ARCHITECTURE FOR GLASS:
The Undeferred Architecture of Emerging Technology

by

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Master of Architecture 2014

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The seamless integration of emerging technologies in architecture negates their architectural expression. As long as emerging technologies in material processing and fabrication continue to be relegated to the lowly status of construction tools their impact on architecture will be deferred. Architecture can only express issues that are considered as design factors. In order to rein in the current trend of geometry driven design characterized by its lack of construction logics, emerging technologies in material processing and fabrication must supplant pure form among architectural design considerations. When these technologies are core drivers of design they have the potential to engender novel architectural expression and, in doing so, their potential effects become undeferred. The Barcelona Pavilion exemplified the undeferring of emerging early 20th century material and technological potential. Current emerging technologies in glass processing and fabrication will be undeferred in a reimagining of that project: The Glassroom Pavilion.

Acknowledgments

I would like to thank my supervisor Colin Ripley for his guidance and for constantly challenging my work to be more grand, more wild and, in turn, more successful than I could otherwise imagine. I have learned that this is the key to wondrous architecture.

I would also like to thank Harbourfront Centre for the use of their glass-working facilities and Steven Fassezke for his expertise.

Dedication

To my parents, without whom none of this would be possible, to Shauna for teaching me how to balance and to her family for welcoming me so wholeheartedly.

Polkadot

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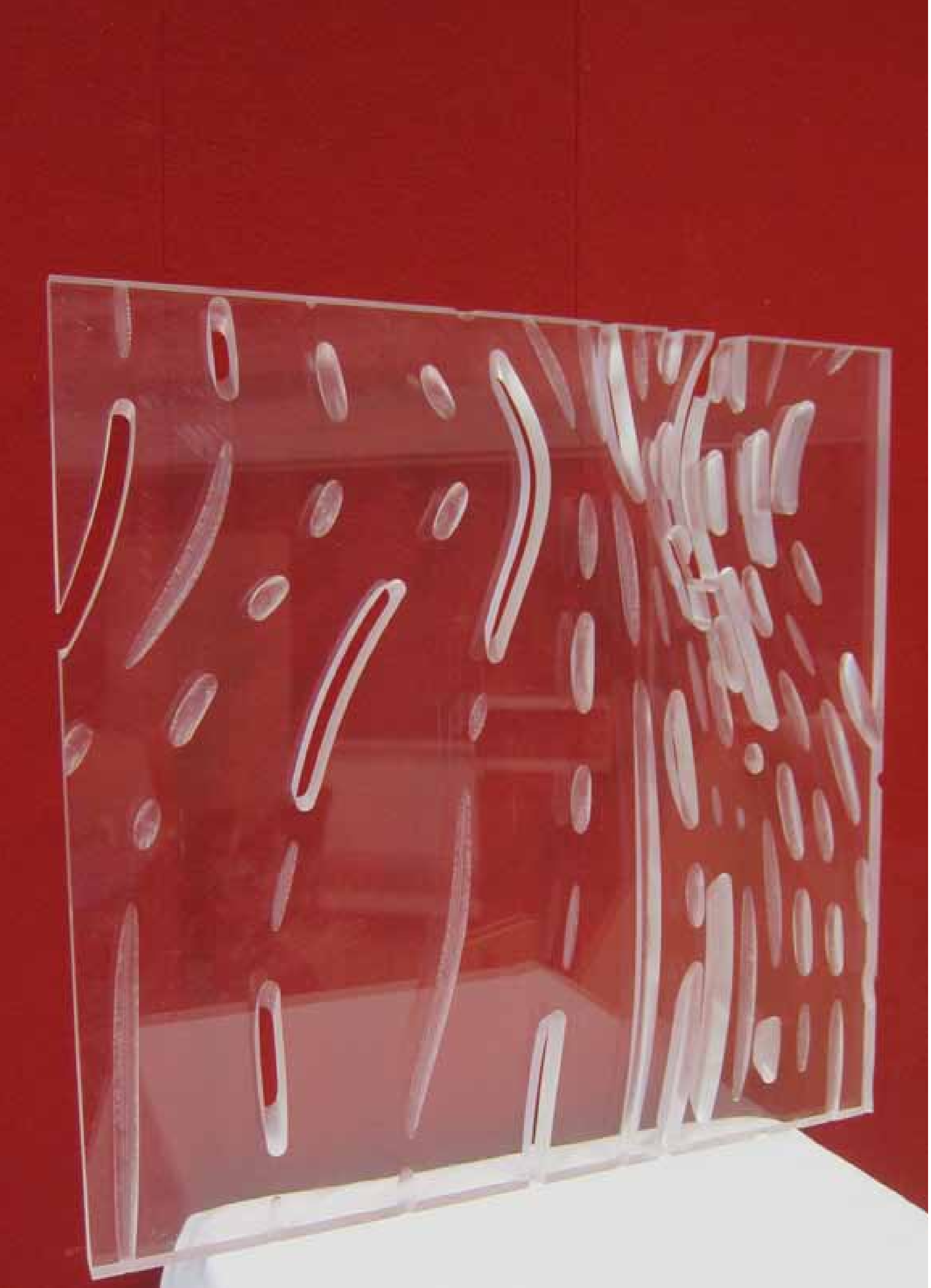


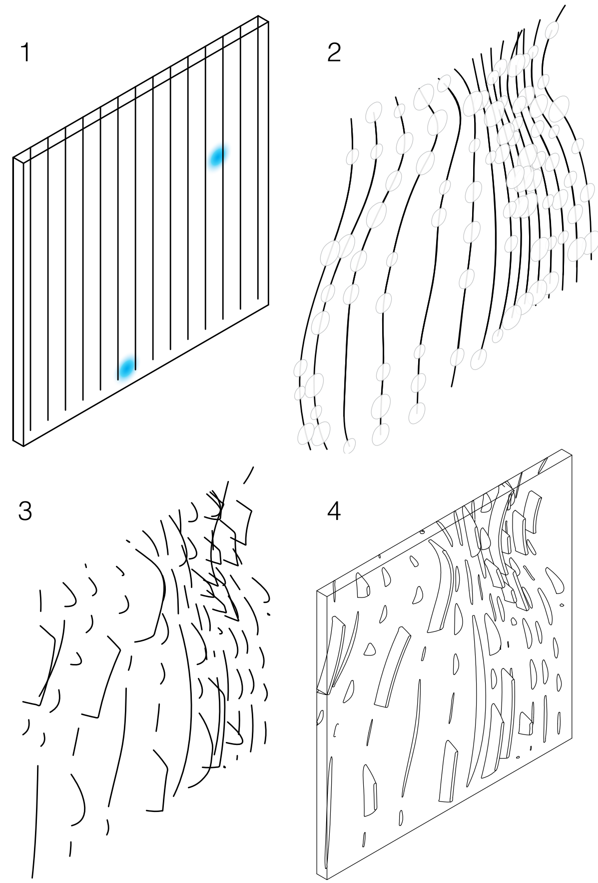


Figure 1: Screen Study 1 (left)

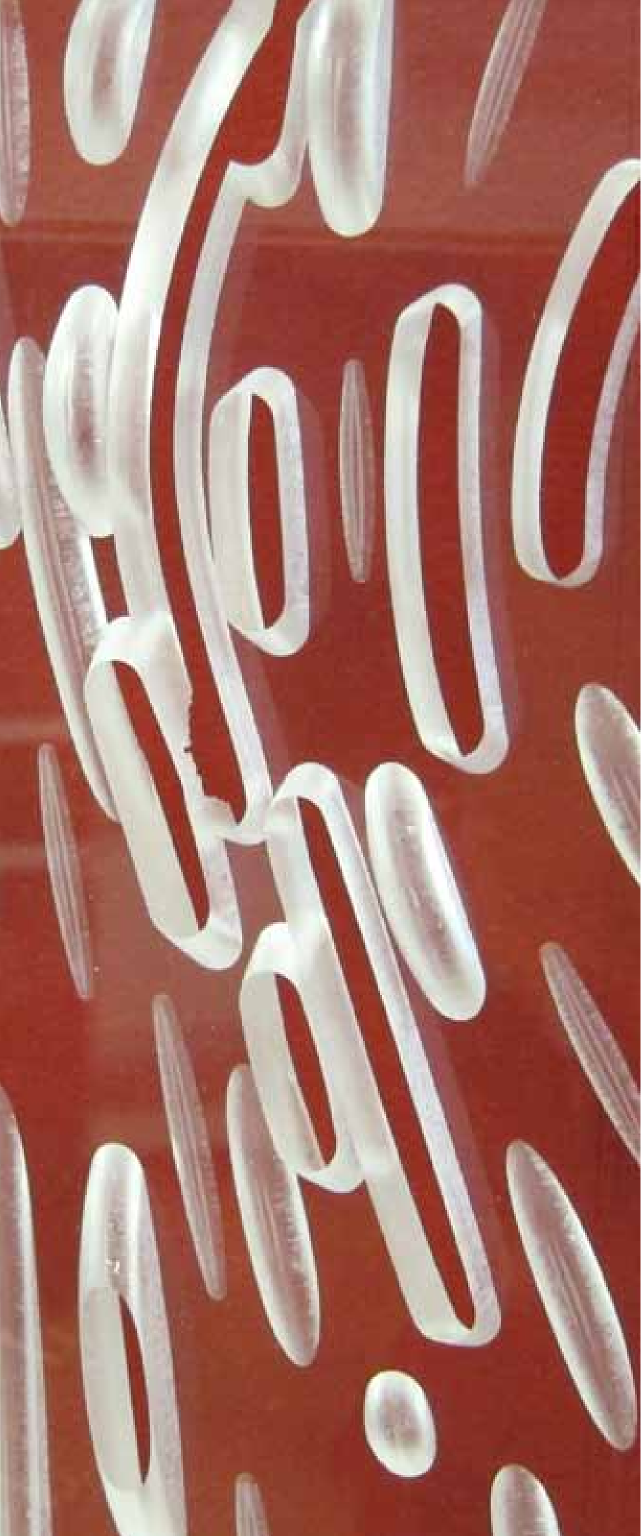
Screen 1 constructed to study how fabrication and material properties can be expressed in a built object by including them as drivers of design. CNC routed channels in 25mm thick clear acrylic, inverting the perception of solid and void.

Figure 2: Screen Study 1 Design Stages (above)

Parametric design stages and visualization used to digitally and physically iterate through various design and fabrication parameters as well as to create final toolpath data.

Figure 3: Screen Study 1 Detail (opposite)

Detail photograph showing dense cutting area.



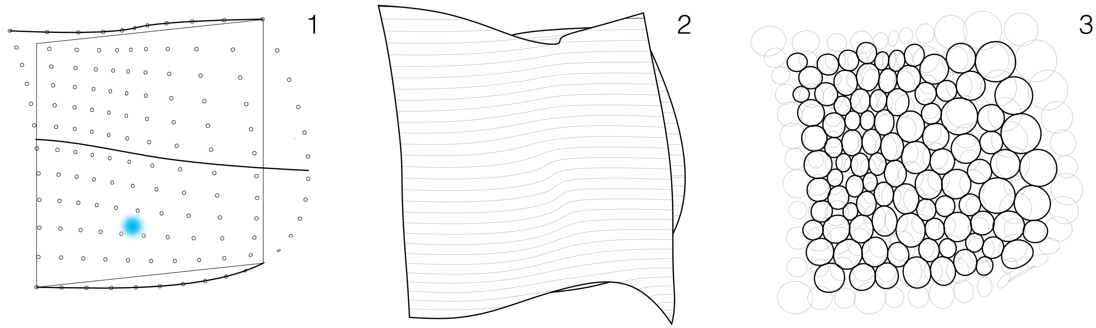
- 1 -
Synopsis

Integration Defers Expression

The architectural integration of new and emerging technologies temporarily defers their ability to create novel forms of architectural expression.

In any fabrication or construction industry radical technological innovations beget dramatic changes in the industries' built products. The results of researching, evaluating and eventually deploying new technologies tend to impact how the final object is produced, but, more importantly, how it is designed, how it functions and how it performs. The transition from esoteric research concept to new design paradigm is a cyclical process that occurs to varying extents in all industries and its duration is measured in the time it takes for new technologies to be visibly and experientially expressed in final products. The speed at which this cycle plays out varies greatly among industries, ranging from the nearly instantaneous leap from invention to incorporation in consumer electronics to the decades long adoption of radical technologies in architecture. In the architectural realm there is a tendency to preempt the sweeping expression of new technologies by adopting them into existing production paradigms. The issue with this tendency is that this seamless, behind-the-scenes integration into production suppresses the potential for these innovations to radically impact architectural expression. This suppressed expressive potential is known as a deferred impact of emerging technologies. This thesis seeks to undefer this impact, to posit new architectural expressions by considering emerging technologies as drivers of design rather than facilitators of existing expressive languages.

Architecture is only capable of expressing issues, concepts or technologies if they are understood as design factors. Current architecture, regardless of how advanced the tools applied in its realization may be, represents an aged construction paradigm predicated on century old technologies. This paradigm excludes emerging technologies in material processing and fabrication from design, so it should come as no surprise that the resulting architecture lacks the ability to express these innovations. Employing these innovations as construction tools, rather than design tools, leaves no room for their impact on the final result. The resolution of the disparity, of their deferred impacts, lies in the incorporation of emerging technologies and their potential impacts on material and construction logics as drivers of design. An architecture whose design is rooted in the novel interaction of materials and emerging technologies as well as issues of site, spatial conditions, Munroe

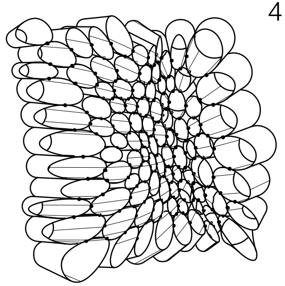


performance and representation, engenders innovative expression.

An initial exploration into the integration of emerging technologies in fabrication and material effects as design constituents reveals that the results naturally express those innovations in logically rooted geometry. These screens are, at best, proto-architectural as they express only the interaction between material and fabrication technology however this reiterates the relationship between drivers of design and resulting expression. The expressive language of these objects is a result of the technologies employed in their construction but this expression is only made possible by the consideration of these innovations as design constituents, rather than simply means to a geometrical end. Current architecture expresses the dominance of geometry at the cost of deferring the impacts of new technologies by relegating them to construction tools; this is architecture BY emerging technology. The architecture of undeferred effects, in replacing abstract geometry with concrete material and fabrication logics, ushers in a new representational paradigm: architecture OF emerging technologies.

By including emerging technologies in material processing and fabrication among the other primary concerns as drivers of design their expressive potentials are undeferred in the resulting architecture; the architecture of emerging technologies.

4



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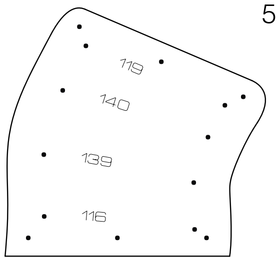


Figure 4: Screen Study 2 Detail (opposite, left)

Detail photograph showing a portion of the truncated cone screen. The cones are thin flexible PETG; cut, drilled and numbered using the CNC router and fastened using rivets.

Figure 5: Screen Study 2 Design Stages (opposite top and above)

Parametric design stages through which the volume and form of the screen are studied. The parametric definition includes visualization as well as drilling, cutting and numbering toolpaths.

Figure 6: Screen Study 2 (opposite, bottom right)

The waviness and thickness of the screen are a function of the aggregate opening angles and lengths of the cones.

- 2 -
Introduction

This thesis begins by examining a significant historical example of the undeferring of emerging technologies in material processing and fabrication: the Barcelona Pavilion. The revolutionary nature of this building is unpacked in terms of what emerging technologies were involved as well as in terms of how those innovations shaped its Modern architectural expression and what the pavilion posits as Modern architectural positions in opposition to its predecessors. A reinterpretation of the Barcelona Pavilion, as well as the Modern industrial ideals it espoused are proposed as the 'site' for a new architecture of undeferring of emerging technologies responding to a new set of 21st-Century ideals. The importance of glass in the Barcelona Pavilion, its suitability for exploring new ideals, as well as its applicability to the concepts of undeferring of emerging technologies in material processing and fabrication challenge this reinterpretation to consist entirely of glass. The Glassroom Pavilion is examined in portions, each area relating to that of its predecessor. The spatial conditions of each part are explained as 21st-Century reinterpretations of the experiential, rather than the

formal characteristics of the Barcelona Pavilion. The Glassroom Pavilion is explored as synergistic grouping of 21st-Century positions, experiential characteristics and near-future emerging technologies that have revolutionized this architectural application of glass. The resulting expression is summarized in the Glassroom-South, a microcosm of the principles and technologies that make up the Glassroom Pavilion, located on the SW corner of the podium. Finally, the conclusion summarizes the significance of undeferring the impacts of emerging technologies for architecture.

- 3 - Context

The deferring and undeferring of the architectural expressions of emerging technologies occur in a cyclical fashion. Prior to their significant adoption within architecture, the vast majority of technologies that have greatly impacted the design and construction of buildings began in other areas of industrial production (Kieran, 2004). Innovations in other heavy industries, such as shipbuilding, aeronautics and automobile manufacturing, impact those fields quickly but the integration of these same technologies into architectural practice is far slower (Kieran, 2004). Initially, once these innovations do enter the realm of architecture, the uptake of begins on the fringes of the discipline. Design research projects in academia and elsewhere, as well as small-scale experimental design work such as installations, are the first bulwark in the influx of these new concepts in design and production. From these fringes, the slow infiltration into mainstream architectural production begins. The architectural use of revolutionary materials and technologies frequently begins for purposes of humble expediency. This is the stage at which the effects of emerging technologies are deferred (Menges, 2008). This stage is characterized by the facilitative ends to which these concepts are applied (Menges, 2008). The crux of the issue of the deferred impacts of emerging technologies is that their application to reduce costs and simplify construction is easily seen as the limits of their purposes. New materials and technologies have the potential to alter architecture far beyond that limit, however that potential remains deferred as long as architects fail to see beyond the pedestrian issues of cost and time. The final stage of the cycle is undeferring these effects, unleashing the transformative potential of emerging technology. This is the stage at which design and architectural expression may be profoundly altered. The undeferred architecture of emerging technologies is powerfully different, both in the ways in which it is constructed and in how it carries

Figure 7: The Barcelona Pavilion

out its role of representation.

Study into undeferring the effects of emerging technology is, by definition, uncertain and speculative. Like all projective research, valuable insight into the trajectory of currently deferred impacts can be garnered from analysis of previous cycles. One of the most powerful and recognizable examples of an undeferring of emerging technologies is Mies van der Rohe's Barcelona Pavilion. Unlike most buildings that preceded it, the use of what were then emerging technologies redefined the formal and experiential characteristics of that building, engendering an entirely new expressive language for architecture.

Considering the prevalent architectural style of the first third of the 20th century, the Barcelona pavilion was radically different in both the means and methods with which it was built and, more significantly, in its architectural expression. Famously rational, devoid of traditional ornamentation and sporting novel spatial arrangements, these visible differences alone are not the most significant factors in its importance as an example of undeferring emerging technologies. It is the relationship between that novel expression and the technologies that lay beneath that position this pavilion as a crucial datum. At building massing scale the geometry of the Barcelona Pavilion expressed new positions on the solidity of building volumes. Where fully defined and enclosed volumes had previously been the norm, Mies employed parallel planes to define space (Quetglas, 2001). Stretched between these planes were thin screens supplanting the thick walls that so unconsciously defined many spatial characteristics of previous architectures. This was, however, far from typical at the time. The growing inclusion of steel in conventional architecture prior to the Barcelona Pavilion, was limited mainly to simplifying or expanding architectural concepts that predated the material entirely, deferring its potential effects. Their thick walls and solid volumes were no longer technological necessities. Glass, in the majority of buildings preceding the Barcelona Pavilion, was limited to relatively small panes seated in equally small openings in the otherwise massive walls. The ratio leaned heavily towards wall, despite the increasing capacity and quality of window-glass technologies. These advances in glass technology had not yet revolutionized architectural concepts surrounding windows. Windows, walls and novel volumetrics were the stage upon which the radical new architectural expressions of emerging materials and technologies would profoundly influence future architecture.

Figure 8: Steel and Screens (above)
Construction photograph of the original Barcelona Pavilion.

Figure 9: Planes and Screens (above)
Photograph of current Barcelona Pavilion taken to match the construction photo.

- 3.1 -

A Pavilion In Material and Technology

The radical shift in architectural expression embodied by the Barcelona Pavilion is entirely related to a number of materials and the emerging technologies that surrounded them. Like the screens constructed early in this research, the architecture of this pavilion represented the clear link between these innovations as drivers of design and a distinct and radically different expression. The inclusion of new material potentials as design constituents led to an architecture to which these technologies were integral, rather than simply facilitative. As such, an analysis into the Barcelona Pavilion, as an example of undeferred architectural effects of emerging technology, must begin with the technologies themselves. In the Barcelona Pavilion, as is true in current innovative architectural practice, the concepts of emerging technology and their constituent architectural materials are indelibly linked. While none of the materials party to the significance of the Mies' pavilion were new, advances in the technologies surrounding their processing and application were, and therein lay their importance.

Standard steel sections were central to the iconic architectural expression presented by the Barcelona Pavilion. What Mies designed, though, was significant not simply because it used steel, rather, the importance of steel in this pavilion lay in the way in which it was applied. The possibilities inherent in the vast difference between the strength to mass ratio of steel compared to earlier structural materials became a central element in the Barcelona Pavilion. The thin expressive roof planes supported by even more delicate cruciform columns were the ultimate architectural expressions of the properties and technologies of steel. The availability of perfectly consistent hot-rolled standard elements, derived from other heavy industries was the technological advance harnessed by Mies to profoundly alter the expression of a number of architectural elements. His recognition of the potentials of steel allowed him to realize a design concept that has since become a central principle of architecture: the disassociation of building elements. The novel application of steel reduced what would previously been a roof to a single large rigid plane. As such, the plane could be read as a spatial delimiter within a new architectonic context, rather than a classically understood multivalent building element.

Likewise, removing the structural necessity in walls reduced them to a pure architectural concept: the screen (Quetglas, 2001). Far more greater than simple semantics, the architectural impacts of the transition to planes and screens revolutionized the architectural spatial experience. The rendition of walls to screens and of roofs to planes was enabled by the now iconic cruciform columns. Their incredible slenderness was a testament to the structural possibilities offered by steel. Devoid of any ornamentation that would have previously adorned other columns, their expression was entirely modern and technical, related intrinsically to the material qualities of steel. Constructed primarily of four equal angle sections geometry too was the embodiment of the architecture of emerging technologies in steel. The chrome cladding surrounding the columns was equally and expression of emerging technology, chrome plating was unheard of in architecture at the time (Berger & Pavel, 2006). This mirrored sheath is the final representation of both their novel spatial and experiential immateriality as well as of their manifestation of emerging technologies. That any of these architectural elements could be so highly engineered as to serve a single purpose perfectly and with no extraneous matter became the expression of sophistication in design. Here, the expressive potentials of steel were undeferred in a novel architectural language.

The Barcelona Pavilion expressed as a series of separate features, each with a single unique function, would not have been possible without advances in steel influencing its design, rather than being applied to its construction.

The application of stone in the Barcelona Pavilion was radically different than its use in traditional pre-modern architecture. Though the ornamental use of rich stones such as marble was not new to architecture, pre-modern architecture celebrated the ornamentation born of those materials whereas this pavilion celebrated stone in an entirely different way. The critical difference is lies in the expression of, and relationship to, technology. Like Adolf Loos, Mies was not given to ostentatious architectural decoration but both men employed richly veined stone veneers (Kolarevic & Klinger, 2008). Their prominent use of stone, particularly that of the Barcelona Pavilion, honored not artistic ornamentation but the technological operations inherent in the perfectly polished stone (Kolarevic & Klinger, 2008). As such, the thin veneers that make up the Barcelona Pavilion screens not only display the characteristics of the stone, they also powerfully signify the new technologies surrounding processing of stone. They clearly exhibit the expressive potential of

Figure 10: Polished Onyx (opposite)

The highly polished onyx was both richly patterned and reflective. Photograph of the Barcelona Pavilion.

