Space and Structure

This paper documents first year design student work which emerged from a syllabus based on “generative spatial processes.” It focuses on the results of a four-week long Design-Build assignment at the end of the course, which examined space through the lens of thin shell structures and which resulted in full-scale spatial constructions.

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INTRODUCTION

This paper documents first year architectural design student work which emerged from a syllabus based on “generative spatial processes.” The course introduced students to architectural space and introduced techniques and processes through which they viewed and handled space as a multifaceted entity. With each assignment, the investigative lens was shifted to focus on the subject of space from a different perspective, to uncover a new distinct spatial dimension. This paper documents work which emerged from a four-week long Design-Build assignment at the end of the course, which examined space through the lens of structure and which resulted in full-scale spatial constructions.

The full-scale model assignment was the final one in the syllabus, and expanded upon earlier explorations of thin shell structures. Students worked in groups of seven and investigated the structural potential and performance of thin shell structures as at full-scale. Because the full-scale exercise was directly linked to previous exercises, and was also tied directly to a specific site that the students chose, the way in which the structure was developed was part of the “generative spatial processes” repertoire that the syllabus offered. By working at 1:1, students were able to investigate the relationship between material behavior, structure and space/form. Structural logics played a key role in generating form and space.

Building further upon the approach of the course, which prioritized first-hand experience and subjective readings of spaces, students were asked to cast a thin shell of an existing part of their actual, physical environment – their studio spaces - at 1:1 (e.g. corner, wall, niches, arch, I-beam, window, etc.). This existing space acted as form work. After the shell had been formed and was sufficiently strong, students removed and repositioned it (flipped, rotated, shifted location, etc.) to create a space in which the entire team could be accommodated. The need for a clear strategy about how the cast piece was positioned in relation to the original site/space was emphasized. Space was created by the specific relationship between cast shell and original building part.

Students roamed their everyday studio space environments searching for forms which seemed to provide both a specific spatial experience and which suggested a structural performance (certain forms like corners or curves obviously performed better structurally than others). Students had to think spatially and structurally at the same time. Thin shells acquire their structural strength through strategic deformation of their surface. The less “flat” a surface is the more stiff it gets. This is a principle about which students developed understanding empirically, through trial-and-error experiments. While the exterior surface of the formwork was “found”, the surface facing the students could be designed in a materially and formally specific manner to enhance the structural performance of the shell. The scale and extent of each cast (or structural component) were also critical, as questions about connecting separate pieces often had to be addressed. Connections had to be dealt with as a structural issue within the overall plan for the shell construction.

Each of the twelve student groups received one of the following six materials: hydrocal, twine, paper pulp, paper shreds for papier mâché, latex and wax. These materials were chosen and assigned because each has its own specific properties, implied fabrication techniques and appearances. Understanding the properties and potentials of the materials, as well as their implied fabrication techniques, was essential. Students experienced a steep learning curve in mastering working with these materials, which are not conventionally used in studio courses for architecture. Students were able to compare the work of the other groups with different materials and expand upon the question of how materials influence form, structural behavior and space.

The work schedule was organized strictly in relation to the structural span of the thin shells: each week, the required span of the proposed thin shell was doubled, until it reached a final span of 16 feet and was able to accommodate the student group as a canopy or enclosure.

2 METHOD

The project combined two main strategies of form-finding: firstly, students were asked to literally find forms by carefully observing their everyday built environment. Secondly, students were asked to find structural form through empirically testing the structural performance of their thin shell structure and the properties and potentials of the assigned material.

