DIGITAL WORKFLOWS IN ARCHITECTURE
DESIGN ASSEMBLY INDUSTRY

THE ASSIMILATION AND SYNTHESIS OF DIGITAL COMMUNICATIONS AMONG ARCHITECTS, ENGINEERS, FABRICATORS AND BUILDERS IS DRAMATICALLY ALTERING HOW WE WORK AND OUR RELATIONSHIP TO THE TOOLS WE USE. NEW DIGITAL CAPACITIES ARE RESTRUCTURING THE ORGANIZATION AND HIERARCHY OF DESIGN FROM AUTONOMOUS PROCESSES TO COLLECTIVE WORKFLOWS. THE HISTORICAL ROLE OF THE DESIGNER AS AN AUTHOR, A SOLE CREATOR, IS BEING REPLACED WITH SEMI-AUTONOMOUS, ALGORITHMICALLY DRIVEN DESIGN WORKFLOWS DEEPLY EMBEDDED IN A COLLECTIVE DIGITAL COMMUNICATION INFRASTRUCTURE. THIS IS CREATING A NUMBER OF PRESSURES ON THE DISCIPLINE OF ARCHITECTURE TO REORGANIZE AROUND THE OPPORTUNITIES, AND RISKS, OF THESE CHANGES.

EDITED BY SCOTT MARBLE, PARTNER AT MARBLE FAIRBANKS AND THE DIRECTOR OF INTEGRATED DESIGN AT THE COLUMBIA UNIVERSITY SCHOOL OF ARCHITECTURE, PLANNING AND PRESERVATION, THIS BOOK GATHERS SOME OF THE LEADING VOICES ON THE ISSUES AND SOLUTIONS OF THE EMERGING WORLD OF DIGITAL WORKFLOWS.

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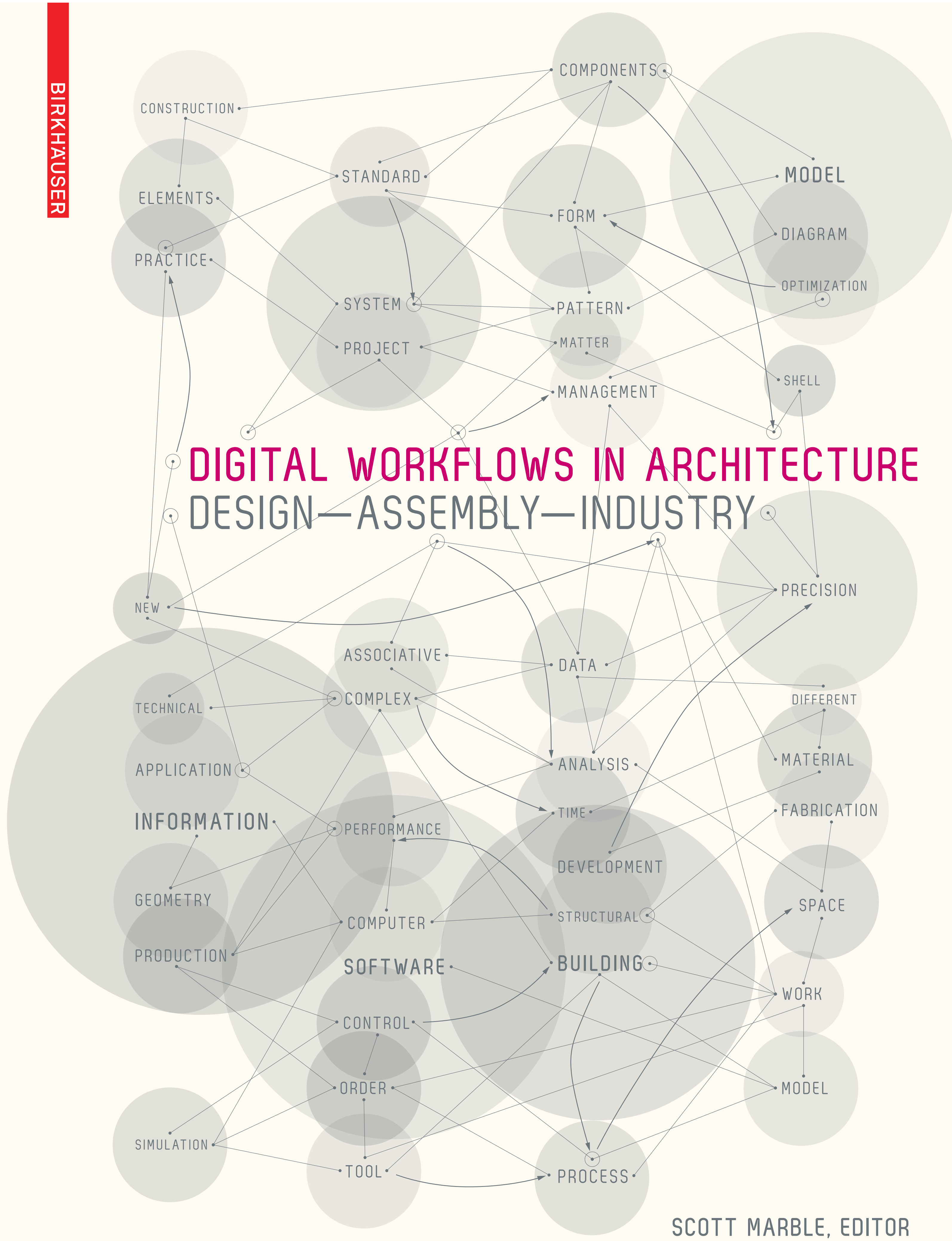
BIRKHÄUSER