Figure 11: Immaterial Screens

A result of emerging technologies in glass production, these revolutionarily large expanses of glazing significantly impacted the architectural experience. Photograph of the Barcelona Pavilion.

innovations in machine driven processing enabling flawless planarity and reflectivity at architectural scales and with complete repeatability. These screens serve a crucial role in the architectural expression of the pavilion. Freed from the necessity to support other structures, the screens become experiential elements, objects in space rather than mundane separators and structural supports. These brilliant embodiments of emerging technology in architecture do not enclose space; as screens instead of walls they constantly refer to what lies beyond producing novel spatial configurations (Quetglas, 2001). Their perfect alignment and repeatability of their seams as well as the noticeable absence of any attempt to cover them up further glorifies their mechanized perfection. The reflectivity of the stone panels is used to great experiential affect. Kolbe's statue Sunrise is expanded by the polished marble surrounding it and those experiencing the Barcelona Pavilion in person experience a similar reduction (Quetglas, 2001). Far from being a default finish, the perfect machining and flawless polishing of stone is a crucial aspect of the Barcelona Pavilion's design. It is this detailed consideration of the potentials inherent in material qualities and emerging technological possibilities throughout the Barcelona Pavilion that engendered such a striking architecture of emerging technologies.

In the Barcelona Pavilion what would have been windows became screens of glass. This use of glass was revolutionary in both its material technology and it its architectural impacts. Compared to its architectural context at the time, both in Spain and abroad, windows in The Barcelona Pavilion were anything but traditional. Just as the concept of walls is expunged from the language of the Barcelona Pavilion, windows that are holes in walls are equally absent. Instead, an entirely new experience is presented, one of seamless connection between interior and exterior. While the concept of floor to ceiling glazing is now commonplace, the effect in 1929 was spectacular (Quetglas, 2001). What is less obvious though, is the fact that the technologies that permitted this spectacle of glass were as novel as the pavilion was.

Traditional windows were small because producing large expanses of flat glass, though possible, was extremely expensive, requiring a great deal of hand grinding and polishing (Pfaender, 1995). While some previous architecture had employed large expanses of glazing, it was often highly flawed and the effect was more akin to a 1800s English greenhouse than the mythical dematerialized architectural façade (Wurm, Peat, & Schwaigerm, 2007). The glazed screens in the Barcelona Pavilion, however, leveraged a newly developed mechanized grinding and polishing process to create large panes of glass with excellent optical qualities. The result was large, nearly perfect, panes of glass that were no longer objects, but portals. The incorporation of emerging technologies alone is not what made the Barcelona Pavilion such a suitable example of an undeferring; instead, it is the way in which Mies understood the potentials of glass and of this new manufacturing process and how both of these profoundly influenced his design. The glazing was heavily significant in the pavilion's representation of Germany as well. The pavilion's utter transparency represented the new openness, flawlessness and technological prowess of po[st]-WW1 Germany (Quetglas, 2001). The perfect appearance of this project was of such great significance that Mies doctored several of the official photos before distribution to disguise minor flaws (Quetglas, 2001). Glass was emblematic to the Barcelona Pavilion. Its profound impact significantly altered the concept of windows in architecture. As an architecture of emerging technologies this was not glass in a pavilion, but a pavilion of and for glass.

- 3.2 -
A Pavilion In Architecture

All architecture represents society but the most significant works also speak to architecture in general. This is especially true when an architect seeks to achieve a new form expression. Mies van der Rohe's commission demanded that he design a pavilion to represent a new era for Germany. As such, a new architectural style was fitting; a new architecture for a new country. The Barcelona Pavilion represented a number of new concepts for architecture. Though not without precedent, these positions were clearly defined through design and were unmistakably presented as oppositions to those that preceded it. Together these positions make up the Modern industrial ideal. The positions: binary oppositions repeated throughout the pavilion, the clear emphasis placed on grand singly optimized elements and the overwhelming regularity, were novel forms expression of architecture. These positions were enabled by emerging technologies. As this pavilion's primary expressive modes, these positions become the means though which the undeferring of emerging technology is communicated.

Figure 12: Binary Relationships

Photograph of the unforgiving edges and boundaries that delineate the binary nature of the Barcelona Pavilion.

- 3.2.1 -
Binary

The Barcelona Pavilion is a composition of binary states. Numerous absolutes are presented in the project, along with their opposites. The most immediately evident of these perfectly finite elements is the

podium, which is presented as a perfect plinth with even the stair concealed so as not to subtract from its purity. Standing in complete opposition to the podium is the abundant landscaping surrounding three sides of the site. In other, less rigorous, architectures of the time some interplay between nature and plinth may have been presented but in this pavilion there is no overlap or softness to the boundary. This absolute exclusion of nature became typical of Modern architecture but at the time it was in distinct opposition to the nature inspired forms of Barcelona's Modernisme[1] movement. The properties and conditions of elements within the pavilion were equally binary. No plane or screen was less than perfectly defined, no deviations from planarity were allowed, nor were any penetrations. As a result, spaces were finite, coverage completely present or completely lacking (Quetglas, 2001). The intent to create semi-defined outdoor spaces might have been realized by perforating the ceiling plane in places but this element, and all others, were inviolate. The binary nature of the Barcelona Pavilion expresses a very clear rationalism that subsequently became central to the Modernism whereas 21st – Century architecture opposes those strict ontologies.

21st-Century architectural thinking, recognizes that the rigidity inherent in binary states forgoes a great deal of possibility in design. Born, in part, of an age of scientific certainty and calculation, the ability to ontologically classify ideas and objects into singular states was powerful and productive sentiment during Modernism. However, society is increasingly recognizing that diametric binaries are no longer sufficient to describe our world. No longer novel in their ability to be executed precisely, binary oppositions in architecture now only highlight lost opportunities for interplay between conditions. 21st-Century architecture exceeds the absolute nature of edges and boundaries (Lally & Young, 2007). Reconsidering the Barcelona Pavilion in these terms greatly alters how experiential and formal elements would be presented. The inviolate water's edges, for instance, would become areas of flux between wet and dry. Rather than a finite condition, the perfect rectangles of water would be given over to varying depths and degrees of wetness. Doing so would entirely alter the relationship between the occupant and the previously infrangible water. Just as the Barcelona Pavilion defined the binary position,

1 Not to be confused with the Modern, or International, style of architecture, Modernisme was the Spanish art and architecture movement both similar to and concurrent with Art Nouveau.

so would its re-imagining posit a position of gradient conditions and flux.

- 3.2.2 -
Singly Optimized

The massive disassociation and specialization of building elements marks the second architectural position of the Barcelona Pavilion. This single optimization is both a clear representation of emerging technologies and a significant aspect of Modernism. Every piece of the Barcelona Pavilion is fully singly optimized in that it is not only functionally separate from every other, but also spatially removed. This had huge implications for spatial planning and experience in architecture. This pavilion, in opposition to other buildings of its time, presents separately all the elements that make it what it is: roof planes, columns, screens, the podium; even the chairs are each singly optimized, discrete entities. In the Barcelona Pavilion emerging technologies enable this expression. The optimization of each element is a highly technological process. Enabled by steel, the optimization of the structure is expressed in the columns and ceiling planes. Similarly, perfect expanses of glazing are the ultimate optimization and spatial disassociation of windows from walls. The concept that an element could be so perfectly refined and reduced to the point that it could perfectly perform a single function and no others is a quintessentially Modern industrial ideal.

Building assemblies in current architecture are the epitome of single optimization (Oxman, 2010). Every single architectural function is broken out into separate elements, each element is highly optimized and each attempts to achieve its primary function independently from the rest. The complete separation conflicts with minute interdependencies throughout the assembly leading to a multiplication in complexity. Single optimization is predicated on the concept that a single completely refined element is capable of serving its purpose better than one that serves many. The growing opposition to that concept posits that multiple optimizations provide synergistic opportunities for increased efficiencies and novel, unexpected functionalities (Ingber, 2010). A method of executing this new paradigm would be to modify the properties of existing materials in a variable manner, optimizing certain areas for stiffness or density and others for elasticity or transparency (Oxman, 2010). Composite materials could also be employed in similarly varying built up configurations to cater to different structural and programmatic requirements (Kolarevic, 2005). The shift to technologically advanced multiply optimized configurations of materials would dramatically alter the spatiality of current architecture. Just as the Barcelona Pavilion radically distorted

Figure 13: Single Optimization (opposite)

Photograph of the Barcelona Pavilion depicting the radical separation of building elements.

Figure 14: Regularity

Photograph of the unflinching regularity throughout the Barcelona Pavilion.

perceptions of architectural space, multiply optimized assemblies would reinvent the architectural experience.

- 3.2.3 -
Regular

Perfect regularity is the final Modern industrial ideal espoused in the Barcelona Pavilion. Throughout the pavilion various elements: columns, stone tiles, glazing mullions as well as screen and plane edges, repeat and align in exact regularity. The suppression of any visible connection detailing in favor of endless perfectly aligned seams serves to highlight this strict rationality. This was a highly staged expression of technology. Common to the Modern movement in general, this flawless regularity was seen as the height design expression but in the Barcelona Pavilion it equally espoused the precision of emerging technologies shaping architecture. Most obvious in the exactly identical and perfectly aligned floor tiles, it was recent developments in stone processing technologies that enabled the length, width and thickness of each tile to be exactly correct and infinitely repeatable (Kolarevic & Klinger, 2008). This technology reveals itself in an architecture of predictable repeatability and does not shy away from perfect alignment. This is distinct opposition to the traditional architecture that preceded this pavilion, which was often predicated on the large cumulative tolerances imposed by the variability in hand-produced elements. As with the other technologies conveyed in Mies' pavilion, the ability to have infinite identical machine produced elements was not employed to facilitate an outdated design paradigm; instead it was leveraged to create a fitting, novel, architectural expression. Minor elements that previously handled irregularity such as trims and reveals were superfluous because in this technologically driven Modern architecture there could be no imperfection. Whereas now, such seamlessness isn't as remarkable, the transition in the Barcelona Pavilion from slight yet prevalent and noticeable irregularity to completely ubiquitous regularity was extremely significant.

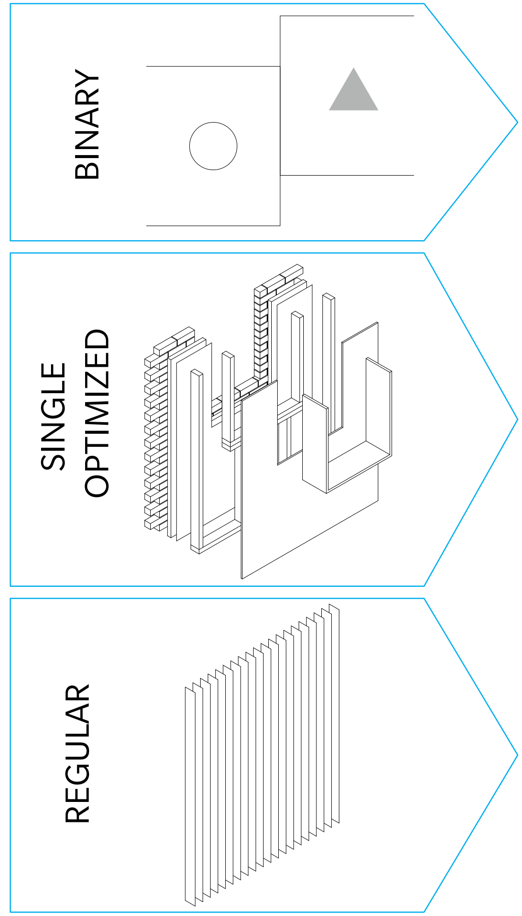
Like the overwhelming assertion of binary contrasts, attempts at flawless regularity represented a specific Modern view of the world. While the ability to execute this rationality may once have been seen as man and architecture succeeding in expressive perfection, it is clear that this achievement is very limited in its range. Regularity excludes the natural and thus the productive irregularities that abound in our environment. Whereas the Modern era saw perfection in regularity, 21st-Century design finds perfection, and inspiration, in nature (Ingber, 2010). An architecture that looks beyond regularity has the potential to recognize and capitalize on the opportunities that lie between, or beyond regular elements. Exactitude in architecture does not necessitate regularity, instead new design worlds are found in precise irregularity and continuously variable properties, spacings and elements (Mitchell, 2005).

- 3.3 -
A Pavilion In the Architecture of Material and Technology

Advances in material technology permeate and define the novel architectural expression of the Barcelona Pavilion. Emerging technology was not just a part of this building's production; it was a crucial aspect of the design and of the subsequent experience. Though the materials and techniques had been used elsewhere in previous architecture, their incorporation as design constituents engendered a series of novel effects and affects. Beyond simple facilitation, this level of integration and of powerful new expression highlight the Barcelona Pavilion as a prime historical example of the undeferring of emerging technologies. From this example becomes clear that the effects of emerging technology in current architecture are, as of yet, deferred and that the 21st-Century awaits its Barcelona Pavilion.

- 4 -
Project

The current growing application of emerging technologies in material processing and fabrication bound within with a design process that is blind to their expressive potential is analogous to the conditions that immediately preceded the Barcelona Pavilion. A coming shift will reconcile the fullest expressive potentials of old and new materials enriched by emerging computation and fabrication technologies by repositioning them as drivers of design. This undeferring will radically reinvent the way architecture is created and experienced in the same way that the Barcelona Pavilion did. However,



a design that considers only material and fabrication opportunities inevitably leads to, at best, a proto-architectural result. The Barcelona Pavilion exemplifies the blending of a traditional set of design considerations with the inclusion of material and technological considerations. This pavilion expressed emerging technologies through specific architectural positions: binary opposition, single optimization and regularity. In turn, those technologically enabled positions

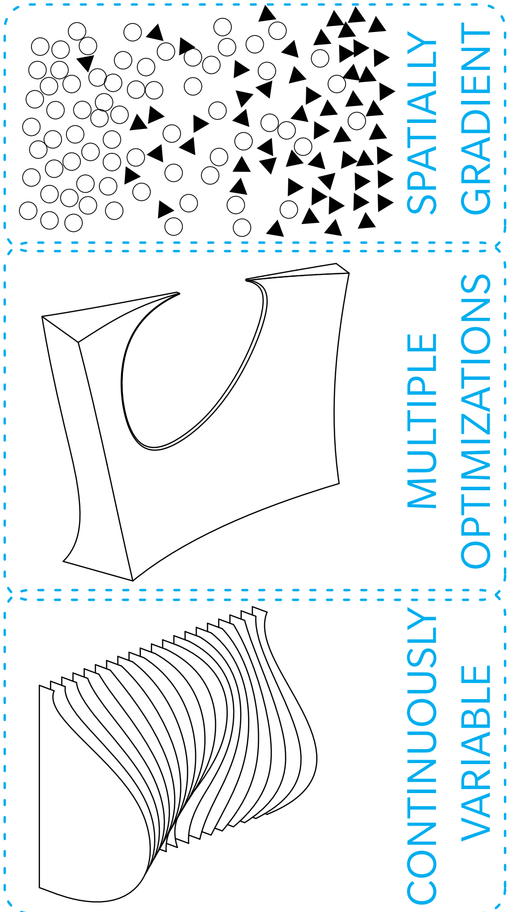


Figure 15: 21st-Century Positions

shaped an entirely new architectural style.

A 21st-Century undeferring of emerging technologies in material processing and fabrication demands a much needed inclusion of these innovations among the other core constituents of design. The selection of materials and their configurations must be part of a reciprocal design process that allows these aspects to influence the potential spatial and experiential conditions and for those considerations to effect the material treatments in return. This process will result in a pavilion whose novel expression will be intrinsically linked to these emerging technologies while still achieving an appropriate well-rounded architecture. Like the Barcelona Pavilion, the emerging technologies interact with basic materiality and will be expressed and shaped by three ideals or positions. Contrasting their Modern precursors, 21st-Century positions would be: spatial gradients, multiple optimization and continuously variable environments. The concept of spatial gradients seeks to exceed the limited scope of the binary elements of the Barcelona Pavilion. In doing so, spatially gradient design defocuses finite concepts such rooms and program in favor of the potentials of blurred interfaces and gradations of characteristics. As the characteristics of architectural space blur so will the optimizations of its constituent elements. Multiple optimization finds new realms for expression and efficiency in reconsidering the roles and potentials of material and technology in architecture. Finally, the concept of continuous variability continues the integration of emerging technologies into an expressive language that eschews regularity for precise and productive irregularity. Separate elements and separate states are merged and reimagined as a singular composition of constant becoming. As proven by the Barcelona Pavilion, technologically enhanced material properties can be powerful means of defining the experiential environment. Spatial gradients, multiple optimization and continuously variable environments will likewise guide the expression of emerging technologies.

The Barcelona Pavilion revolutionized the expression of glass in architecture. Using the same site and podium the Glassroom Pavilion will revolutionize glass in architecture again. Mies' revolution was entirely enabled by new technologies in glass and through their application as drivers of design the resulting architecture undeferred the expressive potential of glass. Despite their powerful application, however, at that time glass technologies were very limited. Technology has progressed significantly since 1929 and current emerging technologies in glass suggest, once again, a radical new expressive potential. The Glassroom Pavilion will incorporate the near-future advent of computer controlled, freely reconfigurable moulds, increases in the scale and material pallet of additive fabrication technologies and the potential to alter material qualities at micro scales to substantially expand the role of glass in architecture. A 21st-Century undeferring of emerging technologies in glass would acknowledge the powerful potential of glass technologies as a driver of design to revolutionize architectural expression, as the Barcelona Pavilion did before it. The result will be a pavilion solely of glass, employing spatial gradients, multiple optimization and continuous variability to express the possibilities and undeferring of emerging technologies.

- 5 -
Glass: Immateriality Materialized

Though flat glass has been used for more than 2000 years modern glass use begun in 19th century greenhouse architecture (Bos, Louter, & Veer, 2008). Used then for pragmatic purposes, glass became the emblematic material of openness and in contemporary architecture; immateriality (Bos, Louter, & Veer, 2008). The Barcelona Pavilion was a significant step toward realizing the architecture of immateriality in glass. Glazing in Mies' pavilion was more than simply a material strategy displaying impressive effects. In *Fear of Glass* Josep Quetglas argues that this material is one of the most significant aspects of the Barcelona Pavilion because it is leveraged to stimulate a specific experiential affect (2001).

- 5.1 -
Modern Glass

The design of the Barcelona Pavilion is predicated on the careful and explicit materialization of binary oppositions, single optimizations and regularity but the reflectivity of glass is devastatingly employed to disrupt those rigid ontologies. The reflectivity of large expanses of perfectly polished glass was frighteningly new at the time the Barcelona Pavilion was unveiled, leading to descriptions likening it to a carnival house

of mirrors (Quetglas, 2001). The affect of the perfect reflectivity was startling. It gave the glass a limitless depth and in those ever changing reflections the glass collapsed the regularity and blended the binary elements that existed so cleanly beyond the pane. Tinting certain areas of the glazing black exaggerated the reflectivity by eliminating transparency. This left nothing but a screen that collapses its context into reflections. Beyond a fascination with the reflective qualities of glass, Mies' work showed a grander interest in the material. His curvilinear glass skyscraper belied a desire to expand the architectural effects of glass beyond planar screens. Mies saw potential in the revolutionary material what was plate glass that could not be realized at the time due to technical reasons. As is the nature of glass, no matter what Mies achieved in the Barcelona Pavilion more lay beyond, through the Glassroom.

- 5.2 -
21st-Century Glass

Glass has not experienced the dramatic advances in material technologies that other common building materials have. Wood, steel and concrete have been radically reimagined in the past thirty years. New processing technologies have shifting wood and steel from standard sections to high performance unique custom

elements while new formulations and form technologies in concrete have allowed for the creation of stronger thinner shells, light transmission and a new plasticity. Glass is not without technological advances but the majority have not applied to architecture. Different atmospheric gasses used on the float glass production line and chemical tempering have produced astonishingly thin and strong rolls of glass for use in cell-phone screens while flexible glass cables abound (Detail Magazine, 2013) but these advances have yet to be architecturally significant. Architectural glass, on the other hand, is not evolved far from the revolutionary material Mies used. Float glass is more

Figure 16: The Revolutionary Experience of Modern Glass (opposite)

Photograph of the Barcelona Pavilion at night.

Figure 17: SANAA's Toledo Glass Museum

Single curvature and the relatively unchanged expression of glass.

than sixty years old and its expression in architecture has not significantly changed (Pfaender, 1995). Windows have changed, technological advances have created larger, lighter, better performing glazing units but the glass itself is no different. Expense and other challenges have relegated the majority curvature in glass to single arcs, used repeatedly to amortize the mould cost (Wurm, Peat, & Schwaigerm, 2007). Structural applications of glass have been the only area of significant architectural innovation (Wurm, Peat, & Schwaigerm, 2007). Enabled by advances in tempering and laminating structural glass is a new expression of glass in architecture but majority of its applications are neither novel nor are they expressive of the potential immateriality of glass (Wurm, Peat, & Schwaigerm, 2007). Often the most impressive part of structural glass are the connections and laminated into massive elements, the frailty of glass becomes a gimmick rather than exhibiting the magical qualities, simultaneously reflecting and projecting, of being and not being.

Despite its age, glass remains a fascinating material because of its unique properties. Unlike even glass-like plastics, during formation glass cools with no grain or directionality whatsoever, rendering it truly monolithic and isotropic (Wurm, Peat, & Schwaigerm, 2007). This property does not change as glass is reheated meaning that, barring any reduction in dimensions, curved glass is equally strong at a molecular level as planar glass (Pfaender, 1995). Unlike other transparent materials, any thickness of glass remains nearly completely transparent and its stunning reflectivity at shallow angles continuously reinvents its appearance. Though its brittleness necessitates overcompensation in multiple laminated layers in structural applications, glass is an extremely strong material. The practical compressive strength is of glass, 50kN/cm^2, is double that of steel and twenty-five time higher than concrete (Wurm, Peat, & Schwaigerm, 2007). Flaws in the surface can greatly reduce that number but tempering and laminating ameliorate this issue to a certain extent (Wurm, Peat, & Schwaigerm, 2007). Visible light attenuation increases due to the additional internal reflection. Practically, this indicates that, given enough layers of glass, no transparency would remain and the assembly would appear green if it were plain float glass (Wurm, Peat, & Schwaigerm, 2007). All of these qualities suggest a vastly different expression of glass in architecture than is currently exhibited.

- 5.3 -
A Pavilion In Glass

The concept of a purely glass structure is not necessary novel from a material

Figure 18: Laminate House
Photograph of Laminata House

Figure 19: Laminata House Construction
Conventional architecture rendered in laminated glass

Figure 20: Fluid Fascination

One of several glass slumping excises intended to explore the characteristics of curved glass as part of projective research regarding expressively and structurally novel glass systems. These tests were undertaken at Harbourfront Centre, Toronto with the assistance of glass artist Steven Fassezke.
For further photos see Appendix A

standpoint but previous attempts have fallen short of the full expressive potential of glass. Kruunenberg Van der Erve Architecten's *Laminata House* advances the discourse on reimagining glass in architecture and while the result is spectacular, it is predicated on a singular expression of a single property of glass. Furthermore it is still, architecturally speaking a Modern house. This building exhibits none of the revolutionary new expressions of architecture that the Barcelona Pavilion did with glass eighty-five years ago. While it is very striking, the *Laminata House* and other laminated glass projects like it fall short of revolutionary architectural expression because they are predicated on applying glass to conventional architecture.

Glass is a challenging material to employ in any configuration beyond simple windows. Convoluted fabrication techniques and challenging structural constraints paired with unique optical and performance characteristics as well as promising near-future advances in glass create a fertile ground upon which the Glassroom Pavilion will undefer the material technologies at hand. The pavilion will powerfully express the emerging technologies in glass processing and fabrication in an architecture shaped by the 21^{st}-Century positions.