The first strategy emphasized the direct, personal experiences that students had with a chosen, everyday space. The emphasis on working from a personal reading of space was deliberate, since, in this early stage of architectural education, students are not yet immersed deeply in the discipline. Subjective experiences and readings are therefore a better source of knowledge. Working with everyday surroundings was also meant as a perception-sharpener for the students. They worked from their experience of a space, which meant that they had to become more self-aware and reflective about their experience of spaces. Personal experience, analysis of personal experience, careful observation of everyday, lived-in spaces and finding unexpected qualities informed the students’ production of form/space significantly. From this experiential starting point, students were asked to make very careful, deliberate observations and critical interpretations of their given situation. The discovery and description of formal and spatial qualities, which might otherwise go unnoticed, was key to the way of working. The syllabus aligned itself, in this regard, with the work practitioners such as architect Sigurd Lewerentz and artist Rachel Whiteread. Lewerentz’s investigations on fundamental, everyday architectural elements like the window opening gained their power because of his unusual rigor in observing and rethinking of these elements. Colin St. John Wilson wrote about Lewerentz's skill to observe in his essay Sigurd Lewerentz and the Dilemma of Classicism :

> It is said that he could sit for a long time just looking at a common nail and asking himself how many ways it could be used – for out of the simple question a surprising answer could come. And we read also of his instruction to a despairing metal worker: All I know is that you are not going to do it the way you normally do… what is at issue for Lewerentz is the search beneath conventional appearance for the shock of a renewed truth.[1]

Whiteread's work also offers an example of how to interpret everyday situations in radically new ways and charge them with new meaning. Her most noted work, House,[2] transforms an ordinary London terraced house, slated for demolition, into a powerful sculpture by simply using it as the formwork for a cast of its entire interior. Whereas the methodology of casting, producing a solid-void inversion, was a controlled decision and act, the resulting forms were inherited by the existing house.

The second strategy, which required students to cast a thin shell using a site in their studio space as formwork, imbued the forms with a double meaning. The shell structures were looked at as experienced space and as structure. Monocoque thin shell structures are especially suitable for this task as they are often inhabited structures. Monocoque structures support loads through their external skin, similar to an egg shell. They work through having an uninterrupted skin that encloses space. Spatial enclosure and structural performance are achieved with the same element. Thin shells are able to be so thin because they minimize moment forces; mostly compressive and tensile forces act in the thin material. Because these structures are so thin, they can be lightweight and minimize material while providing total spatial enclosure. A prominent example of a thin-shell structure is the the Deperdussin Monocoque airplane fuselage from 1912 This plywood thin-shell monocoque structure was strong enough to carry a person and withstand the forces acting on an airplane, but was, at the same time, so light that it could be carried by a single person. It is a structure that exhibits a similar scale and at the time experimental material use as the student projects.

The Swiss engineer Heinz Isler is one of the most important structural engineers that has worked on thin-shell concrete structures. His approach is unique as he focused more on empirical test modeling instead of mathematical calculations for the form-finding of his designs. His ice shell structures are well-known for their innovative approach and singular forms. To create his forms, Isler hung fabric over tree branches to form a catenary dome in the winter months. After wetting the fabric, it froze and created a solid, ice shell. When the ice was completely rigid, he flipped the shells to create intriguing, translucent, thin-shell structures.

For the students, the task of constructing a full-scale, thin-shell enclosure necessitated a constant flipping back-and-forth between an experiential and a performative reading of form and space. Space, material and structure were integrated into a unified whole.

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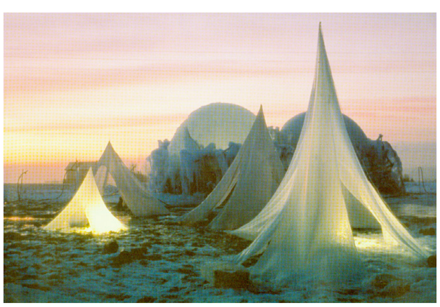

Figure 1: Ice shell experiments by Heinz Isler

3 DOCUMENTED PROJECTS

The following section documents three selected thin-shell structures developed in the course, made using concrete, latex and string.

