**SO – IL**

**Amant**

**Brooklyn, NY**

**A Dirtier Truth**

In contemplating form, we have no desire to honestly represent a building’s inner workings on its exterior, or for that matter, to make a project’s generative diagram legible. Nor are we interested in elaborate façade manipulations to produce some new type of ornamentation or surface effect. As we perpetually rearrange arrays of atoms, we inevitably consider the visual and visceral effects of how users experience our new compositions. The volumetric definition of a building mass reflects a negotiation between internal and external domains, realms that are never one and the same. We are interested in pursuing forms that resist clarity.

In our new building proposal for the gallery Artes Amant, the form shifts between discernible and amorphous, sharp and blurred. As in the fable of the blind men who discover an elephant for the first time, the project’s volumetric presence remains unresolved. By alluding to an essential character of a private arts organization that offers space for both the production and experience of contemporary art, our proposal investigates a formal expression that oscillates between articulation and ambiguity: a form not invested in legibility, only flirting with it.

An array of formal experimentations results from material experiments: blow-dryers shrinking latex over ferrous frames and foam core volumes, shaping subtle curves that rapidly transform into steep inclines and sharp angles. Without warning, these sweeping curves give way to flat planes. Each formal test offers a different opportunity for spatial definition and specificity of use: shallow vaults and intimate spaces are produced as architectural surfaces transition to extreme heights and diffuse the natural light within the galleries. Stretched taut around the gallery volumes, the smooth curvatures allow for a synthetic understanding of the building as a whole and further suggest a relationship between the gallery spaces and their exterior openings. Both an assembly of pieces and a peculiar whole, the form is an uncomfortable presence along the street.

These formal tests were only the beginning. As we developed the design with increasing detail, each iteration added a new layer to the formal logic. For instance, the digital modelling of physical studies required a new precision to the curvature and intentionality of seams. At the same time, the shell as a structural system imposed new geometric constraints as well as challenges. Finally, the desire to work with exposed architectural concrete soon revealed the necessary logic of formwork systems and the unpredictability of shaping a liquid into a solid. Rather than dilute or compromise our original ambitions, we used each new layer of information to interrogate our rational method and to find new ways forward in terms of both design and construction.

**Bastard typologies**

*Formal typology would seem to be distinct as defining characteristics clearly identify one form or geometry from another. While geometric topology is objective, the expression and reading of form is not always so simple. Moreover, certain forms can be duplicitous, belonging to seemingly mutually exclusive categories simultaneously.*

While the initial studies of forms were comprised of individual, isolated shapes, we tested them as assemblages—or parts joined into a whole—that unified larger building moves and organizations. In this process of assembly, curved surfaces hinted at new qualities that were not necessarily native to the original tensile forms but instead belonged to a larger formal logic concerned not only with curved surfaces but also edges. Selected seams between surfaces became highly articulated, while others became invisible. The complexity of these double-curved surfaces increased with the addition of new edge constraints, such as an orthogonal window frame introduced into a stretched wall surface. While these moments of specificity were small, their impact on the legibility and synthesis of the volume as a whole was paramount. The formal variations evolved into a cohesive language of double-curved surfaces.

At first glance, these double-curved surfaces resembled classic shell structures and thus implied certain types of structural efficiencies and construction methods. Yet, in order to meet these characteristic efficiencies and construction techniques, the surfaces would have to follow strict and non-negotiable geometric rules. Structural purity and geometric topology were locked together.

Similar to arched vaults and saddle-like hyperbolic paraboloids, our project’s double-curved forms could not fit neatly into a single structural category. Felix Candela’s shells are not only sculptural: their form is synonymous with a structural logic. His work boasts an “honesty” that structure and form are exactly as they appear. Our intention to generate a diverse array of spatial experiences through adjacencies and overlaps made geometric duplicity both inevitable and more important than simply clarity or honesty.

Rather than hew to an expectation of structural and geometric legibility, we pursued impure logics and hybrid typologies so that each double-curved surface would not belong to only one geometric topology. We fused edges and forced tangencies between adjacent curved and flat surfaces; the identity of individual surfaces belonging to different geometries started to blur and bear new similarities. Like slant rhymes—phrases that seem to rhyme, when in fact they do not—we created very different formal conditions and their resulting systems subsequently looked and acted like they belonged to one cohesive, formal idea.