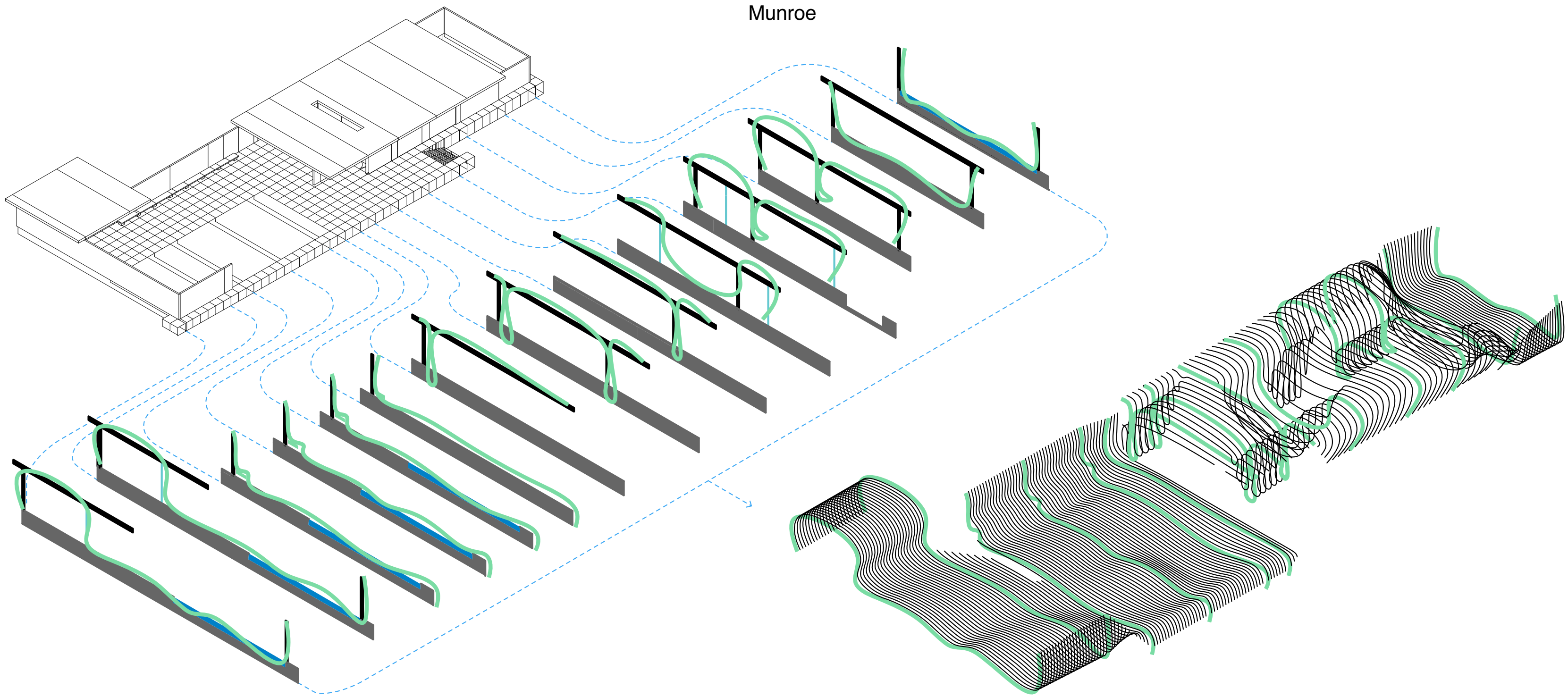


Figure 21: The Glassroom Pavilion (above)

Render highlighting the way in which the curved glass profiles are enlivened by the reflections and refractions of the lush greenery beyond.

Figure 22: Barcelona Pavilion: Sectional Analysis (opposite)

Each geometrically pure section is reconstituted with single line that incorporates the same spatial effects of the original configuration in an irregular manner. A surface interpolated through these curves is understood as multiply optimized as it incorporates all of the spatial considerations of the original sections while inducing a new smooth mixing of conditions between sections.

- 6 -
The Glassroom Pavilion

- 6.1 -
Planarity

Infinitely differential curvature is the future of architectural glass.

- 6.1.1 -
A Pavilion in Section

A spatially gradient, multiply optimized and continuously variable reading of the Barcelona Pavilion begins with a section interpretation. With the goal of capturing the various states of enclosure and isolation present in the original pavilion, a number of transverse sections are assessed. Each section abstracts a moment in the pavilion, removing it from its context and, in doing so, reduces that moment to its primary geometric elements. These sections uncover the vital relationships between celling plane and podium, external and internal screens as well as general internality and externality. In doing so the resulting compositions reveal the binary and singly optimized nature of the rational geometric elements. Despite the section frequency being such that each geometrical move in

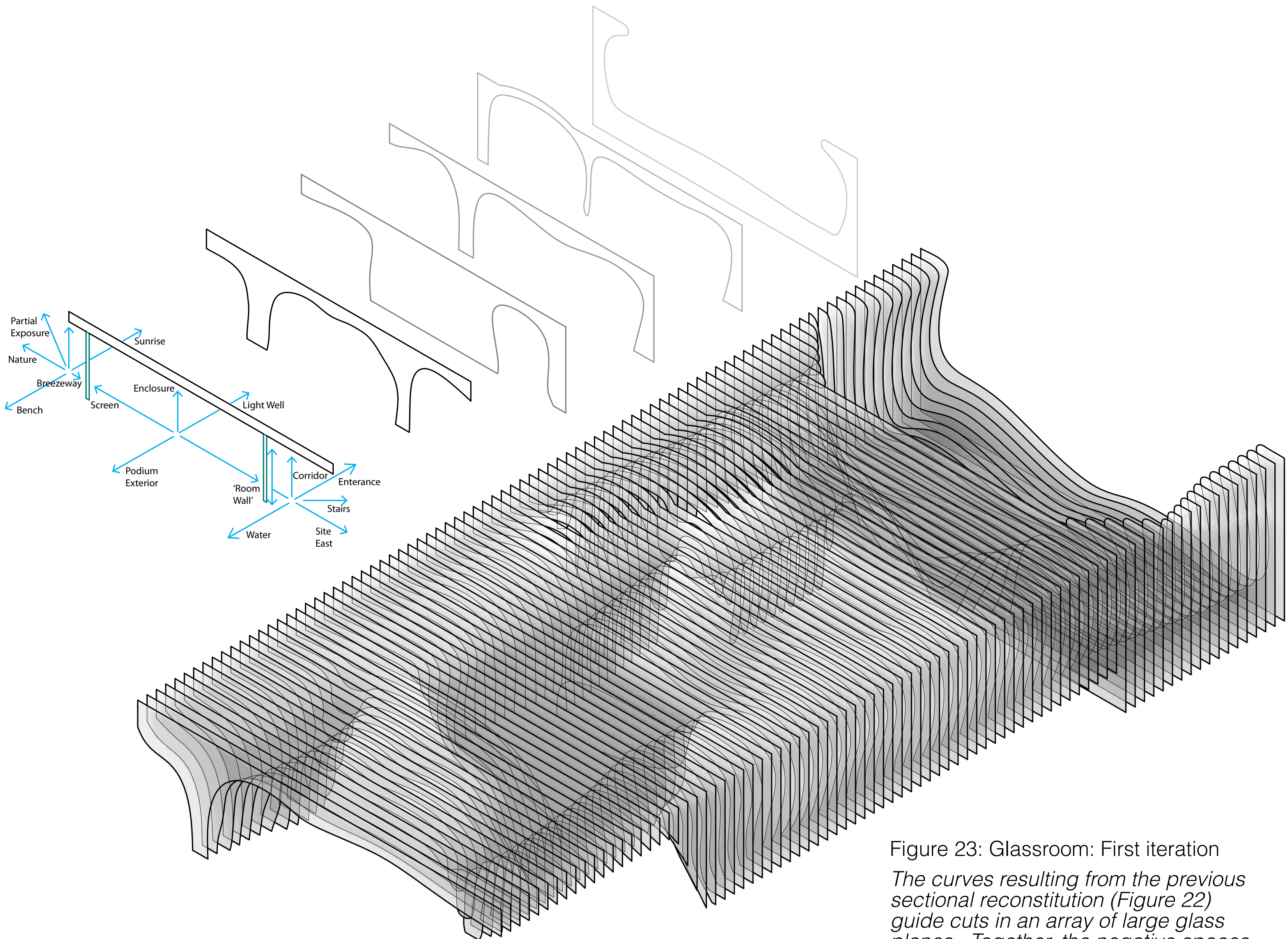


Figure 23: Glassroom: First iteration

The curves resulting from the previous sectional reconstitution (Figure 22) guide cuts in an array of large glass planes. Together, the negative spaces of each plane define new interior spatial characteristics.

the Barcelona Pavilion is captured, the hard cartesian edges reveal the finite nature of its spatiality. These sections are one of the primary means through which the reinterpretation of the Barcelona Pavilion takes place. Two sets of information are gleaned from the sections. The first set is that of the Pavilion's geometric characteristics and the second is that of its spatial conditions.

Rather than reading the sections as sets of geometrical elements, an inverse analysis focuses on the white space between the geometry. Even when not vertically demarked, these programmatic edges are highly defined and movement between each section becomes a disjointed series of relocations. Discarding the hard edges of these zones, one is left with spatial characteristics alone. Returning these spatial characteristics to podium of the Barcelona Pavilion, the 'site,' the resulting non-binary assemblage of conditions is re-specialized. Like the Barcelona Pavilion, the concept of program in the Glassroom Pavilion is supplanted by a set of spatial conditions. Unlike Mies' pavilion, these spatial characteristics are not read as finite elements. Instead, these sectionally derived characteristics are taken together to form a set of experiential characteristics. No longer disjointed, the characteristics flow from one to the next, forming a field of conditions. Whereas the Barcelona Pavilion was experienced as a collection of spatial states, the Glassroom Pavilion is a gradient of conditions, each moment constantly becoming the next.

The singly optimized and highly regular natures of the Barcelona Pavilion are present most visibly in the geometry. The initial sectional deconstruction bear out this truth, whereas a similar analysis of a multiply optimized and productively irregular pavilion would look significantly different. While the sections in the Barcelona Pavilion display the distinct screens, ceiling planes and glazing they equally reveal the complete lack of interplay between them. Ground and ceiling planes may never touch and screens span the two completely, never falling short and never exceeding. This Modern composition denies the opportunity for interplay between the elements but a post-modern multiply optimized section would be far more given to expressing links, synergies and shared proximities. Given the additional notion of continuous variability these sections are reimagined into a single curve that comprises all the functions of the multiple elements that preceded it. Given the origin of the section its companion curve might comprise full or partial overhead enclosure, horizontal separators, glazing, ponds or, in true multiply optimized form, seating the single hard programmatic element of the pavilion. As with the spatial characteristics, this collection of curves is recontextualized on the podium. Individually these curves are still finite moments but, in order to visualize of the value of the space between them, a surface is interpolated through the curves, linking them into a single element that incorporates all of the functions of the original disparate features. Together with the field of spatial characteristics, this surface describes a continuously variable interpretation of the Barcelona Pavilion while retaining its original where they do not conflict.

The interpolated surface is, at this stage, simply a three-dimensional representation of spatial functions. While the Glassroom Pavilion is predicated on this continuously variable and multiply optimized surface, its expression is more involved. As a diagram, this surface lacks construction logics and simply an enclosure of space like a typical building. Reproducing this surface directly would be the epitome of geometrically driven design. Instead the intended spatial characteristics and functions represented by the surface are intersected with the properties and potentials of glass to move from a simple diagram of space; to architecture. Though any sheet material could be wrangled into the geometry of the continuously variable surface, the result would in no way be related to the material properties, especially not if that sheet material were glass. Instead of attempting to construct the surface directly, its intent solely as a signifier of space is rendered

architecturally by defining the overhead areas as a series of voids in large planes of glass. Employing waterjet cutting to carve out the cavities in this horizontal array of glass while maintaining the rectilinear exteriors formally reconciles the swooping continuously variable surface with the orthogonal Barcelona Pavilion.

The material properties and potentials of glass react in a highly productive manner in relation to the field of spatial characteristics and the multiply optimized and variable formal aspects. Though each of the unique glazed panels arrayed along the pavilion is transparent, their multiplicity blocks sight along the podium's length. In doing so the profiles incite movement throughout the pavilion as every step taken alters what can and cant be seen ahead. The reflectivity of glass plays into this sense of discovery as well, providing constantly changing glimpses to the lush nature beyond the podium. Together the gradually shifting interior profiles create an implied texture. From any point within the pavilion, due to the nature of glass, the nearby profiles are visible more as a collection of edges, of thick green ribbons. While the shapes carved out from inside the planes define the spatial and formal characteristics of the pavilion it is the properties of glass and the enabling technology of water-jet cutting that engender a novel architectural expression.

Given the desire to expand the limits of glass, the profiles are sized to be cut from a single, seemingly impossibly large pane of glass. From a processing standpoint, however, this is not as difficult as it seems. The height to the top of the profiles above the podium ground plane is equal to the useable maximum width of current float glass production lines. The production of panes of glass equal to the transverse length of the podium is unusual, but not unheard of (Wurm, Peat, & Schwaigerm, 2007). Given that float glass is produced in a continuous ribbon to be resized later, the maximum length of piece of glass produced on modern float glass lines far exceeds those proposed here (Pfaender, 1995). The full profiles in the Glassroom Pavilion would consist of two 8mm outer layers and one 22mm inner layer, all tempered then joined by a standard PVB lamination process for additional strength and safety. The resulting panel would then be transferred to a CNC waterjet table to cut out the interior shape of the profile. A waterjet is the ideal means of cutting the profiles since it does not create a weakened HAZ (heat affected zone). around the cuts (Wurm, Peat, & Schwaigerm, 2007). Though a very large machine would be required to cut the whole sheets, CNC machines of this size are common in the aeronautical and shipbuilding industries (Kolarevic, 2005). Setting aside, for the moment, the need for a secondary structure, the technologies exist currently, to create this momentous work of glass.

Despite its ambition in the application of glass, this design iteration is still predicated on fifty-year-old technologies. The profiles, while strong enough to resist gravity loads would still be vulnerable to the torsional loading imposed by wind and the cantilevered areas. The concept of horizontally arrayed profiles is a fascinating reinterpretation of how glass can perform experientially but the result is still not the spectacular undeferring of 21st-Century emerging technologies as drivers of design. Furthermore, while the profiles successfully express elements of the continuously variable surface and multiple optimization, the manner in which they do so is still quite regular. This design, so far, is an evolutionary step from the *Luminata House*, not a revolutionary one. This regularity as well as the unresolved structural issues suggests that further iterations could leverage the experiential success of glass driven by its materiality while attempting a more holistic structural resolution.

- 6.1.2 -
A Pavilion in Plan

The experiential characteristics suggested by the horizontally arrayed planar profiles have been, up to this point, strictly sectional in nature. While those are

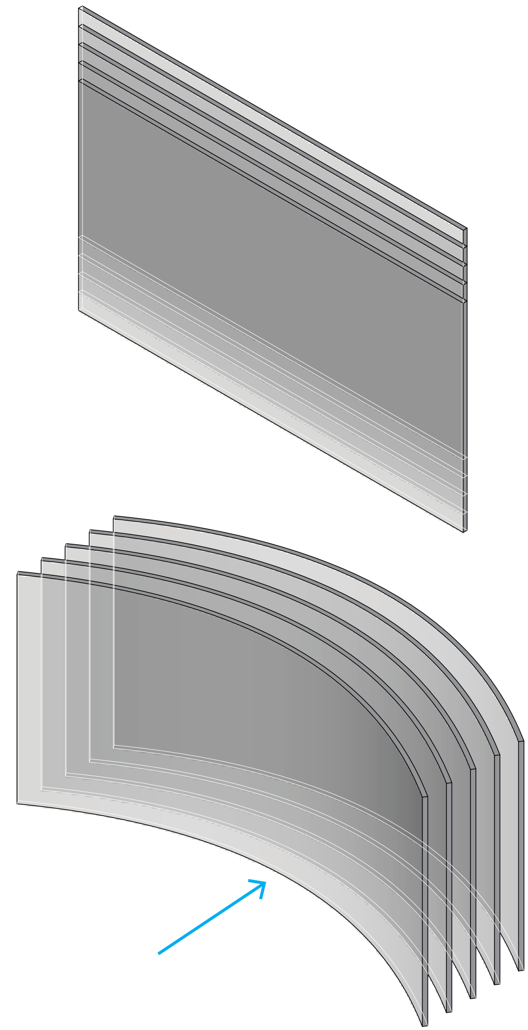
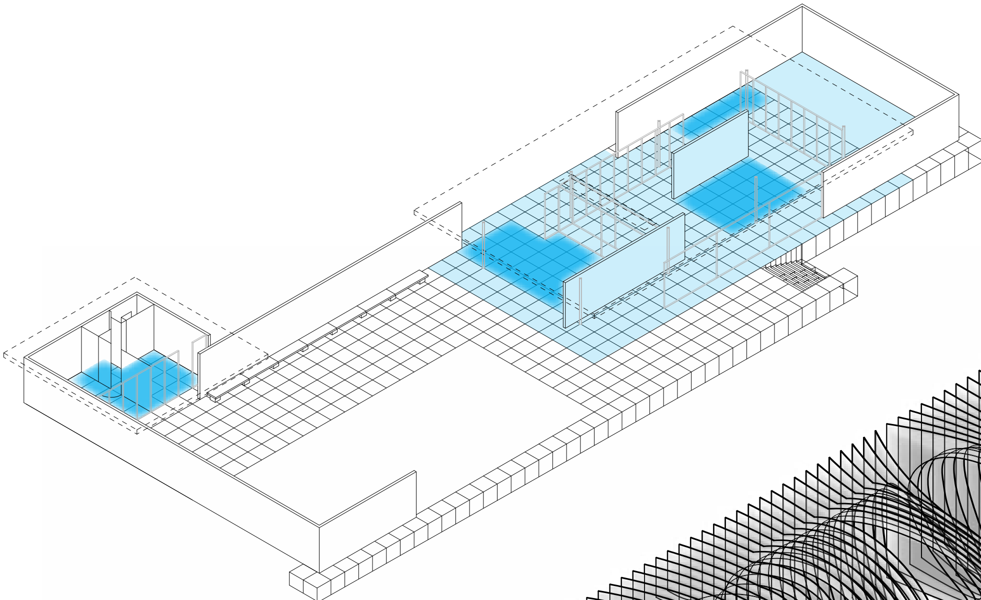


Figure 24: From Planes to Single Curves

The second iteration of this portion of the pavilion explores current single curvature techniques.

Figure 25: First Iteration study Model (opposite - both)

Acrylic planar profile study model (scale 1:50), constructed and photographed to examine the aggregate effects of the 86 layers.



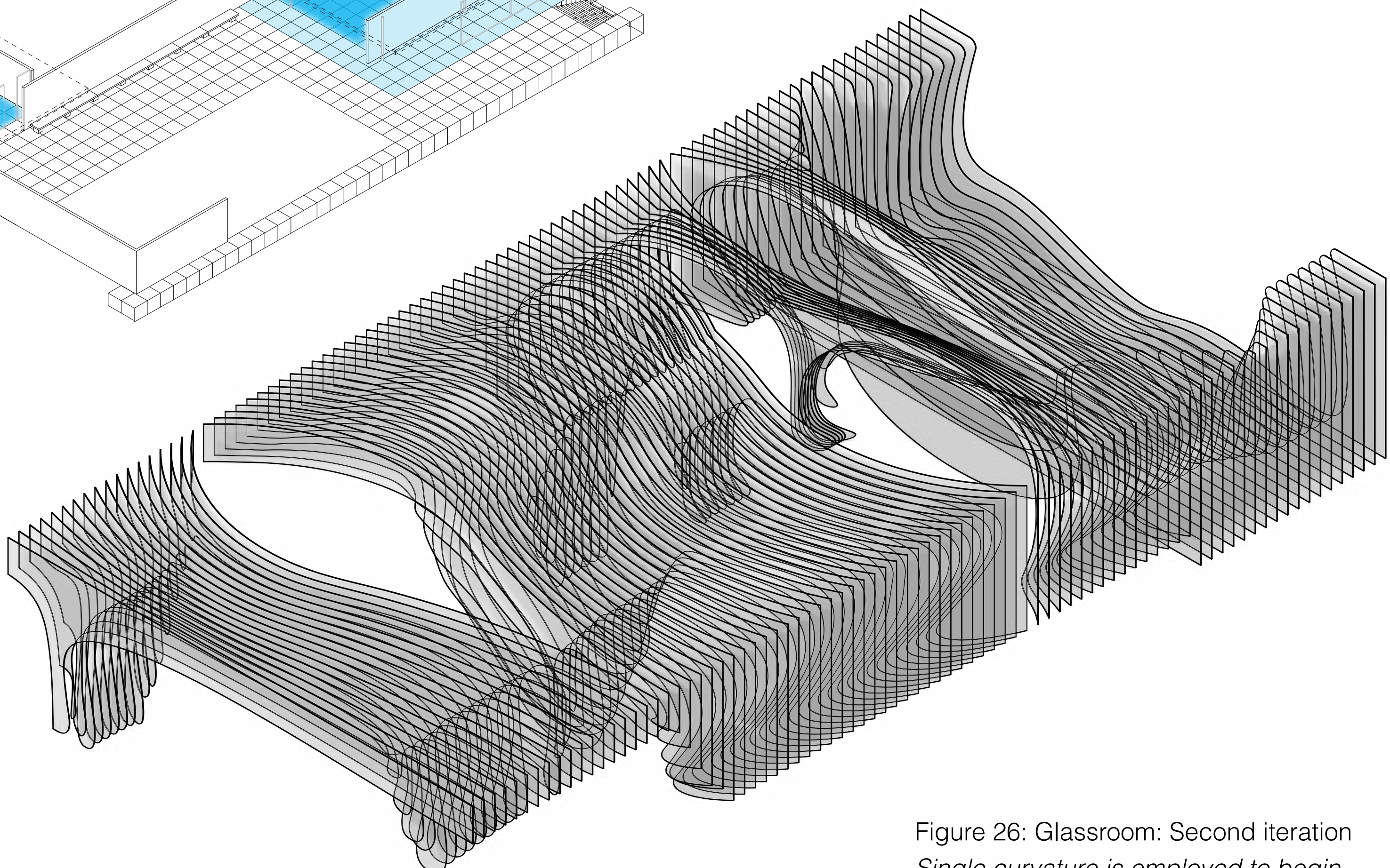


Figure 26: Glassroom: Second iteration

Single curvature is employed to begin to differentiate spaces within the spatial continuum.

powerful effects, one shortcoming is that no additional significance is given to the areas that the desired spatial characteristics suggest are more significant. While the conditions are gradient throughout the pavilion the significance of those conditions may still vary. Functionally this equates to the dominance of certain zones above others in the field of conditions. While this differentiation is desirable, these areas are not any more or less recognizable from those that flow between them. In the initial iteration this is due in part to the strictly sectional analysis and the fact that it was an exercise in geometry and whitespace, temporarily ignoring planographic interpretations as well as the site characteristics. This previous iteration also ignored a significant aspect of glass production, the ability to create curvature without reducing structural capacity or reducing optical quality.

A plan analysis of the quasi-programmatic spaces defined by the Barcelona Pavilion depicts several significant areas. The 'throne room' where the official opening of the German contribution to the Barcelona World Fair took place is of obvious significance as it is the only traditionally programmed space (Quetglas, 2001). Prominence is lent to this space not only though is formal qualities but also through its material expressions. The screen that forms the backdrop to this room is the only one in the pavilion that is clad with onyx. Several other adjacent spaces are created as well under the large roof plane. Though the sectional analysis describes the relative enclosure of these spaces in the amount and character of the occupiable space beneath the profiles, it fails to highlight these areas as variant in comparison to the conditions surrounding them. Rather than define these spaces in a finite manner as Mies did, the Glassroom Pavilion attemps to modulate the spatial conditions in these areas so as to highlight them in a gradient manner. The intent is for these areas to be blurry zones, rather than tightly defined rooms.