3.1 FOLDED CONCRETE SHELL

This project used a wall in the studio as formwork. Concrete was applied directly to the wall in a very thin layer of approximately ½-inch (1.27cm). Early trial-and-error experiments taught the students that a main challenge was to control the weight of the overall structure, as concrete tends to accrue weight rapidly. Weight control became a critical topic in the group, especially as they neared the construction of the final 16-foot (4.87m) span necessary to house the whole group. A main task was then to equip the thin layer of concrete with the necessary reinforcement to be able to achieve the required structural rigidity. A series of strategies were developed to address this challenge. A series of tests were conducted and documented regarding potential reinforcement materials and folding geometries. Expanded steel sheets used as reinforcement proved to be the most successful from a series of tests that involved rebar, fabric and fiber. Additionally, hand-formed rips the shell were added at regular intervals to increase the overall rigidity of the extremely thin material. The overall structural performance, however, was achieved by the folding pattern of the shell. The idea was that, as the thin concrete material was released from the studio walls, it would "collapse" into its final formal composition, as a folded, and space entailing, concrete tent. The way in which the structure collapsed into this new and stable formation was preplanned and the intended folding lines were fabricated by inserting a rope into the thin concrete assembly. The fabrication then occurred in the following sequence: first, the entire assembly was drawn onto the studio walls. Then, the studio walls were covered with a generous layers of Vaseline, which acted as a release agent, so that the concrete layer would part from the wall without resistance and possible cracking and breaking. The expanded metal sheets were formed with the preplanned rip locations. Then, vertical sections of thin concrete, about 8-feet (2.43m) wide, were skimmed as a thin layer onto the studio wall. The folding lines were cut into place and rope was inserted, with some excess length sticking out, so that the rope could later be removed. The prepared (ripped) sheet of expanded metal was then pressed into the creamy concrete skim. While the first layer if skim was still in the process of curing, the second and final layer of concrete was skimmed onto the assembly. Lastly, the pre-folded expanded

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mesh rips were filled and covered with concrete. After the complete surface went through this process, the concrete was left to cure for five days before the structure was released from the wall. The release of the concrete was unexpectedly difficult as the concrete stuck much stronger to the wall than earlier experiments suggested, but after forty minutes the first surface started to come of the wall. The sequence of releasing the cast panels from the wall was, of course, crucial, and it was difficult to predict how quickly the release would occur. After the release of the first panel, large parts of the structure released rapidly, requiring about twenty students to hold the structure until it was fully unfolded and locked into place, free from the wall. The resulting structure offered a complex relationship to its original location on the wall. The structure created an interstitial space between the concrete shell and the existing studio walls. The textures of the wall and the related-but-inverted texture of the concrete shell created a clearly legible dialogue. Therefore, two spaces were created through the thin shell structure: the interstitial space between the original studio wall and the folded concrete, and a core, semi-enclosed space inside the folded structure. The core space was able to house the whole student team. The

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Figure 2: Releasing folded concrete shell from studio walls.

Figure 3: Releasing folded concrete shell from studio walls.

structural performance of the shell was flawless. The whole team climbed onto the structure with no visible sign of deflection or cracking.

3.2 LATEX SHELL

Latex, while not a material that comes to mind immediately when thinking of structural materials to fabricate thin-shell structures, has a series of intriguing qualities that are relevant to the objectives of this assignment. Firstly, latex is extremely light weight. It has a tremendous capacity to endure extreme tensile forces, but no relevant rigidity to withstand compressive forces. It is remarkably elastic. It stretches up to 300% without ripping. Latex typically can be applied with a brush; it comes in a liquid form. It is able to pick-up and register the slightest details and textures from the surface to which it is applied. For this reason, it was popular as a mold-making material, before the predominance of silicone. The main challenge for student teams using latex was the fact that this material needs a partner material – a material with more structural capacity - to create space. By itself, a latex skin simply collapses flat. The student teams used different partner materials and devices to assist latex in forming a structure: parts of the existing studio space, air, embedded reinforcement, or a mixture of these structural partners were used. The project documented here used the floor of a studio space onto which the latex was brushed. The center-line of the applied latex surface was fixed with a steel bar, whereas the edges were stretched vertically up to lines which were projected on the ceiling. This resulted in a frame-type space. The material became translucent when stretched, resulting in a yellowish, glowing interior space. The stretched latex skin also exhibited the textures of the rugged concrete studio floor in a stretched distortion. This texture was emphasized by the ambient light shining through the material. The tilted surfaces were also used to lean against or sit in the structure. The material is very tactile and invites for direct haptic interaction. The body weight of the users was expressed in the exterior shape of the deformed latex skin. The studies began with a span of 2-feet (60.9cm), and the artifacts, at that scale, were already performative in nature, testing structural performance and tactile qualities. Through photographic documentation, glimpses of the spatial potential of the latex proposals emerged. As the span increased, the artifact transitioned gradually into an inhabitable construct. This process also introduced first year students to methods of empirical, material research. Experiments were set-up, a trial-and-error approach was undertaken which could result in failures or successes, observations were made and conclusions were drawn. The exhaustive documentation of this research was part of the assignment and comprised a key part of the material that was presented and reviewed at the end of the semester.