We pursued this duplicity by testing the same forms within different material constraints and system logics. Cast plaster shells could stand on their own without support edges. Sculpted solid foam followed the tensile membrane shapes but could also allow for local behavior deviations around the edges, suggesting seamlessness between surface and volume. Each material study offered new insight on how to manipulate form, and each local sleight-of-hand benefitted a newly synthetic whole. Ironically, this method of grafting and faking surface provided a more formal architectural “consistency” than any prior geometrically or structurally pure form.

**Digital Copies**

*With a posture of precision endowed by unlimited zooming and decimal points, digital models of physical artifacts would seem to be perfect, but like the people who made them, digital tools round, crop, assume, and approximate form.*

Ostensibly a simulation of the heat-shrink process used to make the study models, the translation of physical artifacts into digital form freed the building geometry of several constraints latent in the physical models yet introduced a new set of limitations related to precision and scale. To digitally control the double-curved surfaces, Andrew Witt of Certain Measures produced a set of tools that enabled the modeling and manipulation of shapes we could only model in physical form. These Grasshopper scripts enabled us to digitally create a fabric-like, double-curved surface within a user-defined set of boundary edges. The double-curved surfaces stretched between otherwise orthogonal program elements and structure. We manipulated the perimeter edges that defined the shape of each surface, and then calibrated their curvature and “tautness” in order to control the shape of the gallery spaces inside.

During this process, Witt noted that many of the physical models had definitive characteristics—such as disappearing edges and sharp corners along boundaries—which proved difficult to reproduce digitally. Many of these model details were analog artifacts from the heat-shrink plastic wrap process and the variable tension achieved by differentially heating areas of the shrink plastic.

Witt devised modelling tools that allowed us to manipulate the surface tension through secondary inputs of controlled tautness, which enabled local manipulation and the creation of soft or hard edges. These secondary inputs tailored each surface to the needs of the building: increased height for ceilings, controlled edge tangency to meet vertical walls, and the introduction of seams at corners to meet adjacent volumes. Unlike fabric, the digital tools could control these parameters in precise ways. Witt noted that for some surfaces, we “wanted to control by absolute positions…or relationships,” yet we also wanted to control the surfaces in more relative ways. The modeling script allowed us to achieve this by, “measuring geodesically along the surface” and “manipulating that surface by that geodesic change,” which caused the surface to relax or tighten.

Each digital manipulation enabled local deviations from the formal logic of the purely stretched fabric structure. Witt identified that there was a distinction between the production areas of the surface along edges and the smooth middle region. Edges were inscribed on the surface, with the minimal tension surface itself being only one of the inputs. The localized “mesh surgery” interventions changed the way the triangulated mesh pattern was divided along edges; it also preserved the sharp corners otherwise lost to the digital “stretching” of the surface. In the process of creating the digital copy of a physical artifact, there was a negotiation between a geometrically rigorous form and the necessary building requirements, such as clear ceiling heights and flat walls for mounting art. The digital tools facilitated the calibration of this balance.

With the local manipulation of surfaces, we questioned whether we were creating an ‘authentic’ geometry or merely a sculpted one. Each manipulation was not fundamentally an aberration of a known original, but rather a new territory of the surface with separate governing logics, what Witt referred to as “regimes.” Instead of merely sculpting of an *a priori* form, the process introduced new (unnatural) inputs that affected the dynamic topology of the surface as a whole.

**Shells and Imposters**

*A shell is not a form, but a logic imbued with a Modernist interest in structural expression. This seemingly pure structural logic is ripe for corruption.*

Derived from saddle-shaped tensile forms, the project’s curved surfaces have geometric affinities with structurally-efficient tensile membrane structures (as in Frei Otto’s work) and thin-shell concrete (such as in Felix Candela’s work) and, in particular, with anticlastic double-curved structures. Deemed negative Gaussian curvature or anticlastic, these surface curvatures face down along one axis and up along the other—similar to hyperbolic paraboloids. These unique qualities can allow a fabric membrane to function like a rigid structure when under tension, or a thin concrete layer to function in compression by eliminating the need for steel reinforcement. While the double-curved roof surfaces in our project came with promises of a shell-like structural logic, our architectural ambitions of a synthetic whole—composed of both double-curved and planar surfaces—meant that we had to resist forcing the envelope’s individual parts to a strict geometric regime that could not be applied to the whole.