In order to emphasize the 'rooms' in the Glassroom Pavilion the previously planar profiles are pushed and pulled in plan to create a series of openings. The intent is for these openings to gently fade in and fade out of the otherwise rhythmic profiles. This way, prominence is given to these areas without the determinate edges employed by Mies. The accumulation of glazing overhead obscures the sun enough to case a considerable shadow across the podium and despite certain areas having deeper spans, the shading is relatively constant. The open areas then, are brilliant opposites, open to a far greater range of the sun's path. These areas provide a gradual increase in illumination that tacks the sun throughout the day. Given the warm year round climate of Barcelona and the loose programmatic constraints this pavilion

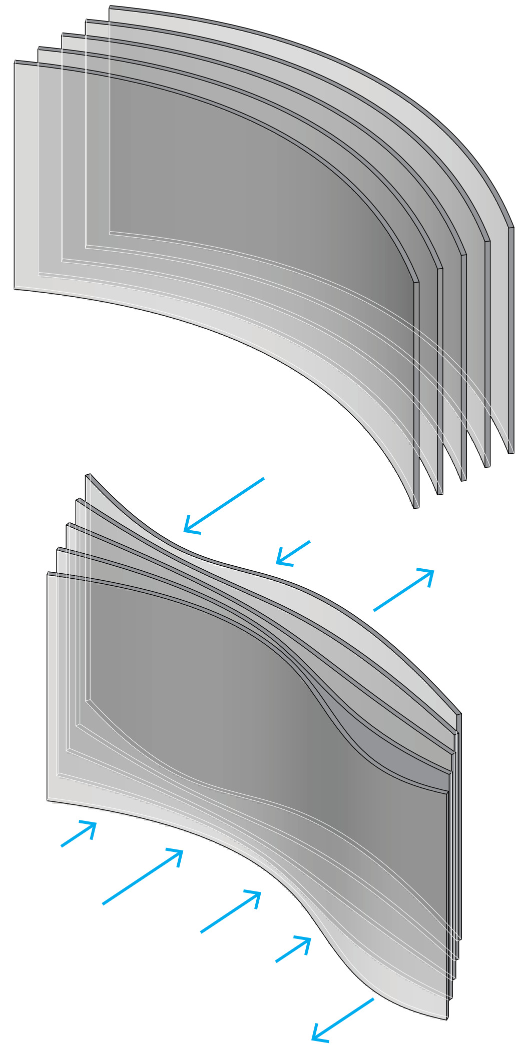


Figure 27: From Single Curves to Unique Curves

The final iteration of this portion of the pavilion explores the expressive potential of near future techniques for glass forming, allowing multiple curvatures on a single pane as well as unique curves for each panel.

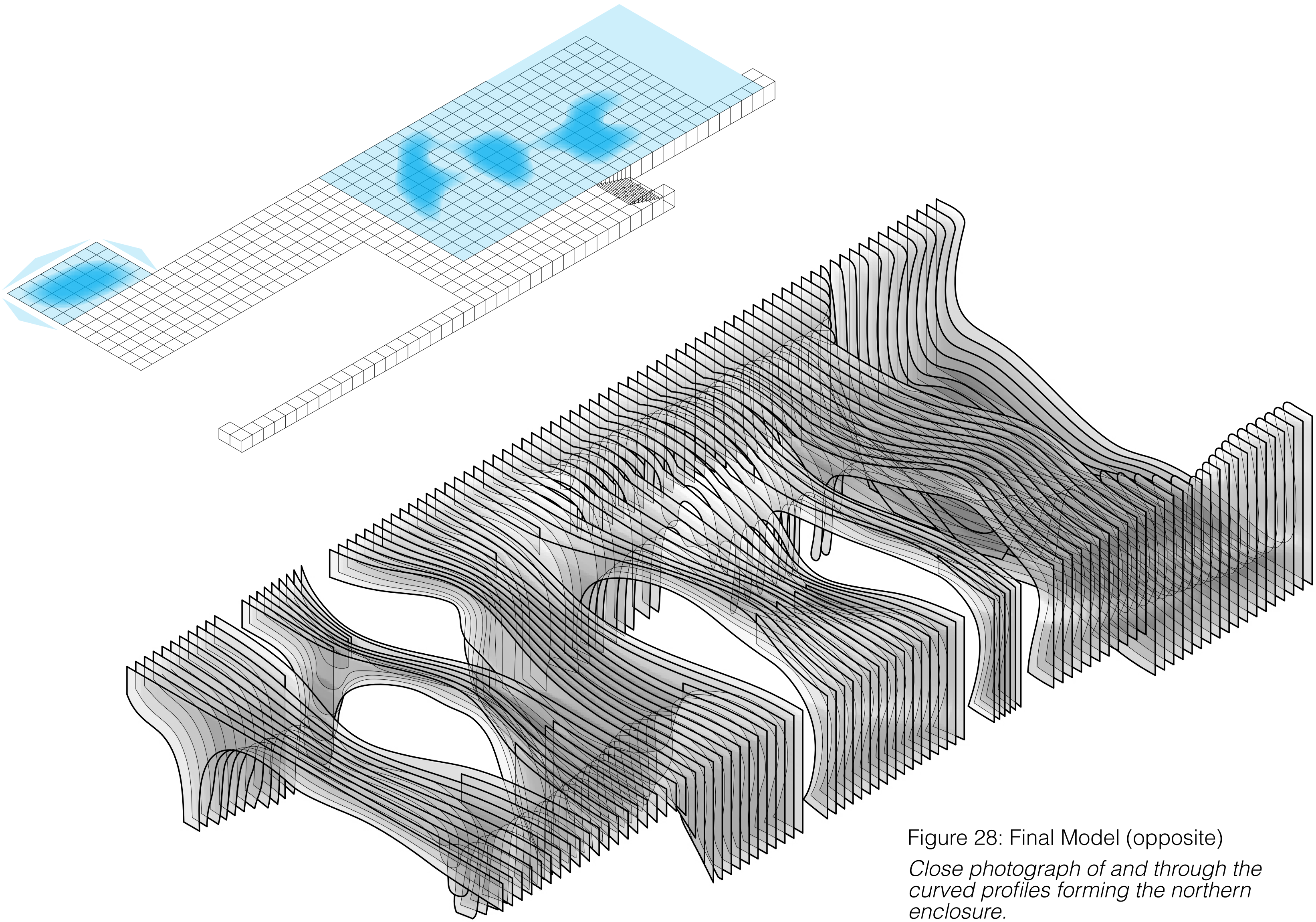


Figure 28: Final Model (opposite)

Close photograph of and through the curved profiles forming the northern enclosure.

Figure 29: Glassroom: Third Iteration

Infinitely differential unique curvatures blur the edges of the 'rooms'.

reconsiders the binary insideness of the Barcelona Pavilion's opaque overhead enclosure. Instead, these profiles generate variable shading, including a brief moment of extraordinary illumination as the sun passes directly overhead. The resulting environment is tempered by the shading glass and open between each profile for cooling cross-ventilation.

The global curvature in the profiles also serves a distinct structural purpose but current forming technologies limit this implementation. As it does in automobile glass, inducing the minor arc shapes in the Glassroom Pavilion's profiles would increase their resistance to lateral loads over a completely planar configuration. Currently, the architectural application of curved glass is limited by the manufacture of the moulds. Single use moulds are typically machined from large blocks of foam that are then used as positives moulds to cast the final negative shape for the glass to slump into. These cast negatives are delicate though, and moulds intended for repetitive use are typically created out of stainless steel, further increasing the complexity of the process (Bos, Louter, & Veer, 2008). The expense of these moulds severely differentiates curved glass design from strictly planar glass, this demands that the majority of buildings employ only a single curvature throughout their design in order to amortize the additional cost. Following their creation the waterjet cut glass is layered, but not bonded, in the desired configuration on the mould. The panes are heated and slump into the form together so that the curvatures match (Wurm, Peat, & Schwaigerm, 2007). The glass tempers during the slumping process and after being annealed, the panes are laminated as usual (Wurm, Peat, & Schwaigerm, 2007).

The expressive potential of curved glass is well demonstrated by the SANAA's pavilion at the Toledo Museum of Glass. This pavilion cleanly executes a curvilinear plan in floor-to-celing glass without the visual distraction of mullions. While this is an impressive exercise in realizing a specific geometry in glass, it is not the fullest expression of glass and its attendant emerging technologies. Though glass is an important aspect of the design, its material characteristics are still holistically leveraged. The glass still serves only as a singly optimized separator. Leveraging its potential as a structural system as well would have significantly advanced the expression of glazing but regardless, SANAA's pavilion was geometrically driven and it made use of glass, rather than it being enabled by glass.

- 6.1.3 -
A Pavilion in Perspective

The ultimate application of planar glass for this portion of the pavilion incorporates the concepts of continuously variable environments in the accumulation of profile shapes and spatial gradients by way of planographic openings in those profiles. The final consideration is fully predicated on emerging technologies in glass slumping and applies those technologies to differentiate the open areas by relating them to the site, refine the structural system and to further induce a productive irregularity. By exceeding the limitations of a single planographic arc shape in each profile this scheme allows for multiple curvatures within each profile and an infinite number of curvatures throughout project, rather than a single set of curves defined by a few expensive moulds. While the sectional geometry of each profile remains the same, their curvature in plan is reimagined as a parametric response to the open areas. Those areas repel the profiles and result in a set of curved profiles that are products of these forces. This expression of the spatial characteristics of the open areas is easily readable in the resulting geometry, the shapes resonate as logical curves that might result from interacting ripples in water, or in iron filings repulsed by a series of magnets. This readability by the Glassroom Pavilion's visitors establishes a rapport, an

Figure 30: Murky Glass

Rendering of one of the 'rooms' defined by the planographic curvature in the glass profiles. This image also depicts the aggregate shading effects of the glass profiles.

Figure 31: Nature Through Glass

Final model (scale 1:50) photograph depicting the way in which the glass profiles both highlight and are coloured by the surrounding greenery.

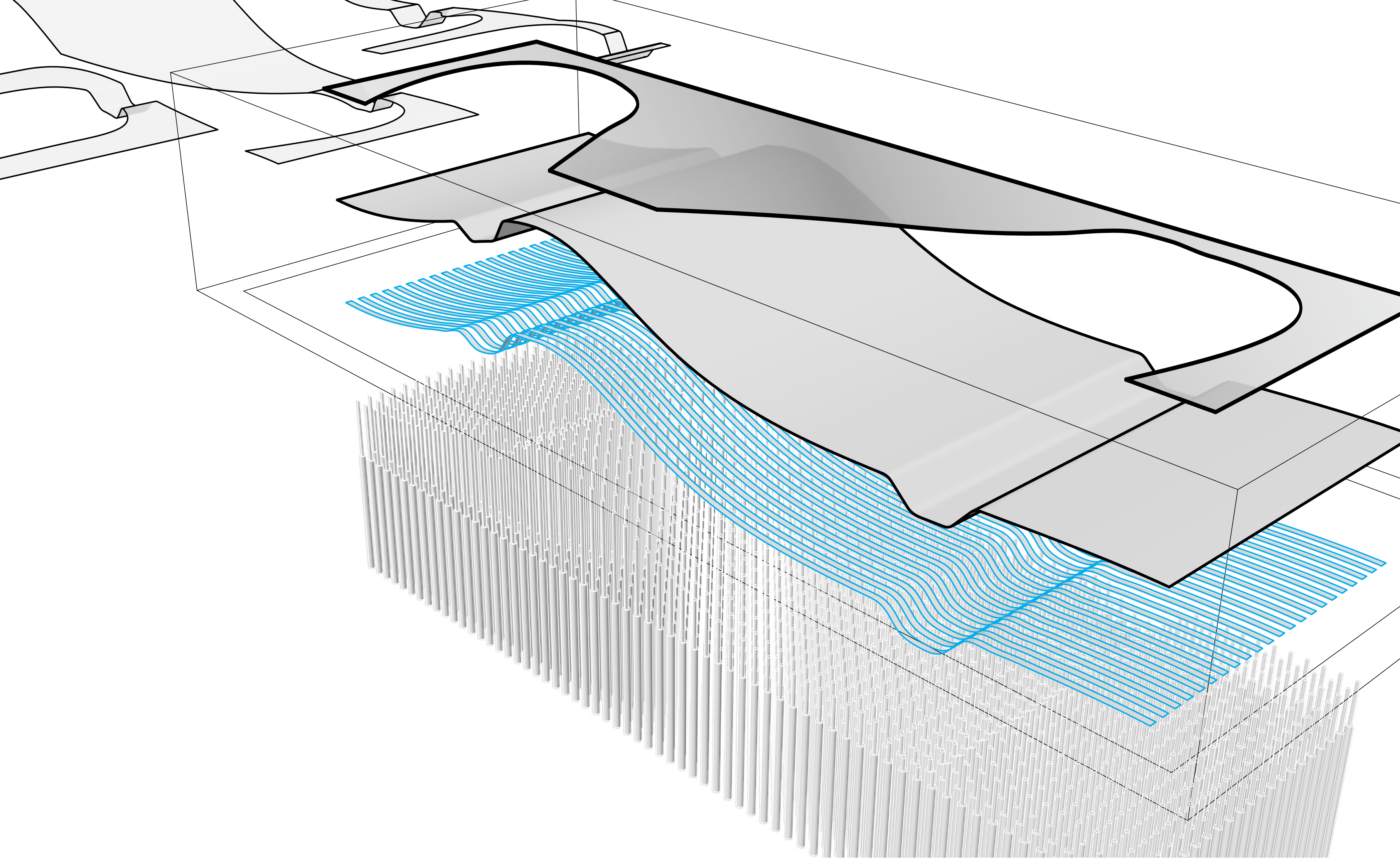


Figure 32: CNC Mould Concept Image (top)

Diagram of the primary components of a theoretical CNC glass forming mould capable of producing unique out-of-plane curvatures with each precut glass profile.

Figure 33: CNC Mould Precedents

North Sails' CNC mould (bottom right) and McGee, Newell & Willette's glass manipulation kiln (bottom left).

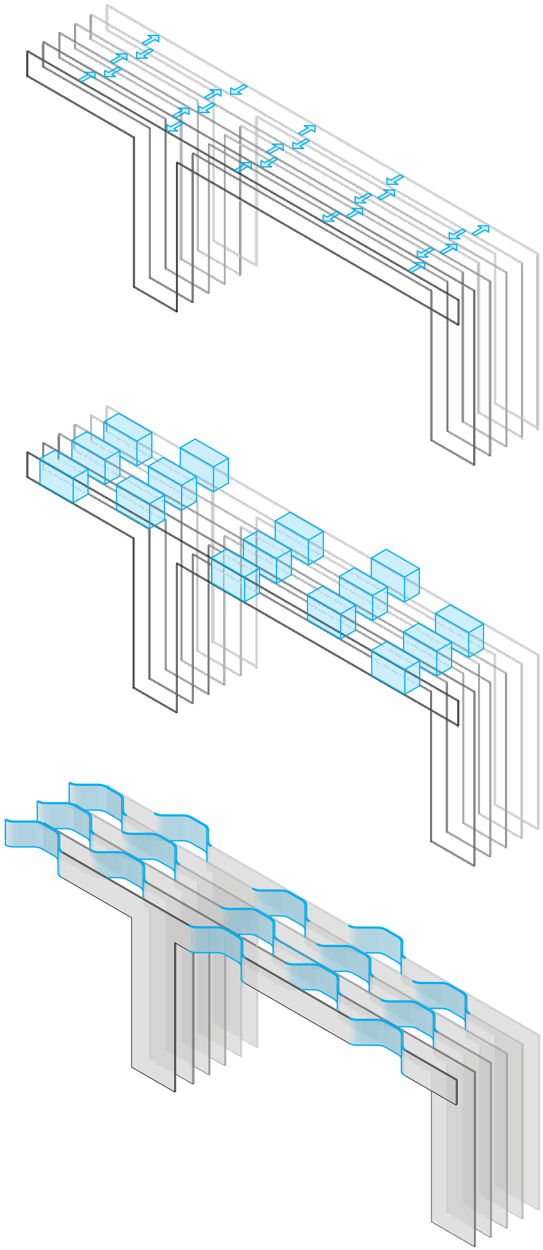


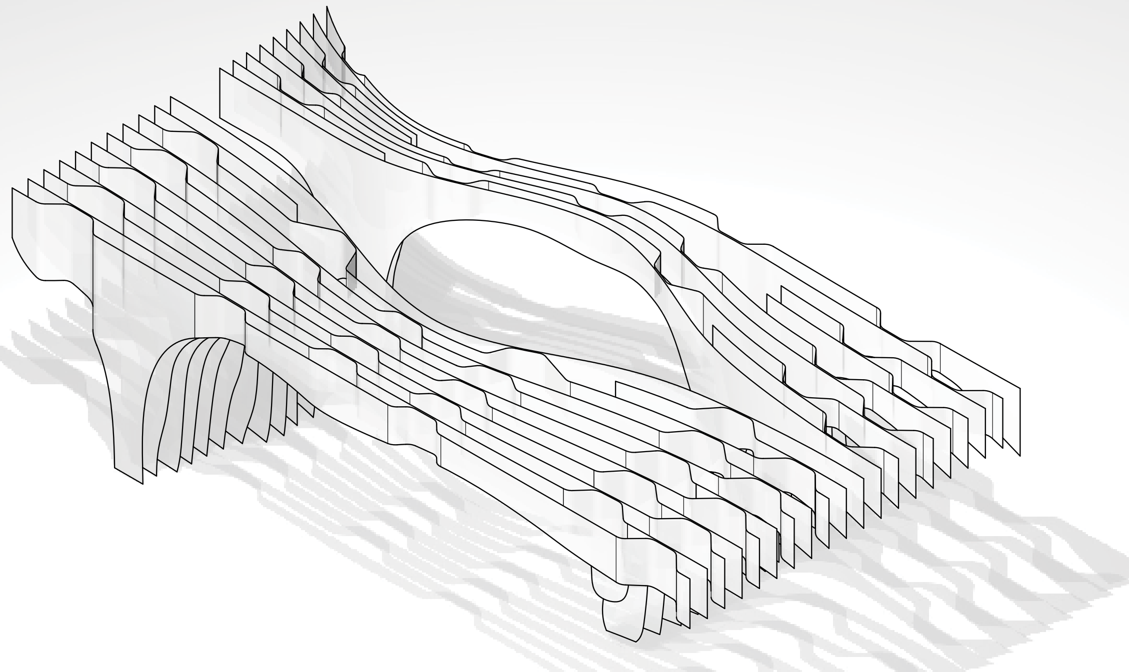
Figure 34: Structural Interlinking

The concept of exact multiple curvatures also suggests the potential for integral secondary structure .

understanding that, although this pavilion is complex, it is also familiar.

Where previously each of the open areas had been similar due to the limiting geometry of the arcs, this new version employs different curvatures in plan while also varying the spacing of the beginnings and ends of the profiles. This move is subtle enough to only be noticed when one is standing in one of the open areas but once there, visitors views are redirected through the newly emphasized East and West openings. This redirection is crucial to blurring the finite boundaries of the podium. In the original Barcelona Pavilion, as the site is approached from the East, there is the distinct presence of the large trees and other greenscaping enveloping the podium. Upon ascending to the podium however, the architecture of the pavilion excludes the natural, with multiple screens blocking the view in most places. While certain areas are privileged with glazing that looks West, this view is always secondary to the pavilion itself. The Glassroom Pavilion inverts this relationship entirely. From any point in the overhead profiles area the abundant nature to the West is visible but the visual connection to the site is exaggerated in the open areas. In a reversal of typical Modernism inward-looking design, each area refers to either the greenery to the West or to the plaza and fountains to the East. The altered spacing of the profiles constructively applies irregularity to draw ones eyes away from longitudinal aspects of the site and through the spaces between the profiles. This creates an additional layer of complexity in the relationship between looking at the profiles, looking through them and looking between them. Each is coloured by what lies beyond but each view represents it differently. The result is a constant flux of direct views, distorted reflections on and though the glazing and of the glazing itself.

In order for this design, and architecture in general, to fully exploit the expressive potential of curved glass, the limitations and expenses of single use, individual moulds must be overcome. Projective analysis of emerging technologies in this field concludes that the concept of individual moulds could be replaced by CNC reconfigurable tooling. The idea of large-scale reconfigurable moulds is already used by North Sails to make large sails in their wind stressed form rather than flat (North Sails, 2014). Since each of these racing sails are unique, a warehouse sized CNC controlled reconfigurable mould was constructed. Another significant precedent in reconfigurable tooling for glass production was presented at Acadia 2012 (McGee, Newell, & Willette, 2012). This project employed several linear actuators to manipulate the glass while it was in the bending kiln (McGee, Newell, & Willette, 2012). Finally, simple curvatures in glass are currently capable of being



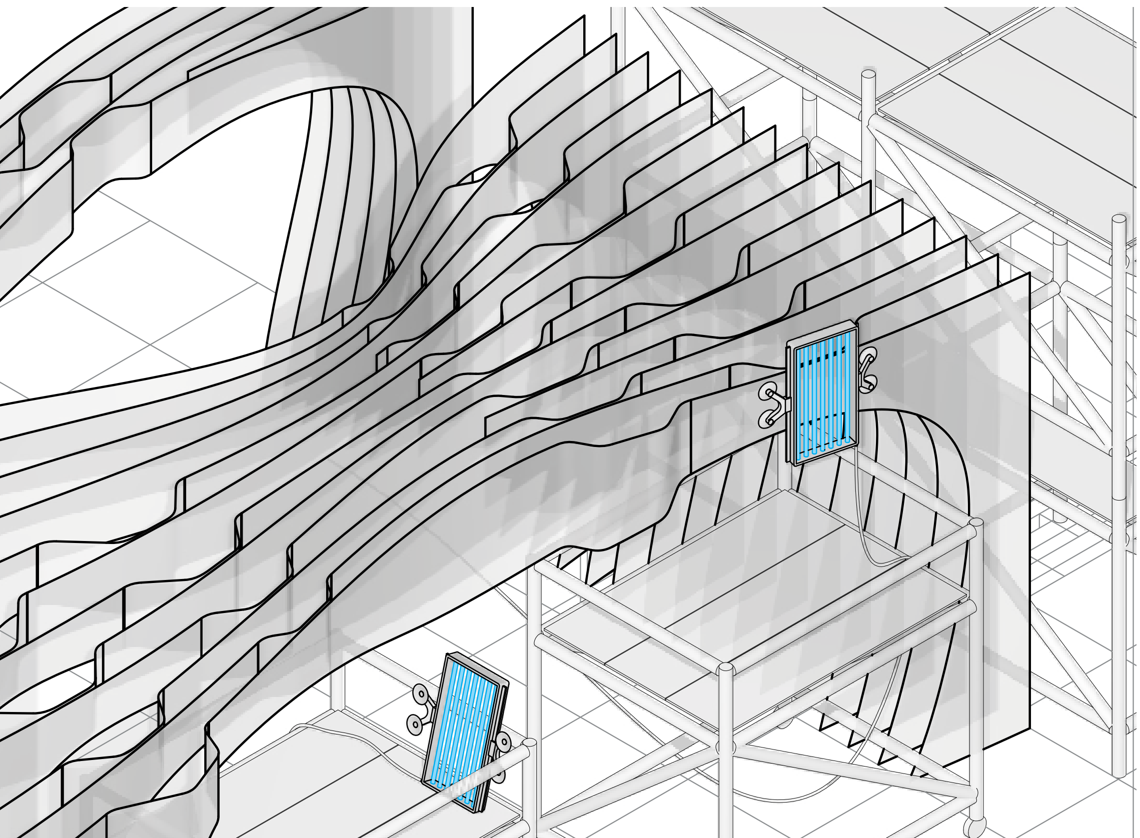


Figure 35: Integral Structural System (top left)

The tectonics of the integral structural system.

Figure 36: UV Bonded Construction (bottom left)

Vignette of the construction process including the use of UV glue to fasten the contact points of the integral structural system.

formed without the use of moulds by employing a zero-tooling method (Wurm, Peat, & Schwaigerm, 2007). Individually none of these precedents could replicate the process proposed for the Glassroom Pavilion. However, viewed from a projective standpoint, together they suggest that CNC reconfigurable moulds for glass forming is a near-future emerging technology.

The concept is relatively simple in principle, the machine would consist of a flexible, heat-resistant and smooth surface that would be actuated from below to create a curved bed for the glass to mould to. The density of the actuators would limit the resolution of the curve, with larger numbers allowing smaller, more gradual and more varied curvatures. Unlike current moulds which require the glass to balance across or on top of curvature while heating to fluid temperatures, CNC moulds have the advantage that the glass begins on a flat surface. Once up to temperature, the surface can be manipulated to create the desired curvatures. This difference would likely vastly reduce the large tolerances associated with current slumping technology as the fluid glass movement is far more controlled. Finally, the entire system, both the moulding surface and the temperature can be controlled by computer to allow for precision tuning and perfect repeatability for any desired shape. The potential of this advance is massive, analogous to the manner in which CNC waterjet cutting enables infinite shapes in planar glass, reconfigurable moulds would enable infinite curvatures.