DIGITAL WORKFLOWS IN ARCHITECTURE
DESIGN—ASSEMBLY—INDUSTRY

SCOTT MARBLE, EDITOR

BIRKHÄUSER



DIGITAL WORKFLOWS IN ARCHITECTURE
DESIGN—ASSEMBLY—INDUSTRY

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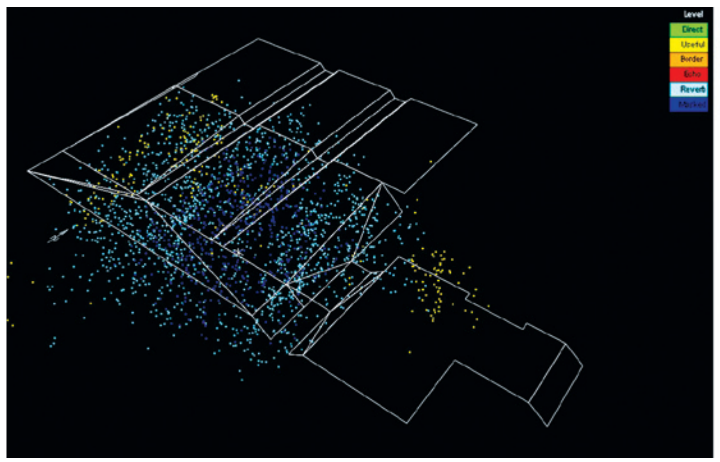
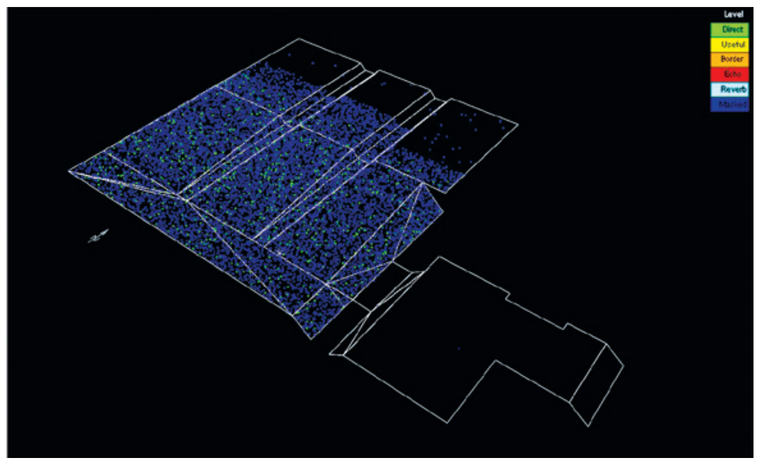
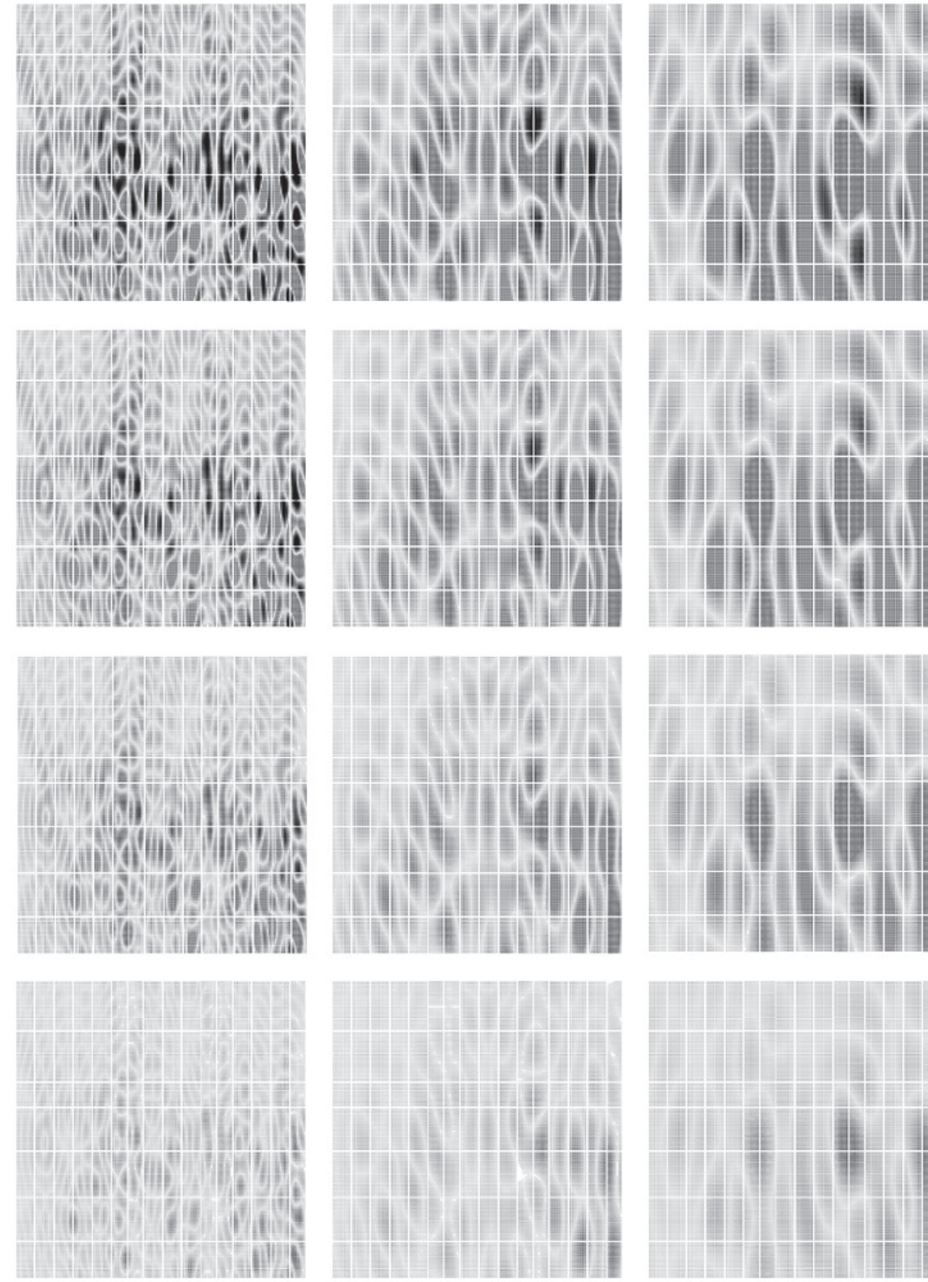
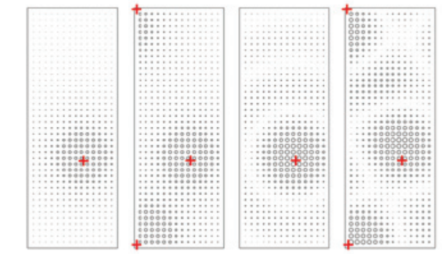