To realize the complex curved surfaces and concrete walls, we collaborated with Schlaich Bergermann Partner (SBP), a structural engineering firm well known for its use of double-curved and tensile structures. The structural design approach for Amant was a patchwork of both true structural shells and structural imposters: structural slabs with shell-like formal qualities. Formally, the two mimicked one another. In areas marked by significant double-curvature, true shell-like structural behavior allowed for extreme thinness. In areas of little or no curvature, the surfaces depended on alternative solutions—thickened concrete, or increased reinforcement—for surfaces to take bending stresses and span the same distances as the ‘true’ shells. Unlike a true compression-only, unreinforced shell structure, the reinforced concrete performed structurally in compression and bent with very little visible difference, which allowed for significant structural bluffing.

We designed four primary roof surfaces, each with different formal objectives. Among these, the largest and most complex roof was over the third-floor galleries, which had the largest area and highest ceiling. The roof was bounded by variable edge conditions, only some of which could be used structurally, such as operable glazing on the west side and double-height open-air volume on the south. Geometrically, this roof deviated the most from the double-curvature required for structural rigidity and was marked by a large central region that approached flatness.

Stephan Hollinger from SBP explained that the roof structure was difficult to engineer because “compared to a pure shell…it was double-curved [and] was not a pure hyperbolic paraboloid.” Due to its size and areas of flatness, the roof had to be designed to resist bending moment, and not only “axial forces within a shell,” according to Hollinger. Additional formal demands, such as maintaining tangency with certain edges, complicated the effort to determine where the surface should perform like a shell and where it would need to rely on other means. The inefficiency of the large surface became clearest in section, where, as Hollinger noted, in order to compensate for the areas without double-curvature, the concrete surface had to be locally thickened. The concrete thickness was also increased at various moments throughout the building including “restraints to the walls” and “especially in corners” where “high stress would lead to a lot of bending moment.”

The two smallest roof surfaces were very close to the ideal hyperbolic paraboloid, and, as Hollinger noted, “the easiest ones to analyze because they had most axial forces and almost no bending.” The smaller surfaces were structurally more understandable compared to the hybrid structural approach triggered by the complexity of the curvature and edge conditions of the large roof surface. Even though these smaller surfaces were more predictable and “honest” in the Modernist legacy of structural expression, we were more attracted to the messy and insistent effort needed to engineer the large roof surface. This hybrid approach of mixing shells and slabs gave a new idea of the entire building as a single structure. Rather that suggesting that certain shells were truer than others, the approach started to fuse planar and curved surfaces as conceptually the same. The building became an assembly of complex surfaces, some acted shell-like (axial forces), and others slab-like (bending forces), although these distinctions were almost impossible to perceive.

**Fabric Forming**

*In an intimate act of symmetry, formwork must bear all the qualities of the finished concrete yet is typically constructed in ways far less plastic. While liquid concrete easily takes any shape, formwork poses a more rigid problem.*

Standard formwork systems do not easily offer a way to form double-curved surfaces. In researching alternatives, we found most methodologies consist of either CNC-milled blocks of high density foam layered onto standard formwork, or sheets of plywood bent across precision routed frames. Eventually, we stumbled across a more radical strategy that had a surprising resonance with our initial physical studies of heat-shrink plastic stretched over rigid forms.

As part of the BLOCK research group at ETH, Diederik Veenendaal researches formwork constructed of fabric. Like tailored clothing, this system uses a high strength fabric, which mimics a structural shell when put into tension. Concrete is applied on top of the fabric, whose shape is designed to account for the deformation from the dead load of the concrete and to take on the designed curvature.