The concept of ubiquitous curvature in this project also has the potential to elegantly resolve the issue of secondary structure in a way that reflects the emerging material technologies of glass, rather than standard steel support systems. While large curves throughout the length of the profiles are used to effect spatial conditions, more pronounced local curvatures could serve structural means. Without the technology of reconfigurable moulds, each profile would be linked using a complex and distracting system of point connections, rods and tension cables. Without a steel primary structure this system would strive to link the profiles in such a way that together they could support torsional loads. However, here similar crosslinking is a achieved using deviations from the global curvature to fasten each profile to the next. Each locally curved area departs from the global curvature path to provide sufficient contact area on the next profile. This novel connection method requires no more material and does not increase the cost of the profiles. The entire fabrication process remains the same, the only difference is that the slumping curvature is more complex, a complexity that is simplified by the CNC mould. The resulting structural system accumulates the rigidity of each profile into what amounts to a single rigid element. Like glue-laminated wood, this system multiplies the rigidity of each member. However, this system arrays the laminations across the podium, like an expanded beam in which the intervening spaces are rendered architecturally productive. The seeming delicacy and transparency of this systems stands apart from the majority of structural glass installations, maintaining the concept of glass as an immaterial element while prevailing on its structural capabilities.

The second consideration of this structural system is fastening these mating curvatures. Maintaining the structural integrity of glass depends on careful management of the stress within a sheet (Wurm, Peat, & Schwaigerm, 2007). Improperly designed or installed mechanical connections create excessive increases in local stresses which lead to failiure under load (Wurm, Peat, & Schwaigerm, 2007). Current architectural glass connections typically fall into one of two categories: mechanical pin and clamp fastening (Wurm, Peat, & Schwaigerm, 2007). Pin connections involve drilling a hole through the glass to though which intermediary hardware fastens the pane to the external structure. This method has two main issues: imbalanced local point loading and large construction tolerences (Wurm, Peat, & Schwaigerm, 2007). Point fastenings create potentially problematic uneven load transfer and they cannot, by definition,

Figure 37: Site Glass

Rendering depicting the distinct boundary of the Modern podium blurred by the reflectivity and refractivity of the curved glass profiles.

utilize the entire glass cross-section. Furthermore, holes cannot be made after tempering the glass as the change in stress causes instant failure of the entire sheet. As tempering must take place before laminating, the holes for point connections must be drilled on each layer separately prior to lamination. The potential for misalignment during lamination and minor dimensional changes during tempering demands large tolerances in hole size and placement (Wurm, Peat, & Schwaigerm, 2007). Curving the glass prior to lamination and tempering would drastically increases those tolerances as well. Linear clamping address the issue of point loading but still requires mechanical fastening and results in a two dimensional transfer of loading. The ideal method of fastening would distribute the load over a surface area, rather than just a line and it would do so with no mechanically induced stress.

Eschewing mechanical connections altogether, this pavilion employs the best practice of glass bonding chemically. The use of epoxy or acrylate glues enables load transfer over large areas, forming a shear connection that is as strong as the glass itself while not inducing any weakness in the sectional glass mass (Wurm, Peat, & Schwaigerm, 2007). These glues are completely clear, long lasting and cure in less than a minute under UV light. UV bonding is currently used mostly display work, creating strong and invisible joints. Current glue formulations limit long term exterior use but this is a rapidly advancing field of chemical science. The architectural potential of these seamless and strong connections, is considerable, projecting the image that the profiles touch gracefully, rather than in a heavy-handed mechanical manner. Considering as well that the profile bases would simply be cast into portions of the podium the final system posses simplistic details. The minimalism of this execution allows for increased complexity elsewhere in design without rendering a project untenable and is a hallmark of successful, forward-looking design (Scheurer, 2012).

Spatial characteristics defined by the void beneath planar profiles, accentuated areas created by variable global curvature and local curvature for structural interlinking form a complex system that is driven by the properties of glass and enabled by emerging technologies in its processing. This system is employed as a driver of design. Rather than specifying a geometry and seeking to apply a material in the most cost effective or expressive manner, the Glassroom Pavilion deploys material and technological potentials in a generative manner. These emerging technologies surrounding the formation of glass interact with the 21st-Century positions and indented spatial and experiential characteristics to engender a novel new architecture. The Glassroom

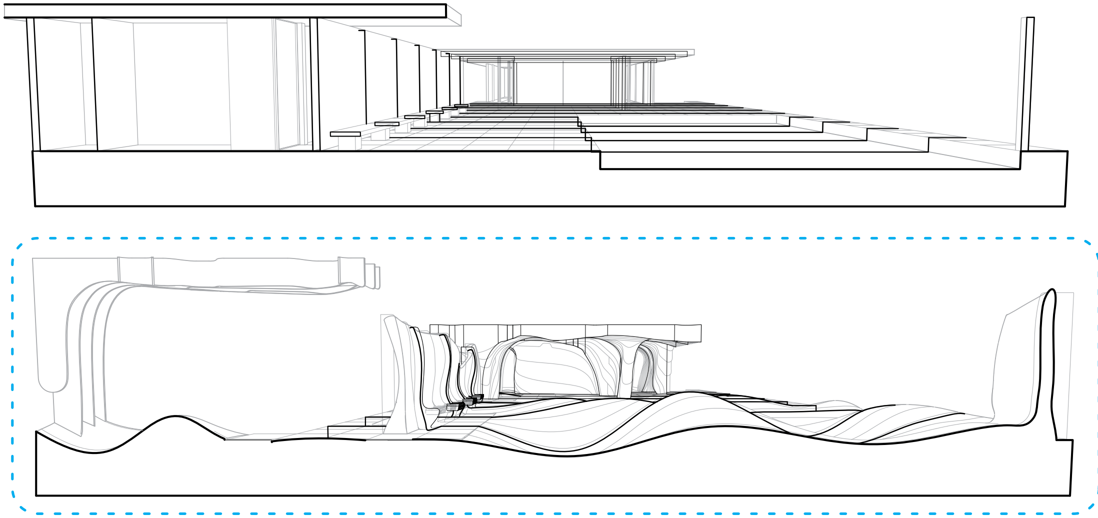


Figure 38: 21st-Century Landscape Sections (left)

The regular and binary natures of the Modern exterior space reimagined as a 21st-Century gradient landscape.

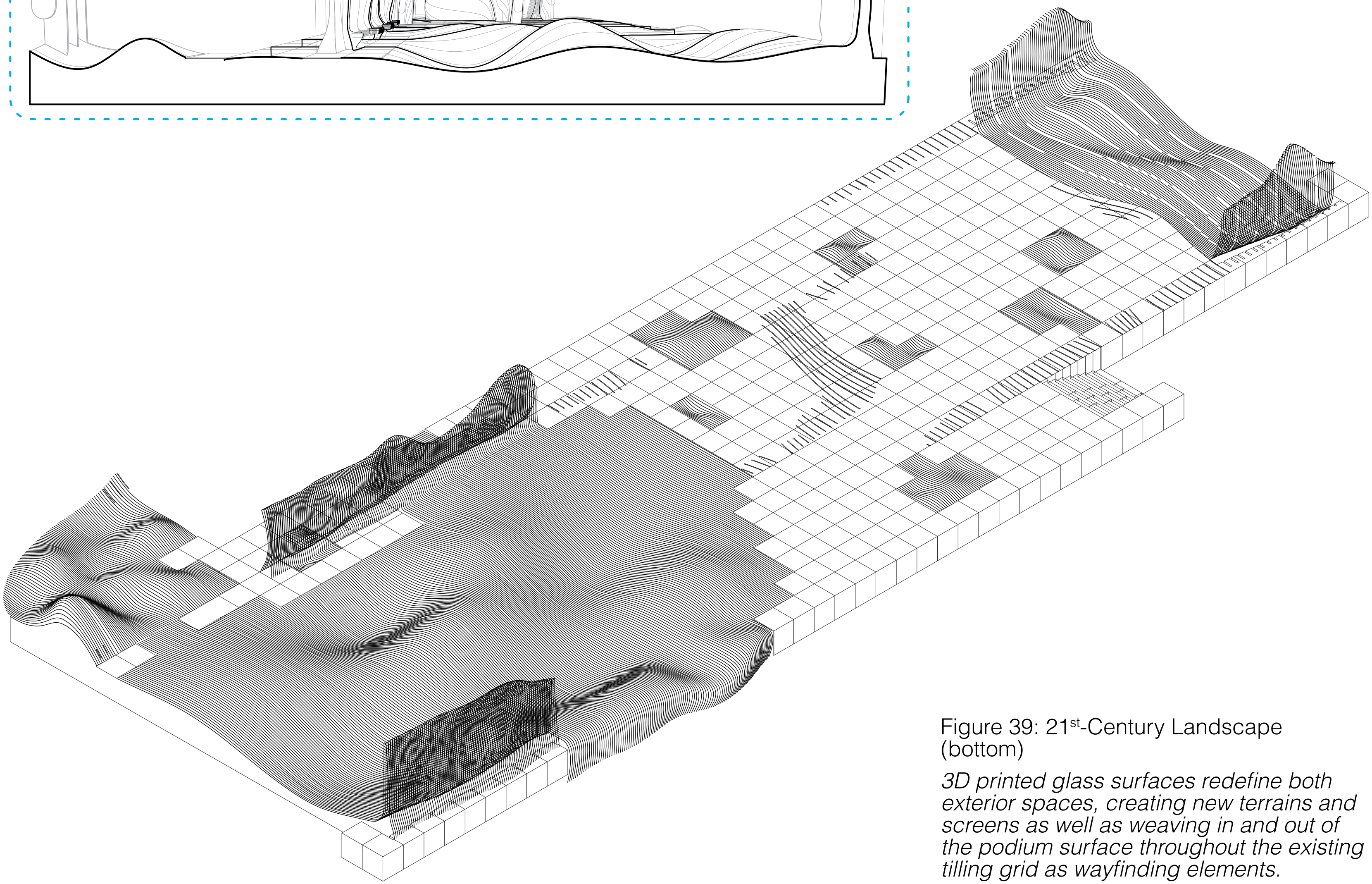


Figure 39: 21st-Century Landscape (bottom)

3D printed glass surfaces redefine both exterior spaces, creating new terrains and screens as well as weaving in and out of the podium surface throughout the existing tilling grid as wayfinding elements.

Pavilion is the confluence of design intent and material logics. Like the Barcelona Pavilion, this result expresses the fullest potentials of planar glass and its adherent technologies, undeferring these effects architecturally.

- 6.2 -
Beyond Planarity

3D printing is the 21st century's casting

While the previous section dealt with the enclosed areas of the Barcelona Pavilion the initial sectional analyses also reveals the same binary and single optimization issues in the exterior areas. Here, the sections are once again played out as a series of states that shift suddenly from one to the next. Single optimization is especially prevalent in the palpable disassociation between the long travertine screen, the ground plane, the bench and the water. The binary nature of the ground plane completely excludes any interaction with the pond. The term pond does not even apply, as that term infers some amount of natural interface between ground and water that does not exist within the Barcelona Pavilion, no pond could reside so precisely within the rigidly regular confines of the 109cm paving unit. The Glassroom Pavilion however, reforms the spatial characteristics espoused by the straight-line sections into continuous elements that integrate ground, water, screen and seating into a cohesive whole. Radiating from around the bodies of water, the interpolation of these new sections suggests a rolling, dune-like, landscape given to local variability and gradient conditions. Expanse of this area is expanded through the use of opaque white glazing capping the North and South ends of the pavilion. The reflectivity of this material increases the sense of the areas as limitless landscapes. The topography was parametrically iterated to achieve enough variation to create a semblance of a terraform as well as to engender mystery and curiosity without

Figure 40: A Printed Landscape (above)
3D printed glass surfaces redefine both exterior spaces, creating new terrains and screens.

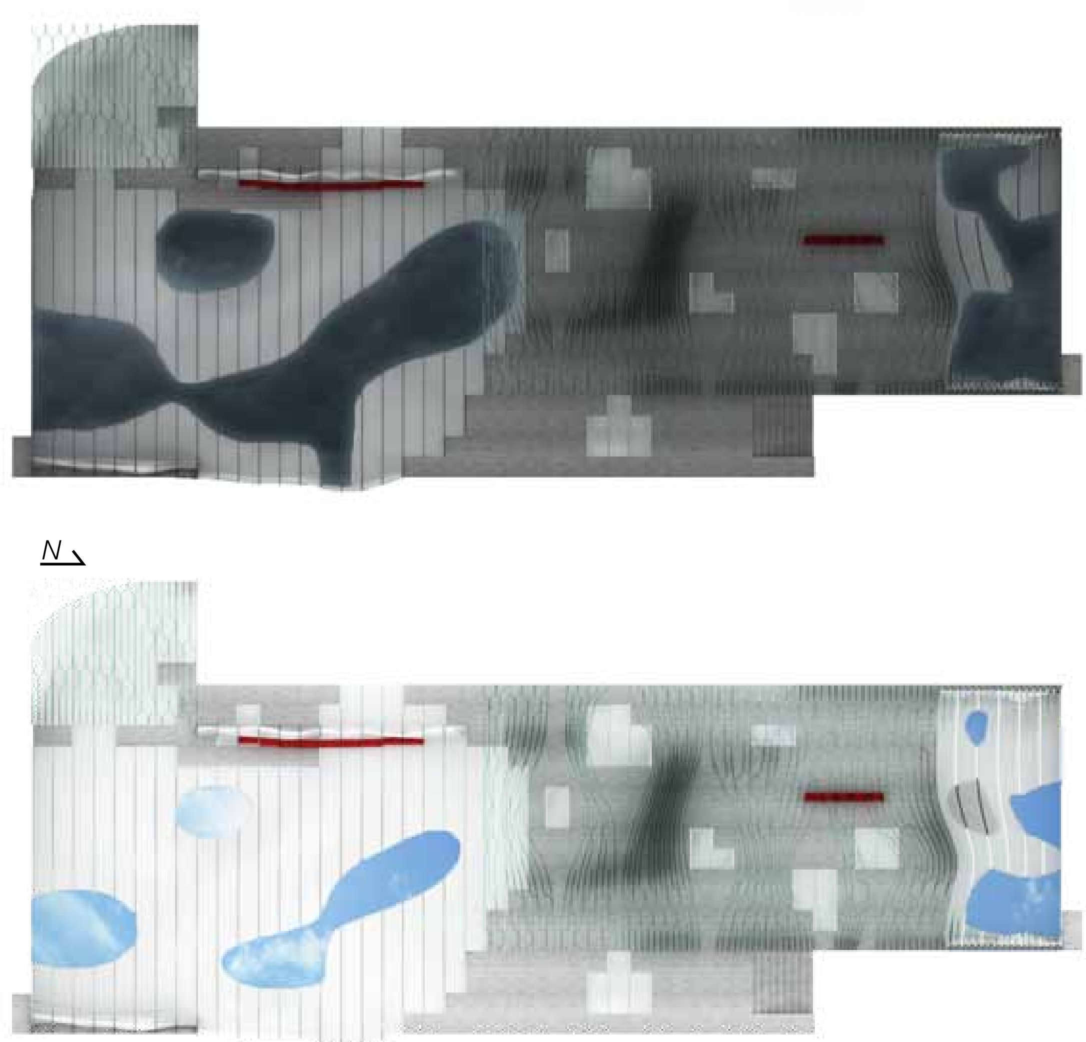


Figure 41: Meteorological Experience

Renderings of meteorological variations registered in the water levels and the resulting impacts on the ways with which one moves about the site.

rendering the exterior unnavigable. This new terrain, woven into the existing podium, invites visitors to explore and occupy the space, rather than wander its empty expanses.

This landscape entirely reverts the Barcelona Pavilion's binary planes of water. Rather than an impossibly unnatural expression of water, the Glassroom Pavilion reintroduces the concept of a shoreline onto the landscaped podium. Instead of artificially containing the water to a single rigid zone of edges and flat bottom a more naturally gradient edge condition occurs. As in nature, the shoreline, occurring both in the southern half of the pavilion and around the smaller northern body of water, is an area of flux. This variability is embraced as the water levels in these areas of the Glassroom Pavilion reflect recent metrological conditions. The low water levels during the summer respond to the lack of rain, while in the wetter seasons areas of the landscape will be impassible. Unlike in the Barcelona Pavilion the variability in these watery zones is embraced and interaction is encouraged by the undefined edges. The gentle slopes of the shorelines challenge visitors engage with the water, rather than simply view reflections upon it. The inviolate nature of the original bodies of water is rejected as well in the creation of an 'island' in both ponds which must be waded to.

The intent is to imagine this pavilion entirely of glass makes a rolling landscape a particular challenge. Nearly all glass in architecture is sheet material, but the variable thicknesses and freeform properties demanded by this topography negates an elegant use of any sheet material. When considering glass processing beyond architectural realms it is apparent, however, that casting has the potential to cater to the suggested conditions. Rather than cater the means to suit the geometry though, the production of this landscape must be a synergy of the intended experience and material technologies. Cast glass has the potential realize the desired spatial conditions but it is rarely used in architecture and suffers from many of the same limitations as current sheet glass slumping. The architectural effects of cast glass are reductively intimated in glass block as well as in 3d kiln glass (Brownell, 2008). however the Glassroom Pavilion calls for a far larger implementation. Outside of standard concrete forms, casting in architecture is a very limited field, one fraught with expensive moulds and labor-intensive executions.

Casting of materials in general has been hugely revolutionized in the last ten years by 3d printing. Additive manufacturing promises to revolutionize production across every scale. Currently 3d printers range from desktop to house sized and print in a wide variety of materials. While plastic dominates the material pallet for smaller printers, some of the wide variety of other materials available includes ceramic, metal and concrete (Shapeways, 2014). Concrete is of particular architectural interest as additive manufacturing promises quicker, more precise and less labour intensive casting. Several projects already exist that employ very large printers in attempts to print entire buildngs (Russon, 2014). This suggests that 3d printing this landscape is a viable option. While the concept of 3d printing in glass offers a host of challenges, it is, procedurally no different than current plastic deposition. A solid material is fed into a heated print nozzle, which melts the material while extruding it in precise layers.

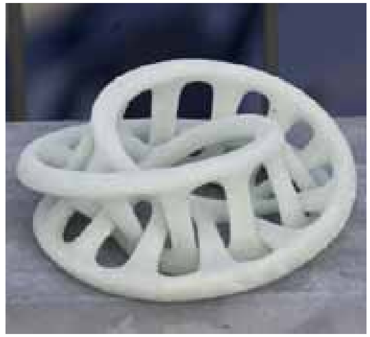
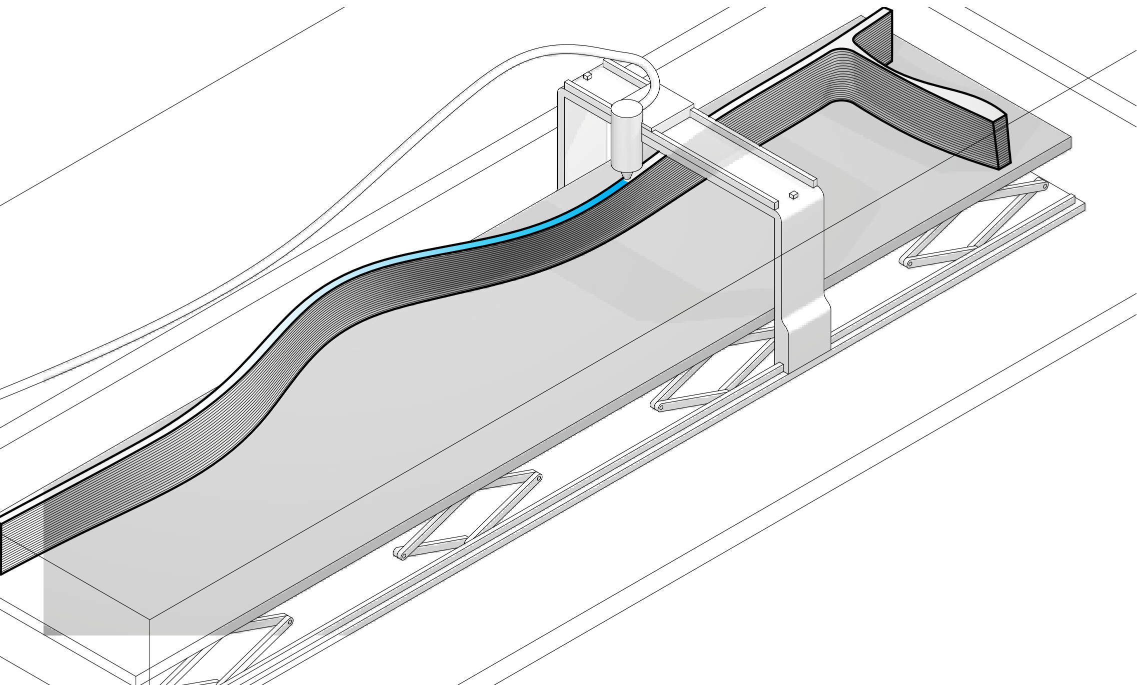


Figure 42: 3D Printed Glass Precedents

Trends in additive manufacturing (clockwisefrom top left) Shapeways 3D printed glass powder in substrate with subsequent firing, Win Sun Decorating Design Engineering 3D printed house, HP Labs 3D printed glass.



Practically the extreme temperatures and specific annealing programs for glass add significant difficulty but Shapeways, an online commercial 3d printing service offers opaque 3d printed glass (Shapeways, 2010). Furthermore, HP Laboratories is actively investigating hot glass additive manufacturing, with several examples printed already (Klein et al., 2012). The confluence of these two trends in 21st-Century casting suggest that 3d printing glass at an architectural scale will be practical in the near future. As with CNC moulds, 3d printing glass will drastically reduce the cost of architectural cast glass because the expense of the machine is amortized over its lifespan, rather than a single project. This technology will allow casting to return to architecture beyond concrete, enabling a new tectonic language of fluid variability, not unlike Soleri's bells (Lima, 2003) . In turn, projected limitations and properties of this technology shape the expression of the Glassroom Pavilion.

Cast glass, including elements that are 3d printed, is not typically clear. This is due, in both cases, to microscopic air bubbles that refract light within the depth of the part. Though HP Laboratories seeks to 3d print entirely clear glass, their best efforts indicate that a milky translucency will be the likely outcome, not unlike traditional cast glass (Klein et al., 2012). This projected quality plays a significant role in the design of the Glassroom Pavilion. While the printed glass underfoot would be mostly opaque during the day but at night, when lit from within the podium, the rolling landscape would softly glow. Beyond rendering the pavilion useable at night, this lighting also exposes variability in the thickness of the cast glass. Conceptually the landscape is a rippling plane but when designed with material qualities in mind, the thickness of the printed surface would vary. Overall this area would still be characterized as a shell, but the thickness would be modulated to achieve the correct density based on the loading. The areas that bear the weight of the water would tend to be thicker, whereas the peaks of the topology would be thinner given their lighter use. These material variations lend an animated quality to the illumination. The need for lighting elsewhere in the profiles area of the pavilion as well as a desire to experientially link these zones through the maintained plasticity of the ground plane demands smaller printed areas throughout. These smaller printed surfaces act as way finding elements, maintaining the rolling topography but at a scale better suited for the 'interior' space.

The translucency of the 3d printed glass is made experientially productive in the area where the rolling terrain bends upward to reinvent the long travertine screen of the Barcelona Pavilion. In the new screen this technologically driven material quality is activated through the varying thickness of the screen. While the thicker areas remain relatively opaque, the thinner regions begin to faintly assume the colour of the natural area to the West. The resulting subtle gradations of luminosity visibly and variably register what lies beyond the screen.

The finish of 3d printed items, from plastic trinkets to concrete houses, is far from flawless. While cast glass often exhibits a smooth surface it would be expected that 3d printed glass would exhibit the same

Figure 43: Terraformed

Rendering looking south towards the white reflective edge plane. This surface, and its matching north side counterpart, reflect a reductive image of the pavilion and its visitors.

Figure 44: 3D Printed Glass Concept Image

Each section of the landscape surface is printed on edge.

Figure 45: 3D Printed Glass Precedents

Rendering of the north side of the enclosure showing the confluence of the original tile grid, the printed surfaces underfoot supported between glass fins as well as the curved glass enclosure profiles as they touch the podium

Figure 46: Printed Surface: Physical Model

Photograph of the final model (scale 1:50) showing the 3D printed ABS plastic surfaces. Also shown are the flat structural glass profiles which sit flush between the surfaces as the load bearing elements.

