its inability to be thin and structural simultaneously.
Figure 7: Diagram of how elements, manually, can move from horizontal to vertical.

Figure 8: Diagram of CEMEX Resilia Mix and its ability to dramatically reduce cracking due to the steel fibers and fine aggregates.

Figure 9: Diagram of how elements, manually, can move from horizontal to vertical.

Figure 10: Structural diagram of stress pattern overlaid onto surface.
The process began with structural analysis and pattern studies of the hollow vaulted elements of the pavilion. The intent was to transport the pavilion to reflect its temporal qualities and a need for lightness, requiring a structural shift from mostly compression and buckling to bending stresses (fig. 7). Therefore, the elements were optimized to carry load in their upright and horizontal position, and for easy mobility, each element only weighs 200 lbs/91 kg. The concrete mix, with extremely fine aggregates, results in high-performance concrete with high strength and lightweight density of 87 lbs/ft³ / 1.4 kg/l (in comparison to 87 lbs/ft³ / 2.4 kg/l for “standard” concrete), allowing for much lighter and thinner elements (fig. 8). The tube-like form of the elements guarantees the individual module’s rigidity. The modularity of the pavilion is comprised of 16 different elements, with the cross vaults split down the center of each facade. As seen in the section, the structural integrity of the pieces was no longer within the compressive strength of a typical cross-vault but within the surface of the forms (fig. 9).

In addition to the thinness and density of the material, the material’s capacity to be radically thin was studied by puncturing the surface with voids. The voids follow both the bending moment diagram in the horizontal position and the compression diagram in the upright position (fig. 10). Besides making the elements lighter, this offered another form of testing the concrete’s capacity to become seemingly transparent. In order to accentuate the fact that the surface held the strength, the pattern responded to the stress and load patterns of the surface as the pieces were moved. Structural moment diagrams were made to test where the highest stress was located on each piece. The arc of the structural diagram informed where the pattern in Grasshopper became denser to ensure that the load distribution would be reduced. The pattern was generated with a digital technique in Grasshopper similar to “diffusion limited aggregation” as a way to distribute the voids in denser areas needing less material (fig. 11). Different patterns were designed to comprise a thin and porous pattern on the surface (fig. 12). It was a question of composition and scale to find an appropriate pattern for all the surfaces. At this stage, the ideal scale of the voids was not ideal for the concrete mix because the CEMEX Resilia™ mix required 17 mm steel fibers, but the mass between voids in the surface was only 15 mm (fig. 13). Eventually, either the pattern, form, or mix would need to change scale to accommodate
the design ambitions. In the end, the decision was to change the mix and reduce the size of the steel fibers, which didn’t exist prior to the project.

FABRICATION

Due to the detailed quality of the structural veneer, the thinness of the walls, and the height of the elements, the challenge was in finding a formwork that would maintain the quality of the finish, the precise shape of all voids, and the diffused corners. The development of the formwork was a challenge because of the combination of a complex pattern and form, the extreme thinness, and the three-dimensionality of the elements. While the design of the structure, as well as the design of the concrete mix, is based on digital tools, the formwork is a combination of state-of-the-art digital fabrication techniques with water jet cut silicone inlays along with the prehistoric technique of “lost wax molds,” using silicone and wax formwork that is melted and reused after each pour (fig. 14). The wax gives the flexibility to design complex forms with a limited set of formworks (three in total were needed for 16 elements). The matrix of the mix, the additives, and the fiber reinforcements were continuously adapted to the development of the form and vice versa. The high strength of the concrete (after 28 days, 65 MPa/9500 psi) creates strong and stiff corners that are needed for crisp corners with voids bleeding to the outer edges of the columns.

First, an inner and outer steel form was made and later braced on the outside with steel angles for additional rigidity.
Figure 16: Axonometric showing the construction layers of each column.

Figure 17: Silicon peeled away to reveal wax formwork (fig. 15). Due to bowing of the steel from the compression of the concrete on the form, gaps formed between the outer steel and the wax, thus encapsulating the wax with concrete and making it impossible to melt away the wax. Later, this was resolved with the additional bracing. To make the pattern, water jet cut sheets of custom-poured silicone sheets were applied to the interior of the steel form to cast the inverse in wax (fig. 16). The wax was poured into the silicon-clad steel formwork, and then, once used as the interior formwork for the concrete casts, the wax was melted away and reused for the next pour. The columns of wax were poured, and then the silicon was peeled away to reveal the wax column in its entirety (fig. 17). The wax inverse columns were self-supporting before adding the steel formwork around the wax molds (fig. 18). After the concrete was cast, each column of wax was melted away with large, tube-like heaters running the length of the columns. This enabled the design of a narrow, tall column that could be pulled out from the steel formwork once the wax was removed.

A crucial aspect for the success of the formwork is its calibration of a complex concrete mix that creates a more fluid concrete. The design of the concrete material had to be fine enough to evenly distribute the steel fibers through the tight, woven pattern without leaving unwanted gaps or holes. The accelerated curing with additives of the concrete allows the elements to be removed from the formwork within three days. This helped to reduce the overall construction time while keeping the amount of formwork as minimal as possible.

The final installation of the pavilion was shown at the Designing Material Innovation Exhibition and Symposium at California College of the Arts in San

Figure 18: Wax column ready to be encapsulated by steel falsework for final concrete pour.

Figure 19: Final installation of THINNESS at CCA Designing Material Innovation Exhibition - photo by Mike Campos.

Figure 20: Wax column ready to be encapsulated by steel falsework for final concrete pour.
only straps to carry the load when moving the columns. The extremely thin walls showcase the ability to combine computational processes, tectonics, and materiality into a novel approach to creating volumetric and spatial qualities with a new approach to being thin.

CONCLUSION

This project is seen as an experiment to develop a methodology of design that is based on the combination of revisiting traditional architectural elements through new modes of production and advanced materiality. The pavilion takes a typical digital process beyond a thin layer to a “thin” volume that is structural, tectonic, and spatial (fig. 23). To make this project possible, the collaboration provided a new mode of design, both through the experimental process of making with advanced materials and the fabrication techniques deployed. Both advanced concrete technology and computational design techniques take the project beyond the scale of a singular object to unprecedented applications (fig. 24). The approach reverses the design process, stretches disciplinary habits, questions the normative protocols of design, and releases the information residing in new technologies.

ENDNOTES


2. Farshid Moussavi and Daniel Lopez, The Function of Form (Barcelona: Actar, 2009), 128.


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