This technique was also dependent on the geometric logic of double-curved anticlastic surfaces. For our project, the method’s feasibility depended on whether it could be used with the forms that deviate most from these criteria, as in the roof surface regions with very low curvature. Veenendaal explained that the fabric formwork, when compared to other methods, “is perhaps the most constrained in terms of geometry,” and that most tests have been “limited to very simple saddle shapes” with clearly anticlastic curvature.

We were interested in the conceptual kinship between this softer formwork system and our first physical study models. Yet the fabric formwork method was not as geometrically forgiving as other approaches. Reinforced concrete could have some zones where pure shell-action could not be achieved, but fabric necessarily has no capacity to cheat. As a test of his method, Veenendaal did not want to advise on the form. Instead, he tested the method to meet the design as given. In analyzing our surfaces, he observed that “in general the shapes are anticlastic, which is a necessary condition,” but that as with the concrete structural analysis, the largest roof surface had regions that were problematically “very flat” and  
“corners and singularities” where the flexible formwork “technique is quite challenging” due to low curvature.

For good or bad, the fabric formwork acted as a test of geometric purity, as the structural analysis had before. As we developed the design through digital models, creating new formal continuities and architectural relationships, we departed from the simple logic of the physical forms. The process of revising the edge tangencies and relative curvatures between the surfaces was important to make the double-curved and planar surfaces work as a synthetic whole. This collage of local edits and manipulations blurred the more geometrically rigorous shells with areas whose curvature was purely an invention. Adapting these surfaces to the techniques and native structural logic of fabric formwork would only undermine the synthetic whole enabled by the local changes. It was a strange realization that the fabric-like forms would be undermined if we used actual fabric to form them. The strictness of the system was too honest. We needed a formwork method that could accommodate true shell geometries and ‘incorrect’ ones.

The continuity of the curved forms played on the ambiguity of the whole, as both a structure and form, and allowed the structural typologies to invisibly bleed into one another. Our intention was to create a whole with parts that resist attempts to demarcate, classify or rationalize them. The exploration of fabric formwork brought into focus new priorities of the form: not for one part to be true, but for all the parts to become a whole.

**Forming Fabric**

When working with Certain Measures, the surfaces were drawn as triangulated meshes. We never viewed this as a representation of an eventual structural or construction logic, but as a byproduct of the tool. Because of their experience with constructing tension systems, SBP reproduced the surfaces using a quad-panelization technique. This had the benefit of rationalizing previously contorted corners and integrating them more smoothly into the topology of the surface. While the triangular meshing was more about resolution than organization, quad panelization started to make visible the underlying logics of the surfaces. In particular, it highlighted the possible relationships to constructability and suggested a new—and undesirable—legibility. Like an x-ray, the graphic and orientation of the grid showed areas more compliant with traditional shells and called out those just playing along. In contrast to structural expressionism, we embraced the undifferentiated concrete and all its fibs.

Daniel Gebreiter from SBP studied alternative modelling techniques to address issues of rationalization and formal control important to the architectural intent. In understanding our desire to fluidly mix structural and formal logic without clear boundaries, Gebreiter looked beyond the world of structural engineering and architectural geometry. As he explained, in order to model the surfaces, he borrowed “a modelling technique from the film industry” called subdivision surfaces, which guaranteed surfaces “to be smooth despite their complex topology and tangential boundary constraints at their perimeter.” Following a set of parameters and guidelines, the method permitted the precise articulation of the “distinct creases which fade into the otherwise continuous surface” while preserving the ability to be “represented using different resolution quad meshes.” This fluidity meant that the “geometry generation, structural analysis, and fabrication could all reside within the same workflow,” while preserving the design parameters, controlling the relationships, tangencies, creases and corners of the surfaces.

As we studied double-curved formwork and concrete placement, there was the nagging suggestion that precast panels held the promise to simplify construction. As questions arose about the feasibility of pouring double-curved concrete, we decided to test how precast concrete panels would change the image of the building. Where seamless cast-in-place concrete allows for structural and geometric logics between walls, floors, and curved shells to be entirely masked, the demand for legible logics with precast panels inevitably provided too much of a geometrical index than anticipated—suddenly, walls and roof surfaces were clearly distinct and defined once again. Like the conceptual problem highlighted by fabric formwork, the material logic of concrete would be undone by coming into in focus too clearly.