Figure 47: Modern Comfort

Photograph of the Barcelona Chair.

linear texturing that current extrusion based manufacturing presents. Rather than attempt to polish this characteristic away, the printing is oriented in such a way that the resulting texture provides traction for walking on the glassy terrain. This sideways orientation during printing also responds to a technological necessity. Typical 3d printers overcome the inability to print portions of a new layer that are not directly supported from below by printing a soluble support material. This material is then removed in post-processing. It is unlikely though, that a suitable disposable support material would be printed alongside the greater than 1000F temperatures required for glass. This necessitates a very specific strategy to print the glass elements that make up the landscape. Rather than requiring a compatible printable support material as well as a printer larger than 900m^2, the surface is divided into thin strips along the original 109cm tiling grid. These strips negate the need for a larger printer as well as for support. Based on current 3d printers that can print reasonable overhangs without support material, it is expected that the topological devations of this landscape would be manageable in this rotated form. Upon reconstituting the strips into the landscape no attempt is made to disguise the seams, instead those seams become the structural interface. The seams become the loci of planar elements of float glass that act as the structure that the printed elements sit within. The float glass is waterjet cut to match the top edges of the printed surfaces with which they border. Each printed strip is bonded to its neighboring profiles to form the structural system. The use of the original tiling grid allows the printed surfaces to blend smoothly to the remaining travertine tiles.

The ability to freely and precisely cast glass in the form of 3d printing has revolutionary architectural potential. The Glassroom Pavilion reinterprets the binary, singly optimized and highly regular aspects of the exterior zones of the Barcelona Pavilion into an enlivened terrain, realized by 3d printing. The result is an landscape of flux, of interactivity with light and water shaped by, and in turn demonstrative of, the power of 3d printed glass. The Glassroom Pavilion thereby stands as the architecturalization of emerging technologies in material formation, engendering powerful new experiential effects and affects.

- 6.3 -
Selectively Flexible

Glass Could be Strong AND Flexible

The only explicitly stated program, in the traditional sense of the term, for the Barcelona Pavilion was to provide expressive space and seating for the King and Queen of Spain to officially welcome Germany to the 1929 International Exposition (Quetglas, 2001). The Glassroom Pavilion expresses a new recognition of spatiality played out throughout the curved glass profiles as well as the 3d printed glass topology. The issue of seating, however, has yet to be addressed. In the Barcelona Pavilion the relationship between the chairs and the architecture is somewhat complex. They are not simply random objects used for that particular pavilion, they were designed explicitly for that use and for that milieu. As such, the Barcelona chairs are explicitly architectural; however, like the rest of the elements that make up that pavilion the chairs are disparate, singly optimized elements. A 21st-Century interpretation of the

Figure 48: Printed Bench Iteration (below)

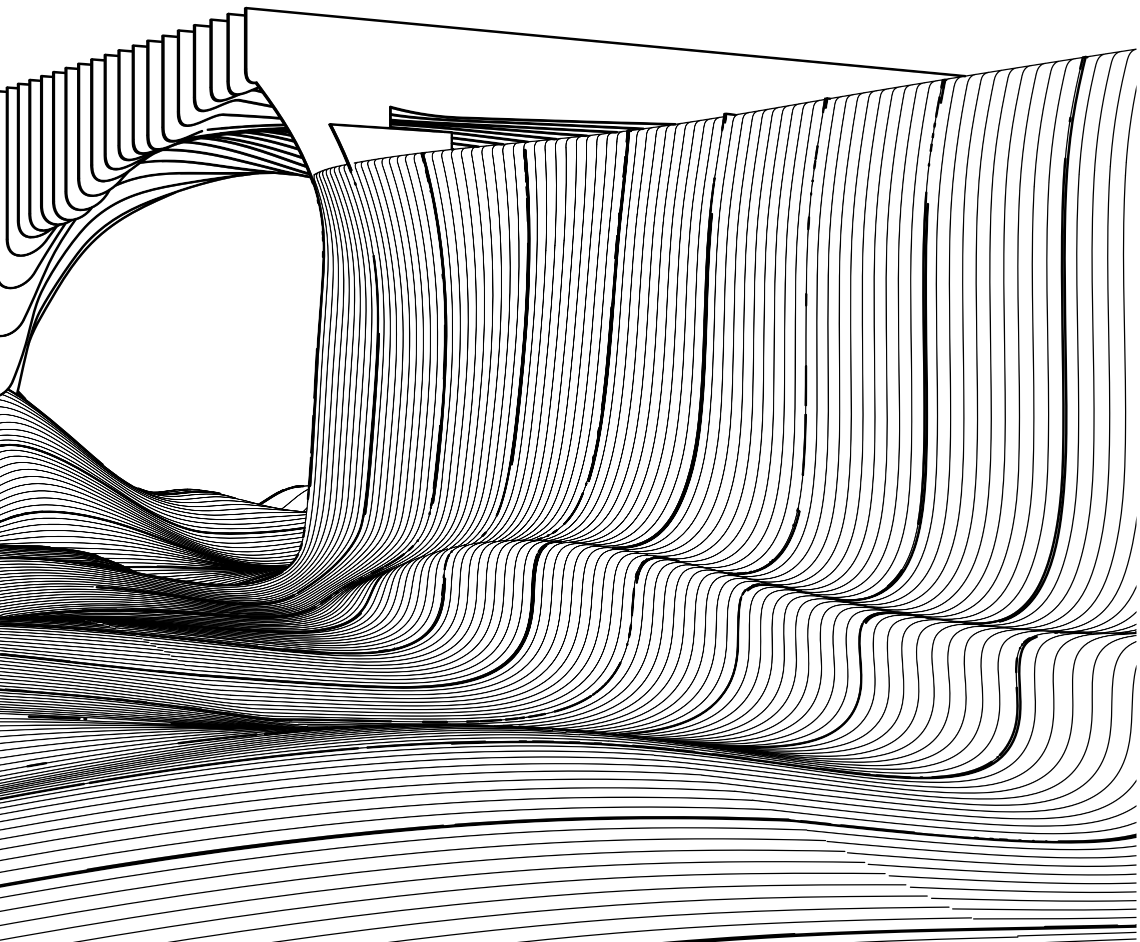
Diagram depicting an initial iteration that integrated seating into the printed ground and screen landscape. This iteration failed to capture the essence of the Barcelona Chair due to it's lack of comfort.

Figure 49: MIT Kerf Pavilion (opposite, bottom)

MIT's Kerf Pavilion materializes the concept of CNC router kerf cuts (Miranowski, Crain, Mackey, & Hoffer, 2012).

Figure 50: Laser Altered Material Properties (opposite, top)

Laser etching an interlocking pattern of microscopic flaws in the glass slides hugely increases flexibility (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014).

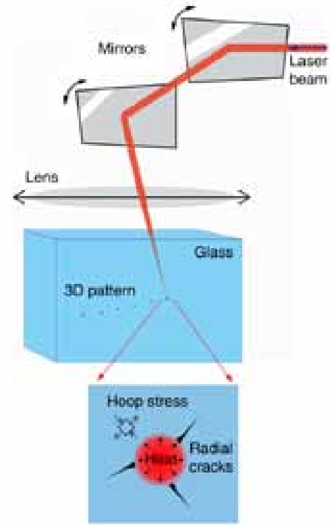


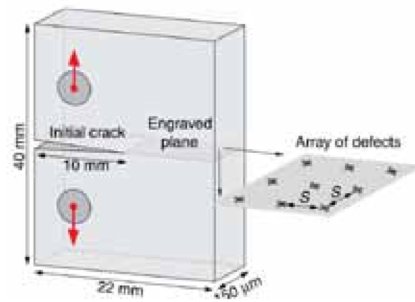
role and relationship of the Barcelona chairs to the pavilion would seek to draw those elements closer into the architecture, seeking the benefits of multiple optimization through integration. Seating in the Glassroom Pavilion is read experientially and functionally as part of the adjacent elements. The earlier sectional reinterpretation into single curves easily incorporates seating into the continuous variability that defines both the interior and exterior spaces. Conceptually that integration seems simple, however, materializing the idea is more difficult.

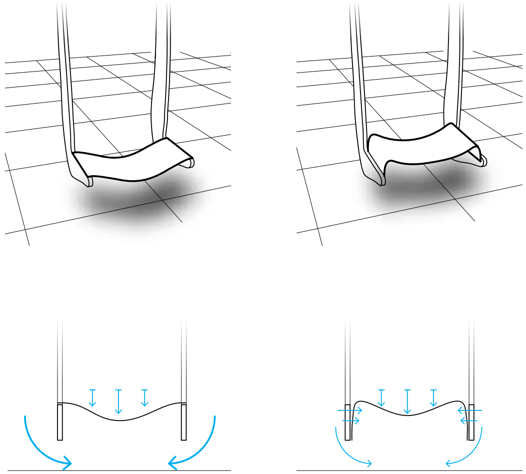
An initial iteration of the inclusion of seating into both the spaces defined by the glass profiles as well as by the printed landscape envisioned their materialization as fluid printed surfaces. In the exterior area this would present itself as a bench form emerging from the terrain as it rises into the long screen. The interior seating would consist of 3d printed seats strung between stalactite-like portions sweeping down from above, part of the interlinked glass profiles. While true to the concepts of multiple optimization and continuous variability, this iteration was lacking in that it simply repurposed a material logic from elsewhere in the pavilion. This lack of a genuine relationship between material technologies and design was clear in the resulting design. The most evident aspect was the lack of faithfulness in experiential characteristics to the original Barcelona chairs. The original ones were more than disjointed architectural elements; they were highly successful chairs in their own right as evidenced in their continued production and frequent duplication (JetSetRnv8r, 2008). The Barcelona chair is both striking and comfortable and that luxury is a fascinating reversal to the rigid rationalism of the rest of the pavilion. The seating in the Glassroom Pavilion had to posit a similar comfort as well as recalling that striking departure from the expected architecture. This would be enabled by a material technology other than 3d printing or slumping.

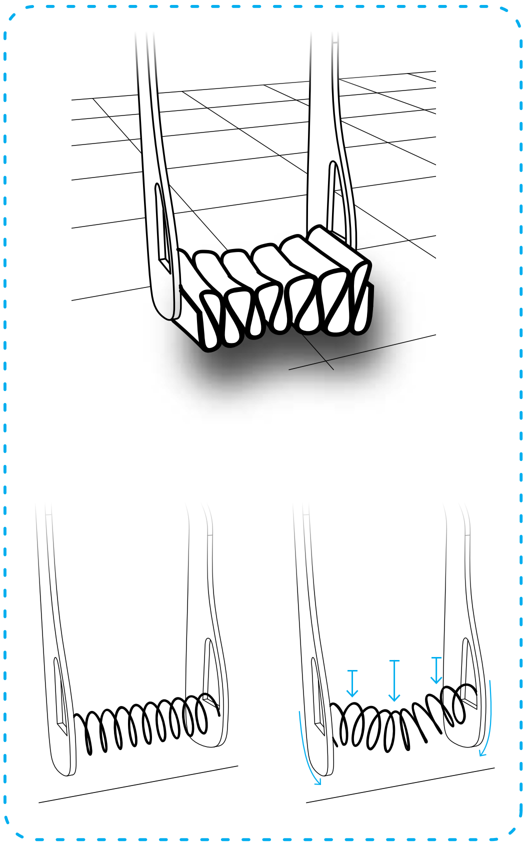
The challenge was to create comfortable seating out of an extremely hard and brittle material. From a material standpoint the Barcelona chair, as with most seating, creates comfort through compression. The compression offers vertical movement upon sitting which is gently limited after a certain distance. This sort of compressive movement, without failure, is unusual in most thin rigid sheet materials and unheard-of in glass. This sort of compressive movement in glass requires reimagining the properties of the material. Current flexible glass does not achieve strength and flexibility; it trades one for the other. The previously mentioned rolls of glass are flexible but that attribute comes at the cost of strength. Furthermore, some rigidity is necessary to avoid the complete collapse of any chair created from it. This seating design is therefore predicated on the concept of *selective* flexibility in glass. Creating flexible AND strong areas in an otherwise rigid sheet of 2mm glass begins to suggest the potential a versatile material with novel performative and geometric potentials.

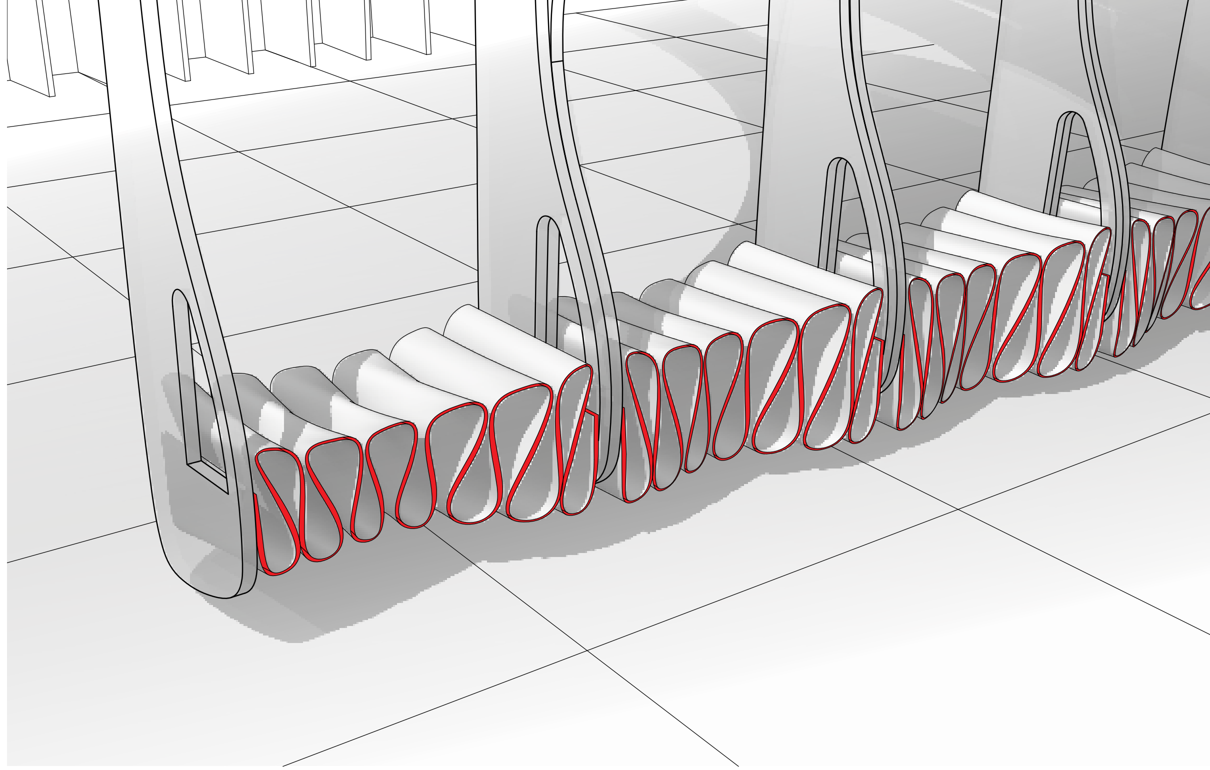
Current research at McGill University has demonstrated that laser etching 3 dimensional interlocking patterns into the interior mass of 1mm thick microscope slides greatly enhances their flexibility (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). These altered slides demonstrated two hundred times more toughness than the unaltered controls (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). This was achieved, unlike the paper-thin flexible glass, without compromising the strength of the slides (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). Traditional architectural materials display either one property or the other, steel can be formulated to be very strong, or very tough (flexible). but never both (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). This mutual exclusivity between strength and flexibility does, however, exist in nature (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). Achieving both characteristics in a traditionally brittle material is a tremendous achievement (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). Though the examples used in this study were clearly altered, the process could easily be





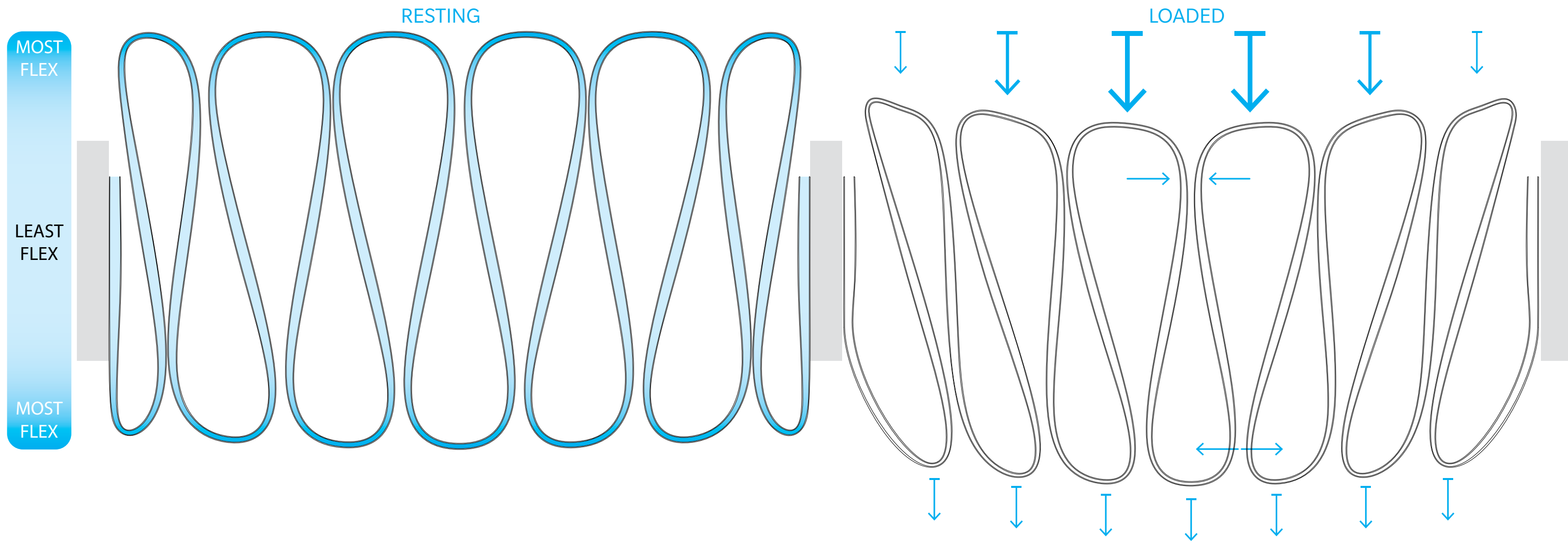






reduced to microscopic scales so as not to visibly alter the appearance of the glass (Mirkhalaf, Khayer Dastjerdi, & Barthelat, 2014). Though seemingly space-aged, this technology, like the rest projectivly applied the Glassroom Pavilion is an extention of current CAM technologies. Due to their typically larger size and reduced cost a large portion of CNC subtractive fabrication machines cut 2d or 2.5d patterns. This includes waterjet cutters, laser cutters and routers. These machines are typically limited to processing flat stock which is then built up to create volumetric elements or to creating surface effects. However, these machines are increasingly being applied to expand on traditional woodworking techniques to create curvature from sheet elements. Kerf cutting in this context is being reimagined as machine driven alteration of a material's properties to increase or revise its performance (Miranowski, Crain, Mackey, & Hoffer, 2012). Unlike the rest of development, this field of CAM innovation examines ever decreasing scales. The McGill study is simply a logical extension of this concept. This technological altering of material qualities is extraordinarily novel and its variable application allows for the seating in the Glassroom Pavilion.

In order to expand and render



productive the possibility of selectively flexible strong materials a specific geometry is required. Simply suspending a sheet of this flexible glass between two of the glass profiles was unacceptable because the thin glass is flexible, not stretchable. Rather than providing vertical movement through stretching as fabric might, this configuration would require the profiles to flex inwards as the thin glass collapsed between. As this configuration inelegantly puts a great deal of additional flexure stress on primary structural members it is unacceptable. Instead a more complex geometry, inspired by the way a spring would behave in a similar horizontal application, had to be adopted. An

Figure 51: Early Flexible Glass Seating Iterations (opposite, top left)

Simple sling configurations cause excessive out-of-plane loading on the vertical glass profile upports.

Figure 52: Flexible Glass Seating: Spring Configuration (opposite, bottom left)

Diagram showing the potential of a spring-like configuration for approximating vertical compression through flexibility alone.

Figure 54: Flexible Elastomeric Interlayer (opposite, top right)

Image highlighting the red flexible interlayer that bonds the two layers of flexible glass.

Figure 53: Flexible Glass Seating: Forces (above)

Compressive forces movement diagram.

exaggerated ripple shape was deemed to be ideal geometry to exploit the selectively flexible glass in this application. The flexible zones are concentrated to the peaks and troughs of the compressed waveform while the straight intervening sections are less flexible to add needed rigidity. Two 2mm layers of glass are processed flat and then formed into the wave-like shape. While any ductile material would be prone to re-straitening itself, the two layers hold each other in shape when bonded with a flexible interlayer. While traditional glass interlayers tend towards rigidity, silicone bonds strongly while allowing limited elastic movement between the two glass layers. The silicone is both a bonding agent and a dampener for the springy glass. Together, this system flexes vertically to approximate compression. These waveform seats are suspended between the glass profiles, rigidly bonded on each edge while allowed to move vertically as well as redistribute horizontally. Though the flexible glass is clear, the silicone is bright red. This adds prominence to the seating, highlighting it through the multiplicity of the glass profiles as well as contrasting the milky white printed glass.