3.3 STRING SPACE FRAME

This project diverted from a thin shell structure to an irregular space frame typology, but it nevertheless related to the studio space both structurally and spatially. The group began by experimenting with reinforcing plaster with strings and progressed into experiments with strings soaked with plaster, transforming string, which can, alone, only take-on tensile forces, into a hybrid material that could also take-on compressive forces. The student team investigated their studio space carefully for clues about where to attach strings. Similar to the student groups with latex as a construction material, the students using string quickly became aware of their need for a partner material or space to help string act structurally. Within the studio space, hot water pipes, a door knob, and roof trusses were identified as potential structural anchors for the strings to wrap around. Then main string axes were strung from the lower anchors (pipes, door knob) to the higher anchors (trusses, pipes) to frame an enclosure. The students then painstakingly brushed plaster onto the

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Figure 4: Inhabiting the latex shell.

strings. After the plaster set, the tensile connection of the strings to the ceiling anchors was cut. As the top strings were cut, students observed carefully the sag and any other changes to the overall structure. Locations where sag occurred or where hair cracks were observed were marked and documented. These locations were used as anchor points for new string connections inside the string structure. Using this empirical approach to observing the weak points in the reinforced string members, the buckling length of the strings was strategically reduced. The form of the overall structure evolved in this additive manner over a week-long period. The resulting "grown" structure was able to carry three students before showing signs of structural failure in the form of cracks.

4 CONCLUSION

In the task documented in this paper, first-year architecture students [3] were tasked with constructing a large span with a weak material in a short timeframe. These strict parameters for the task forced the students to focus solely on the relationship between structure, form and space and not get side-tracked by external concepts. The resulting full-scale artifacts offered a performative dimension (span, sag, failure, etc.) as well as an experiential dimension. The making of the structures necessitated full immersion in focused and systematic material and fabrication experiments. This assignment allowed students to develop critical beginning design skills, including

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mastery of sophisticated fabrication techniques, the understanding of rudimentary structural principles, and an approach to spatial design which integrated structure and material as core informants, which were all anchored in their reading and response to an everyday space.

The main focus of the studio was to avoid a common tendency in design studios: creating – either intentionally or not - a simplistic dichotomy between the real and the represented. Through creating a full-scale, thin-shell, site-specific structure with an assigned material, the original, represented, and performative aspects of materiality and space were dissected and re-assembled into a new whole. In the end, the experiential starting point of the syllabus, which asked students to find a space that intrigued them, which they continued to work with deep into the semester, was revisited through very physical, experimental processes of making that encouraged students to learn complex, interconnected aspects about space and structure in a first-hand way.

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ENDNOTES

1. St John Wilson, Colin. "Sigurd Lewerentz, The Sacred Buildings and the Sacred Sites" in Sigurd Lewerentz, 1885-1975: The Dilemma of Classicism Architectural Association Publications: London, UK. 1989. p 7-29.
2. Rachel Whiteread: House Phaidon Press: London, UK. 1995.
3. The studio ran as the first year, second semester spring design studio. It was organized around 3 faculty and 7 graduate student teaching assistants. The 2012 teaching faculty was comprised of: Georg Rafailidis (coordinator), Matt Hume, Chris Romano. 2013 teaching faculty: Georg Rafailidis (coordinator), Matt Hume, Jen Wisinsky-Oakley.

Figure 5: Plaster string space frame seemingly floating

Figure 6: Folded concrete shell "collapsed" into a stable structural formation.