**Forming Limitations**

*Concrete is forever condemned to be a ghost of the formwork that came before. Does it always have to be so faithful? Sometimes knowing less is more.*

Our concept of the building as a continuous whole composed of both curved and flat surfaces was not only a geometric problem but also a material one. Despite differing requirements of insulation, structure and waterproofing, we believed it was important to construct all surfaces using the same formwork technique and the same concrete mix. Seemingly most native to our design process, the fabric formwork ironically would be most problematic for realizing the project. Accepting cast-in-place concrete was implicit for curved and orthogonal geometry to merge.

The formwork was the first physical manifestation of the form. Besides their geometric and structural fights, the roof surfaces also posed problems from a formwork perspective. The sharp corners that blended into smooth surfaces, as well as very rapid changes in curvature—from mostly flat to double-curvature, with negative Gaussian curvature—each suggested a different formwork construction technique to best describe their individual geometry.

Continuity and smoothness between curved walls, roofs, and floors is not only a feat of formwork, but also of concrete technology and placement strategies. Reginald Hough Associates (RHA) helped to specify and describe a concrete that would support our ambition. As walls became roofs, the thickness of the structural slab and the embedded insulation layer change; making this transition smooth requires absorbing many differences. The biggest challenge was to cast the concrete in two layers with insulation and waterproofing embedded in between, so that both the interior and exterior surfaces would be exposed concrete. We explored using a pressurized concrete spray called Shotcrete, which could easily construct the roof structure and even allow almost vertical curves to be placed without a top form. The Shotcrete concrete mix is controlled at the nozzle and thus the variability of water in the mix was highly dependent on the skill of the operator. Variability in the water/cement mix would mean very inconsistent color in the concrete. It would be a sad end to the project if we had to paint over the exposed concrete to cover up the flaws of the concrete application. Returning to formed concrete, RHA proposed the use of a very liquid form of concrete called self-consolidating concrete (SCC). Because of its density, SCC can be pumped into a form from the bottom and does not require vibration to expel air bubbles. Our investigations into formwork methods were based on using this concrete, since it would allow walls and ceilings to be poured continuously.

Two formwork methods emerged as contenders: curved plywood bent across routed plywood rib structures, and milled blocks of high density foam with an epoxy coating. We explored the plywood method with engineering and fabrication firm CW Keller, and the foam method with two separate companies, Shelter Enterprises Inc—a roofing company with experience milling sloped insulation for complex roofs—and Arbloc, a prefabrication expert in Italy.

The plywood method had many benefits, not least of which was that it seemed the ideal technique if we were to use on both curved and flat surfaces. Yet it also came with its own limitations of curvature: wood can only be bent or twisted into double-curved shapes in very limited ways; otherwise, it must be cut into small strips. CW Keller’s proposed method suggested we use mostly plywood and transition to milled blocks of foam at the moments of extreme curvature. Yet as in the case with precast panels, we did not want zones of foam mixed with plywood formwork, especially because they would most likely be used around areas where the smoothness and continuity of the surface was most critical for the ambition of a synthetic whole. Even though the curved plywood would work in most circumstances, it was a problem too big to overcome and the plywood would fall short in the most extreme moments, when the continuity of the surface was most at risk.

Unlike these other methods, milled foam blocks would offer the flexibility we required. As a method, it is not as materially economical as bent plywood, and does not take advantage of geometric affinities as the fabric formwork. Foam is completely agnostic to curvature or form. It can describe curves or corners with equal precision. Rejecting the purity and efficiency of the other approaches, we chose the method with the least intelligence. Like our locally thickened surfaces, milled foam sponsored the impurity of the system—more structural and shell-like locally, or purely sculptural as needed—and seamlessly formed a tangent edge between surfaces or a sharp corner with similar impartiality. This dispassionate approach was surprisingly the most native to the project.

**Coda**

Unfortunately, this Frankenstein would not come to life. While roof surfaces and walls can merge architecturally, formwork systems and their specialty sub-trades don’t as easily coalesce. For all its ambition toward a new impure fusion, the project’s models, artifacts, and fragments will go on as a body of research and knowledge, catalyzing new projects.