The ability to digitally define, at a microscopic scale, variable areas of flexibility in a brittle material, coupled with an elastomeric interlayer create the technical foundation for a system that completely subverts ones expectations of what a brittle sheet material can do. While the technology is in its infancy at this point, the mechanical logics of a system such as this are sound and the resulting seating is as comfortable and striking as the original Barcelona chair. The resulting architectural effects are novel and a true expression of the potential of this technology but the affect of interacting with such an unexpected and fascinating material system would rival those of the glass

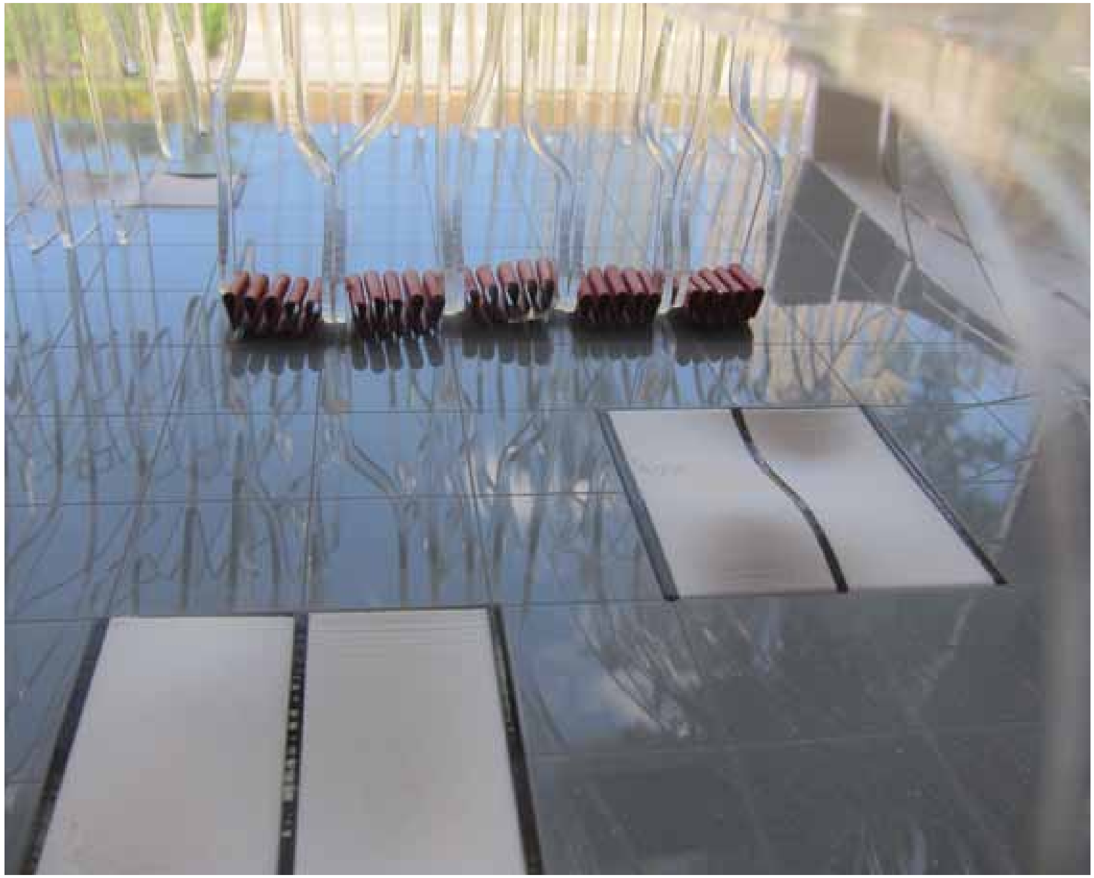
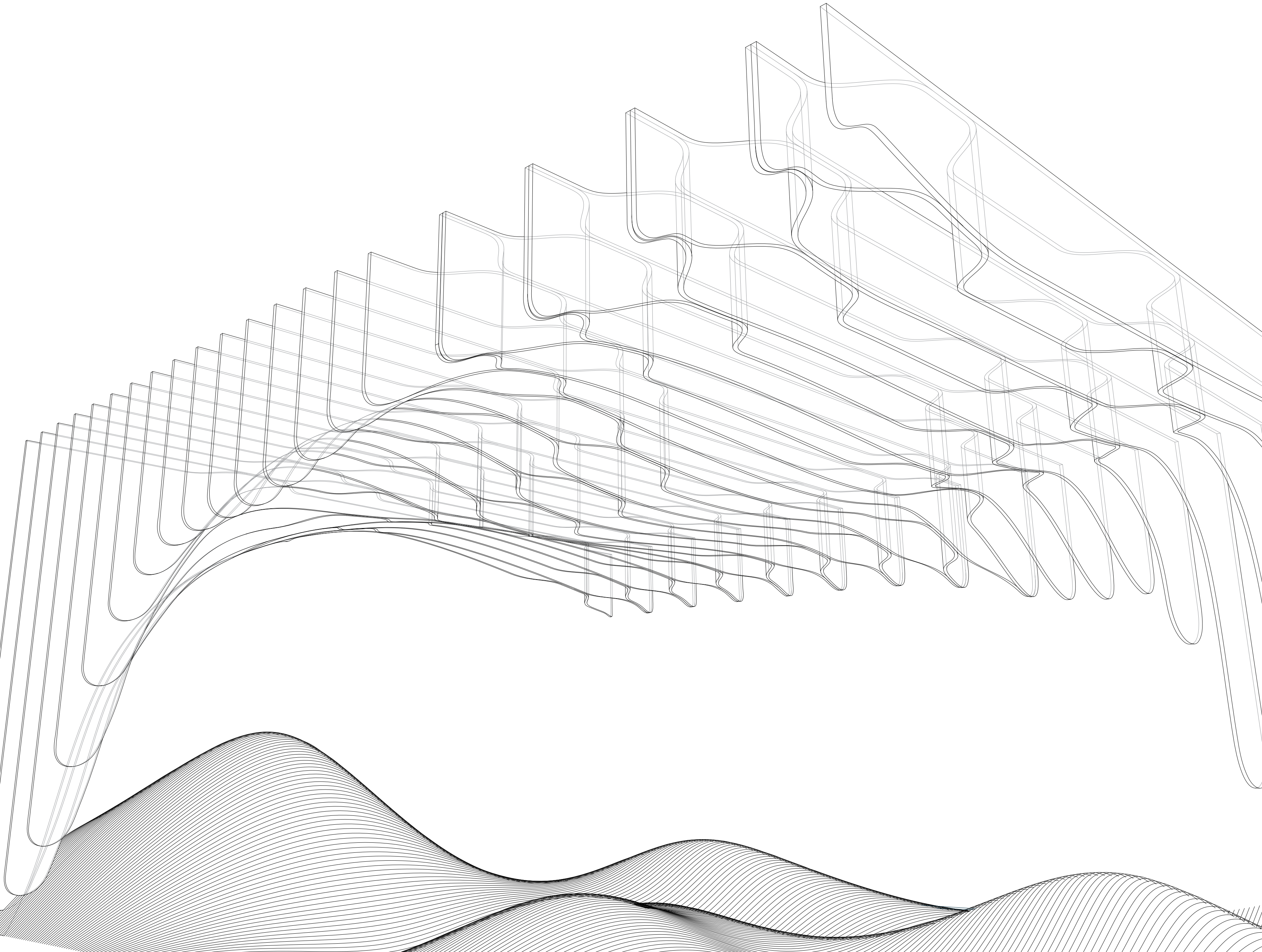


Figure 55: Seating Physical Model (above)
Photograph depicting the formal expression of the glass seating.

Figure 56: Screen and Bench (opposite)
Rendering of the interface between the printed landscape and screens and the glass seating. Each seat section is hung between the same structural glass profiles that support the printed glass strips.



screens of the Barcelona Pavilion.

- 6.4 -
Glassroom-South

The preceding description of the Glassroom Pavilion describes the reconsideration of both the large enclosure an open spaces of the Barcelona Pavilion. However, the smaller enclosure at SW corner of the podium is equally important. This outbuilding presents itself as a microcosm of the entire project, reprising, for the most part, the same materials, techniques, expression and Modern ideals. The smaller size of this pavilion its smaller size negates the need for the cruciform columns and yet this part is every bit as regular and singly optimized as the rest of the project. The lack of columns only exaggerates the role of structural steel in the project and accentuates the pure geometry of the roof plane. The remainder of the pavilion exhibits the same technologically driven perfect alignment of seams and edges as well as the same use of glass as a vertical enclosing screen along one edge. Perhaps the most important aspect of this small pavilion, however, is its placement relative to the podium in plan. While the rest of the project resides strictly within the confines of the rectangular podium, this outbuilding projects, in plan, West into the fore[st]-like landscaping beyond. This unique relationship to the rest of the podium as well as to the natural area posits this outbuilding as a clear example of the stark binary aspects of the Barcelona Pavilion. Despite being surrounded on three sides by abundant green landscaping, this small pavilion establishes no rapport in those direction. This point is the most stark example of the lack of connection between the Barcelona Pavilion and nature in general. This is an entirely binary relationship, the pavilion is exclusive and inward looking, and it may touch the greenery beyond but they never interact. Even the single window on the North side of the small pavilion is placed so as to frame a view of the rest of the podium. This complete exclusion of nature became emblematic of the Modern sensibility but a 21st-Century interpretation of this relationship would seek to invert it entirely.

The Glassroom-South, a subset of the spatial conditions and indented performances of the Glassroom Pavilion reinterprets the relationships posited by the small outbuilding. This privileged extension of the podium embraces its natural location, opening up the trees beyond, rather than turning its back. The three solid walls that focused this portion of the Barcelona Pavilion inward are removed in favor of an immersive openness to the greenery. The Glassroom-South is presented as a microcosm of the characteristics of the rest of the project. Spatially defined as consisting of

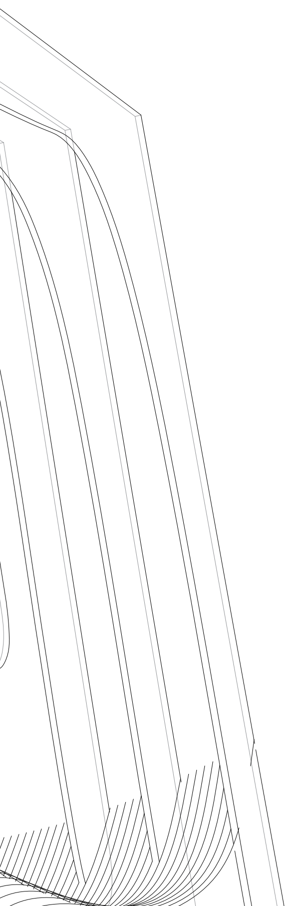


Figure 57: Glassroom-South

Perspectile view of the exaggerated printed terrain and of the glass canopy above.

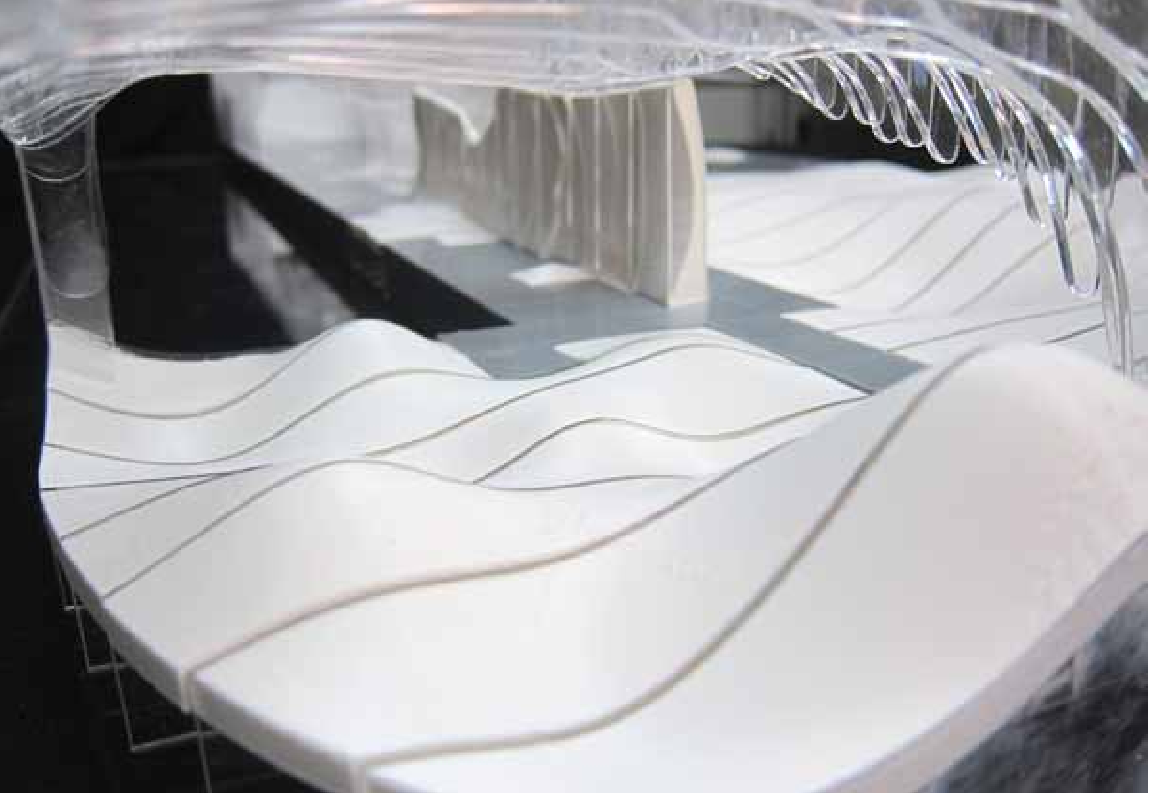


Figure 58: Glassroom-South: Terrain (opposite, top left)

Physical model (scale 1:50) photograph of the exaggerated 3D printed terrain which serves as both ground and seating.

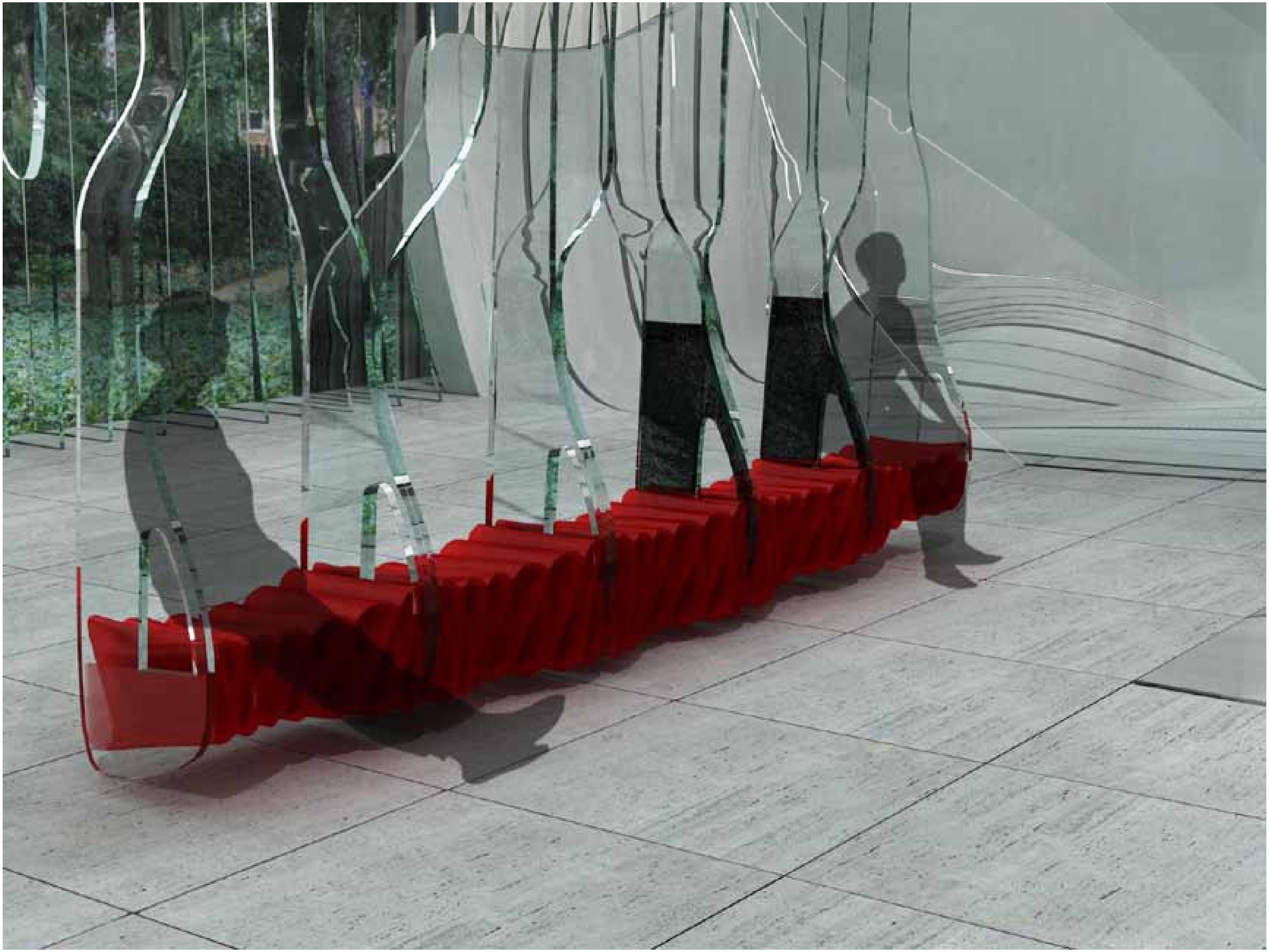
Figure 59: View of Glassroom-South

Photograph of the physical model(scale 1:50) of the Glassroom-South depicting the view from further north on the podium.

Figure 60: Glassroom-South Canopy

Photograph from above of the physical model (scale 1:50) depicting the glass canopy consisting of flat profiles curved only to achieve structural interlinking.

a single surface that wraps from ground to ceiling the majority of the horizontal areas are dematerialized to favor unobstructed views North, West and South. The space is loosely enclosed by a version of the glass profiles above while an undulating printed topology resides underfoot. The small area that is enclosed in the Glassroom-South portion allows the profiles to be simplified with the exclusion of the global curvature while. At the same time the frequency of the rigid local curvatures are increased to compensate for the fact that the entire assembly stands lightly on two opposite corners.   The profiles rise smoothly from the printed surface below reinforcing the expression of this small pavilion as a single continuously variable surface exhibiting gradient conditions though shifts in material strategies. Envisioned as defining a contemplative space, the multiple optimization of this surface is also expressed through the use of the rippling ground plane as seating. Rather than explicitly defining seats to match the resting points along the podium, the Glassroom-South increases the topological variation of the landscape, allowing visitors to rest where they see fit. The podium edge is also pulled inward here as if to suggest its reclamation by nature, ending the Barcelona Pavilion's binary hegemony and engendering a blurred and shared, rather than finite edge. The Glassroom-South is a microcosm of the undeferred impacts of emerging technologies as drivers of design rendered in glass. This use of glass expresses near future processing technologies and material qualities in a novel architecture shaped by the Post-modern ideals of spatially gradient and irregular continuously variable environments.



- 7 -
Conclusion

The Glassroom Pavilion employs glass as the medium through which emerging technologies in material processing and fabrication are investigated. These technologies are expressed in an architecture that is defined by the 21st-Century concepts of gradient spatiality, multiple optimizations and continuously variable environments. As a reinterpretation of the Barcelona Pavilion this design maintains the spatial characteristics and general configurations of the original pavilion but defines them in a totally new manner, shaped by the 21st-Century positions as well as emerging technologies in the processing and fabrication of glass. By positing these technologies and material potentials as drivers of design, the Glassroom Pavilion undefers their potential expressive impacts in an experientially novel composition. The geometric complexity of the Glassroom Pavilion is a result of a material and technology embedded design process and, as such, realizes that intricacy with clear fabrication logics. This proves that geometry, as a design constituent, is not the only way to achieve complex and compelling formal outcomes and that substituting it with material technologies results in a far more tenable result. However, the value of undeferring emerging technologies exceeds simply achieving rational construction logics or espousing new expression for the sake of novelty alone.

Architecture, as the vehicle for socio-cultural representation, both represents technology and is realized by technology. As society becomes increasingly technological this complex duality becomes ever more crucial to comprehend and explore. Architectural expression and technology, however, do not advance in lock step. Deferring and undeferring of potential technological expression is a cyclical process and out of sync architecture that does not fully exploit technology defers its ability to completely express its techno-cultural context. Revolution in architecture lies in the reconciliation of technology and expression. In order to maximize the representational relevance of architecture constant effort must be made to explore, though design, the expressive potentials of emerging technologies. This exploration, with the goal of expressing what will soon be, rather than what recently was, gave rise to the Barcelona Pavilion just as it did the Glassroom Pavilion.

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Photograph Credits

Figure 5: Pabellón Alemán para la Exposición Universal de 1929 [Photograph]. Retrieved from: http://laformamodernaenlatinoamerica.blogspot.ca/2013/04/pabellon-aleman-para-la-exposicion.html

Figure 17: SANAA Glass Pavilion, Toledo Museum of Art [Photograph]. Retrieved from: http://cmuarch2014.wordpress.com/2010/08/13/sanaa-glass-pavilion-toledo-museum-of-art/

Figures 18 & 19: Half Dose #29: Laminata House [Photograph]. Retrieved from:http://archidose.blogspot.ca/2006/08/half-dose-29-laminata-house.html

Figure 32: McGee, W., Newell, C., & Willette, A (2012). Glass cast: A reconfigurable tooling system for free-form glass manufacturing. ACADIA 12: Synthetic Digital Ecologies [Proceedings of the 32nd Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)., San Francisco.

Figure 33: North Sails 3Di - The How and the Why [Photograph]. Retrieved from: http://www.sail-world.com/indexs.cfm?nid=73109

Figure 42 Top Left: Shapeways (2010). You can now 3D print in glass with shapeways. Retrieved March, 2014, from http://www.shapeways.com/blog/archives/401-you-can-now-3d-print-in-glass-with-shapeways.html

Figure 42 Top Right: Russon, M (2014, April 12). China: Recycled concrete houses 3D printed in 24 hours. International Business Times. Retrieved from http://www.ibtimes.co.uk/china-recycled-concrete-houses-3d-printed-24-hours-1445981

Figure 42 Bottom Left: Klein, S., Simske, S., Parraman, C., Walters, P., Huson, D., & Hoskins, S (2012). 3D printing of transparent glass: HPL-2012-198. Hewlett-Packard Development Company, L.P.

Figure 49: Miranowski, D., Crain, T., Mackey, C. & Hoffer, B (2012). MIT: Kerf pavilion. Retrieved March, 2014, from http://architecture.mit.edu/architectural-design/project/kerf-pavilion#

Figure 50: Mirkhalaf, M., Khayer Dastjerdi, A., & Barthelat, F (2014). Overcoming the brittleness of glass through bio-inspiration and micro-architecture. Nature Communications, 1-9. doi:10.1038/ncomms4166

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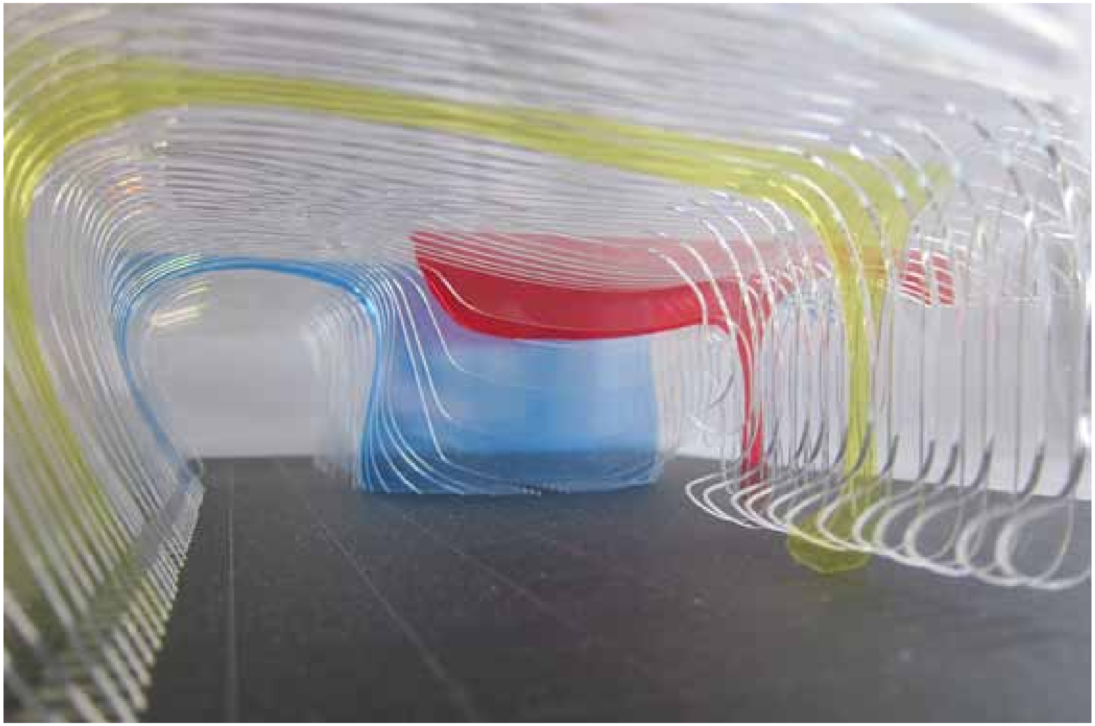
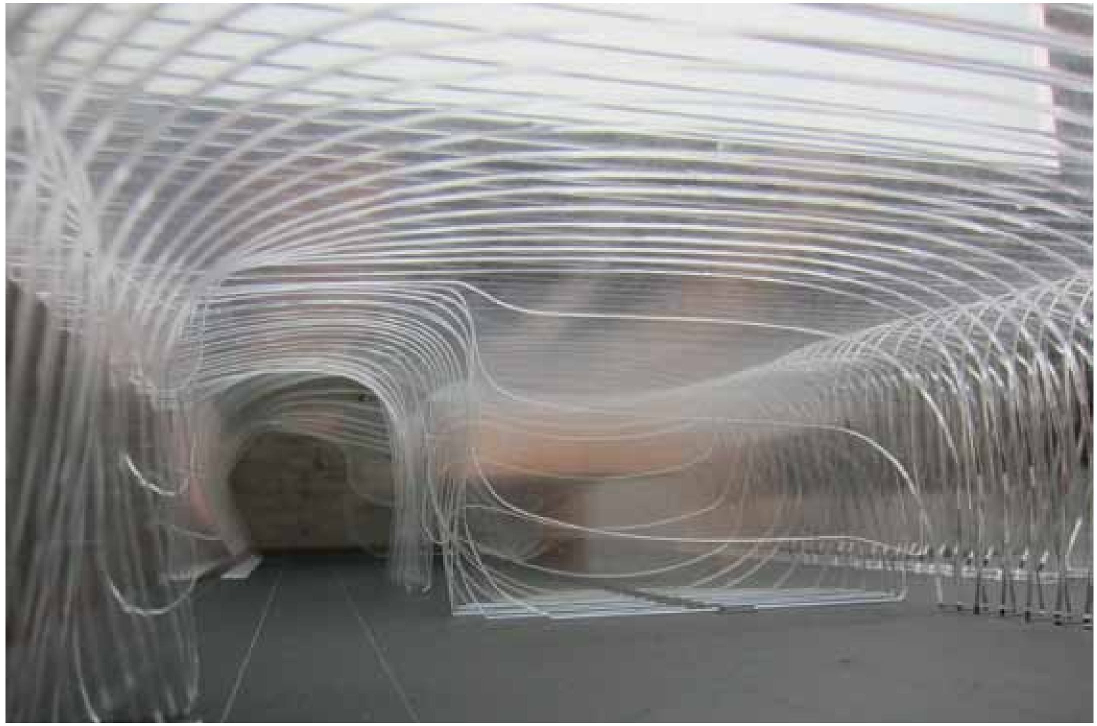
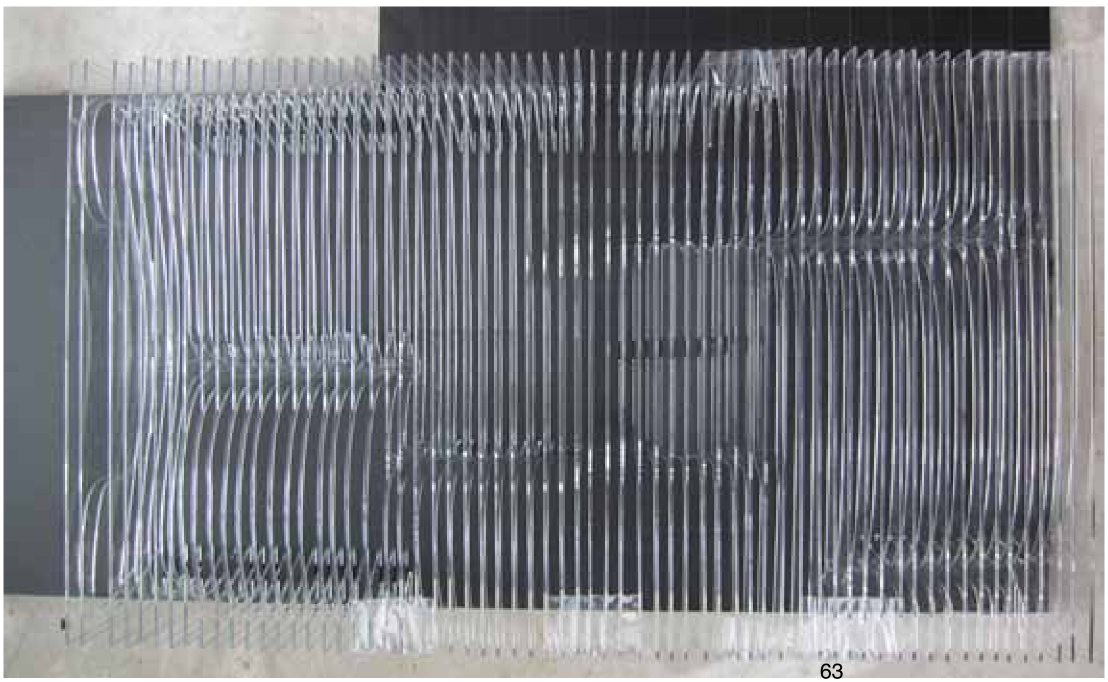
(Opposite) Architectural screen studies into how fabrication techniques and material properties as drivers of design impact the expression of the objects. Top left and right: CNC numbered, drilled and cut PETG plastic, rolled and riveted by hand. The numbers denote matching edges among the truncated cones.
Bottom left, middle and right: Two versions, 12.5mm grooves CNC routed in 25mm acrylic.

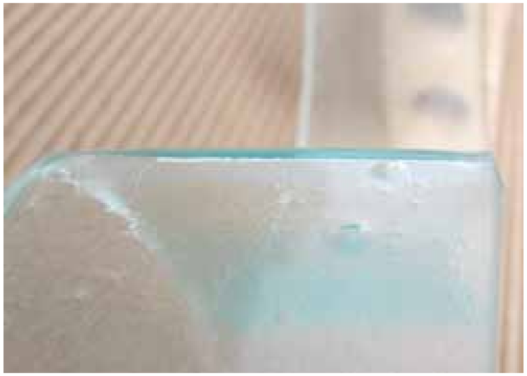
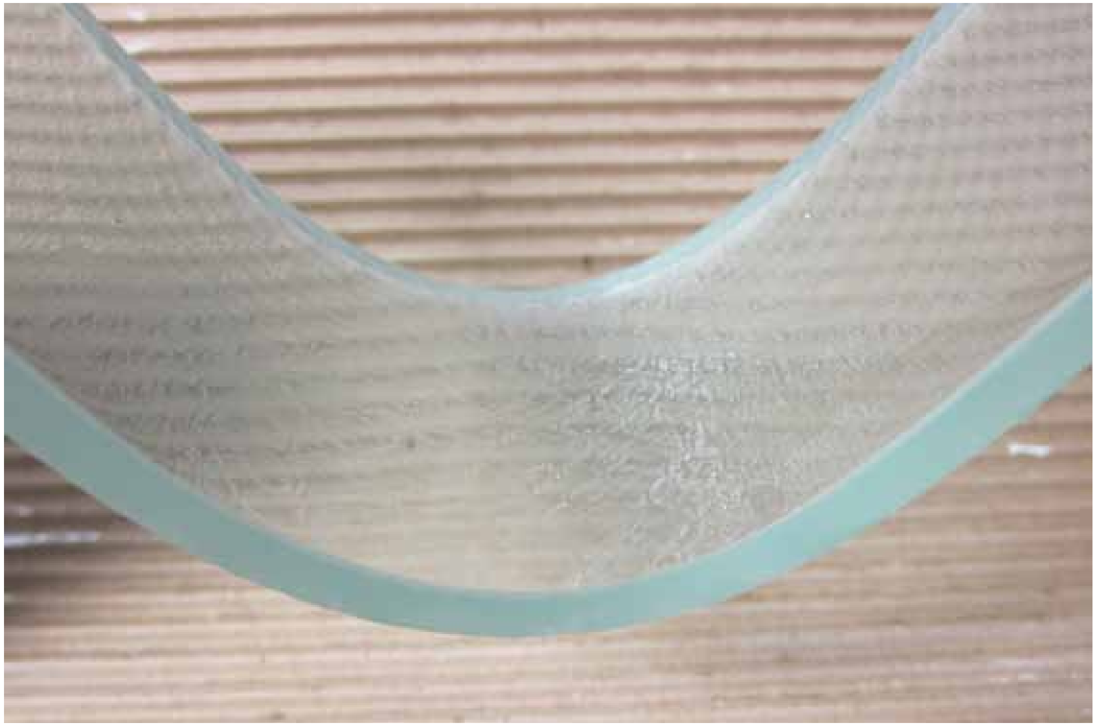
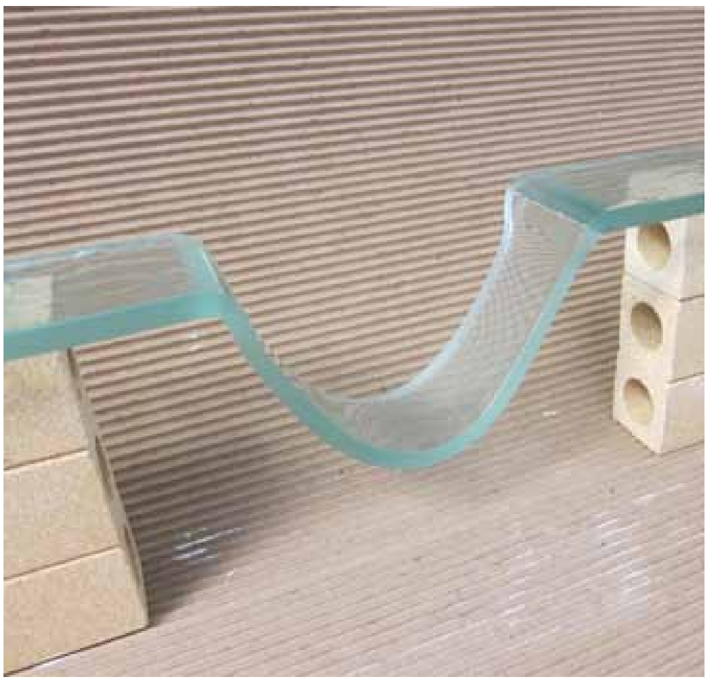
Appendix A: Supplementary Photographs

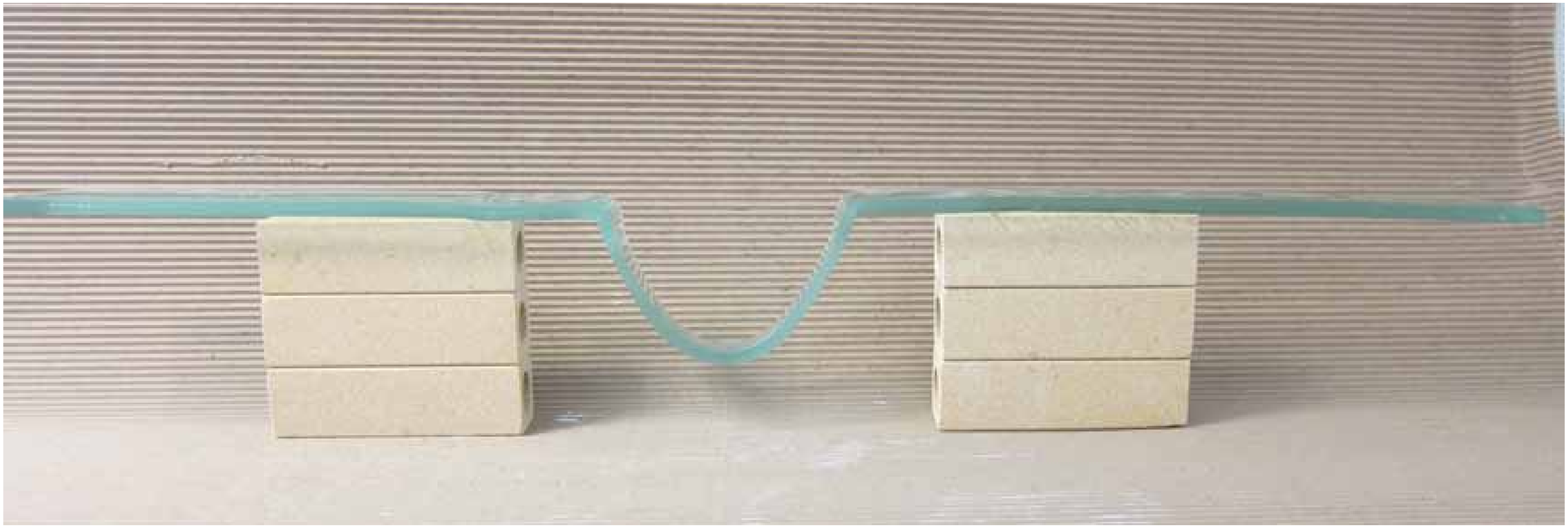


1:50 scale study model for the first iteration of the Glassroom Pavilion enclosure. Laser cut 3mm clear acrylic. Exploring aggregate effects, colour, spatial considerations and model fabrication techniques.



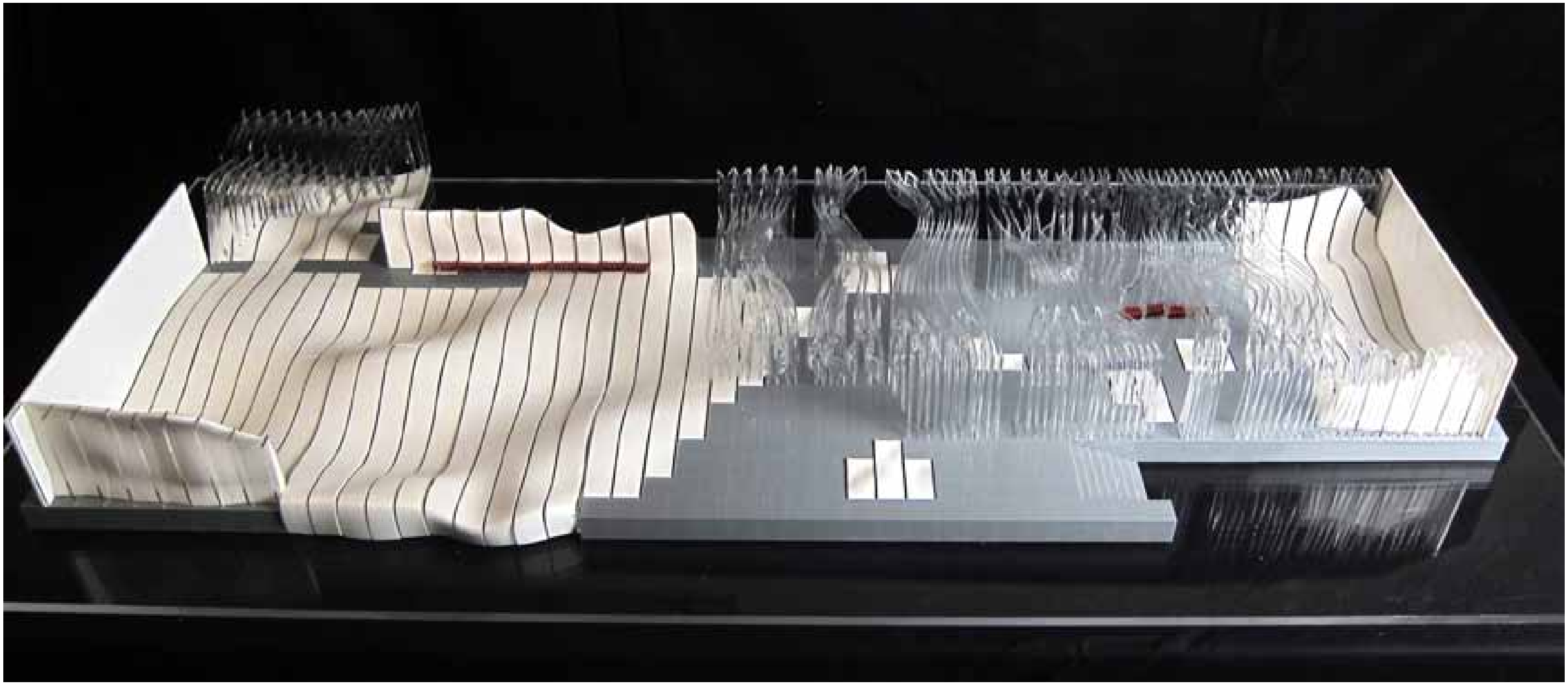


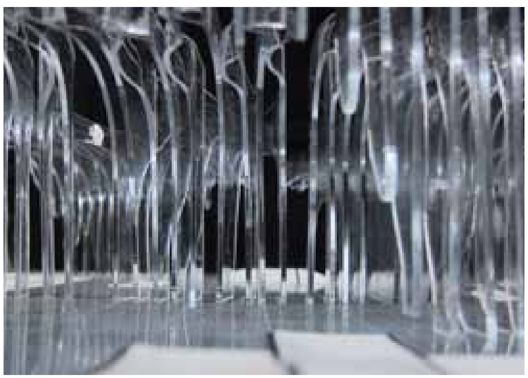





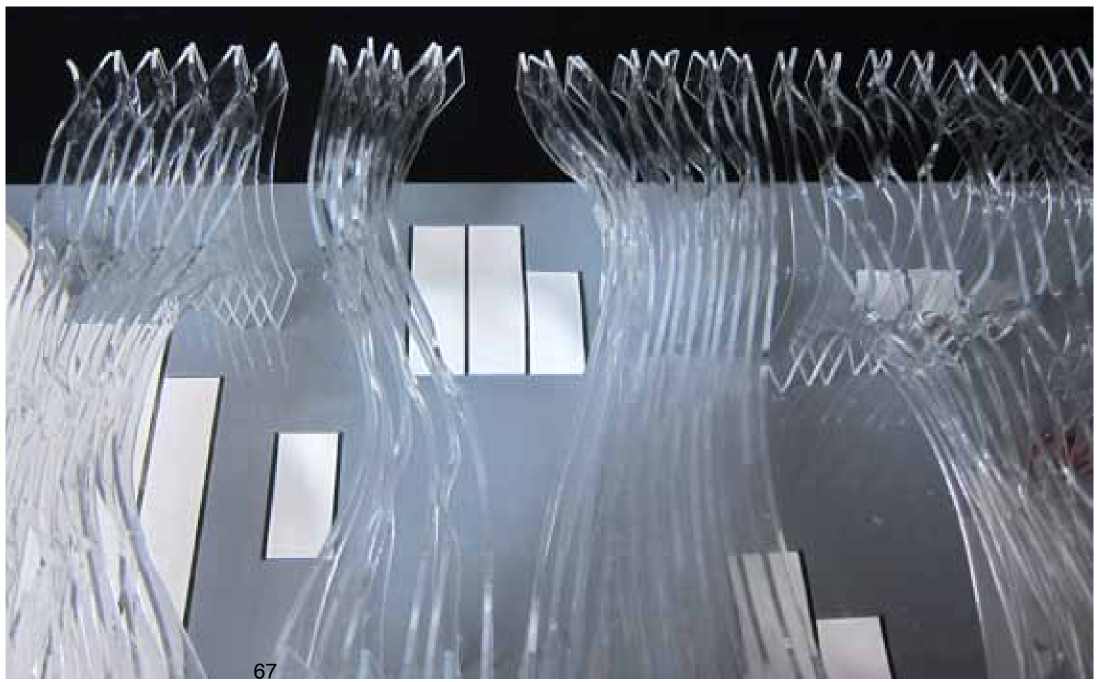



6mm float glass kiln slumped into silica-plaster (shown: opposite, top left) and steel moulds.

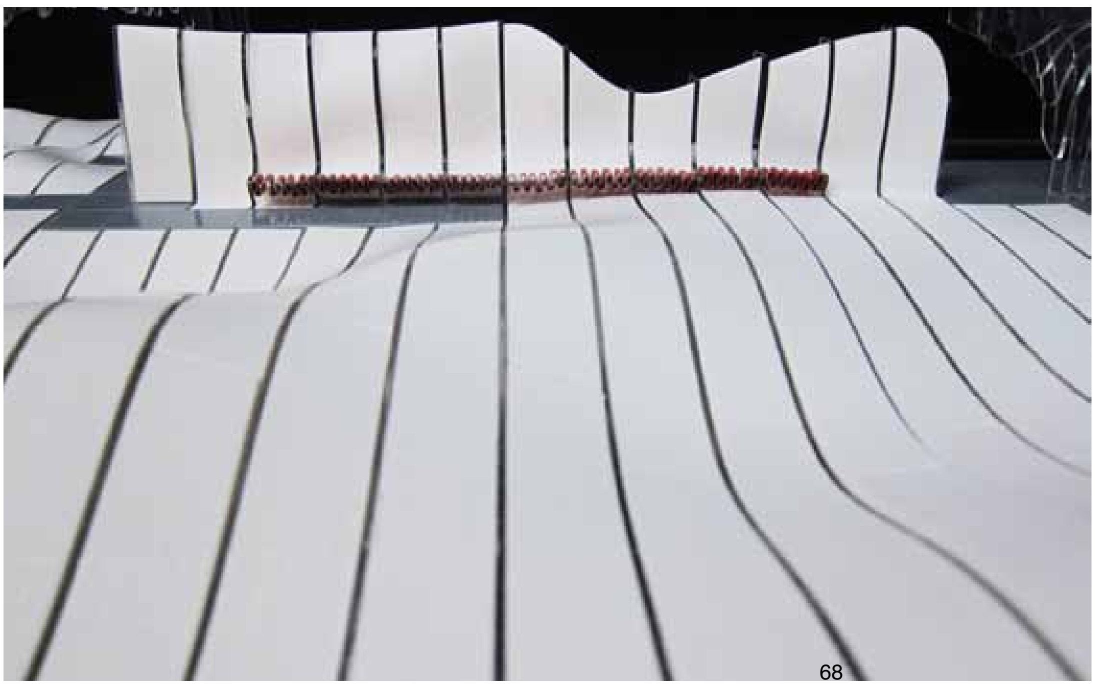
3mm float glass kiln slumped into silica-plaster moulds. The glass was pre-treated by laser etching thick diagonal lines. These lines were intended to show, by distortion, the degree of deformation in the glass. Instead the etched areas were less prone to slumping, giving a rippled appearance. The cloudiness between the stripes is minor devitrification caused by an incorrect cooling profile.

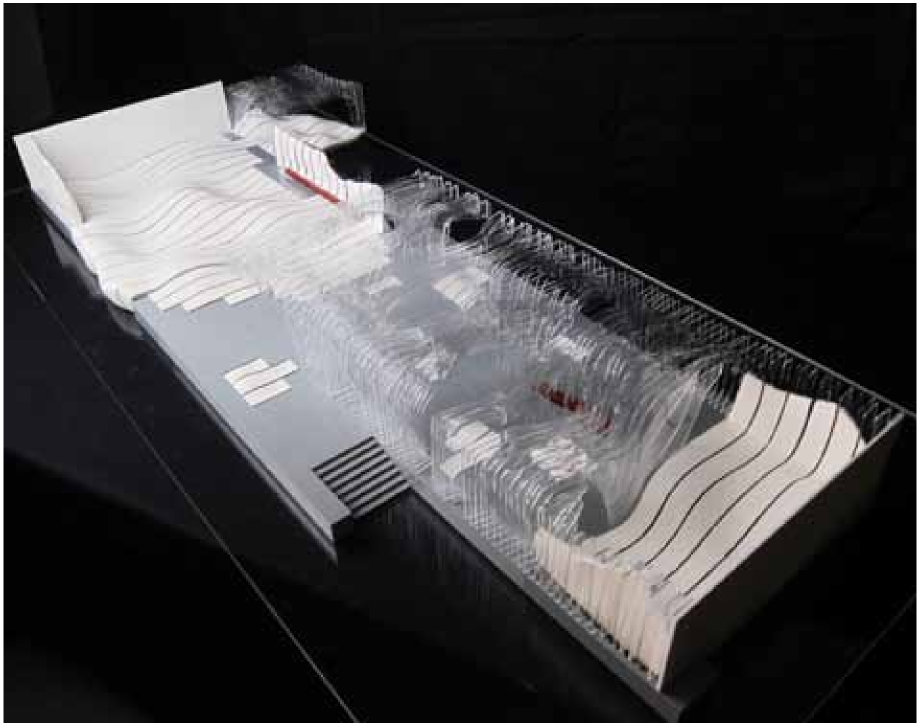


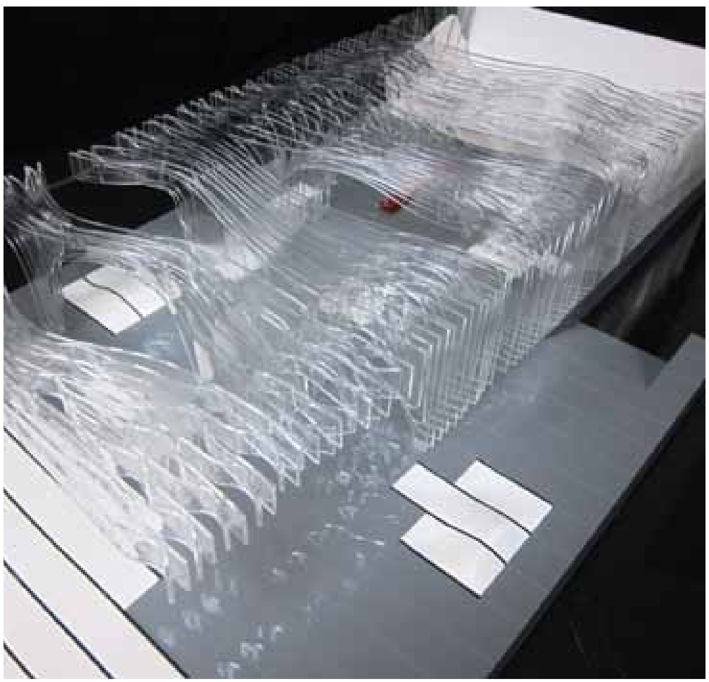




Physical Model (scale 1:50). Terrain: White ABS plastic, 3D printed on edge. Base: 3mm grey acrylic, laser cut. Enclosure: 1.5mm clear acrylic, laser cut flat then individually heated to 300F and shaped on corresponding 2-part moulds. Moulds: EPS blocks manually hot wire cut using laser cut 3mm mdf guides. 120 enclosure profiles, 240 mould parts, 480 mdf guides.







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