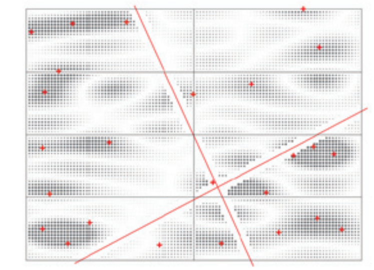
Workflow 2 (top). Zone #1: Social Hub. The first zone, the ceiling of the social hub, is designed to provide an acoustically absorptive surface. The logic of the perforation pattern was developed in two phases: first, an acoustic model of the space was developed to drive the density of perforations, and a second subsequent scripting process integrated panel geometry, lighting and sprinkler layouts into the algorithm and incorporated these elements into the pattern. The digital model became the repository for these technical constraints but also provided flexibility to test and refine the more qualitative aspects of the pattern. The final perforation pattern satisfies the acoustic demands of the space while also providing a dynamic index of its generative process.

Workflow 3 (bottom left and right). Acoustic Simulations & Zones of Intensity. Several scenarios were generated within the acoustical model to identify the zones of the ceiling that, through increased acoustic transparency, would reduce and eliminate reverb and echo effects in the space. These points then became “zones of intensity” or “attractors” for the pattern generation script—areas where the perforations would become larger and provide more acoustic absorption.

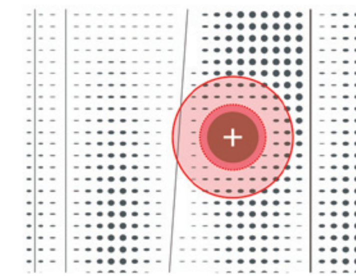




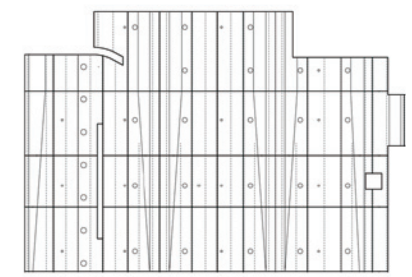
Perforations intensify at attractor locations



Pattern adjusts to panel joints and bend lines



Perforations respond to light and sprinkler cut-outs

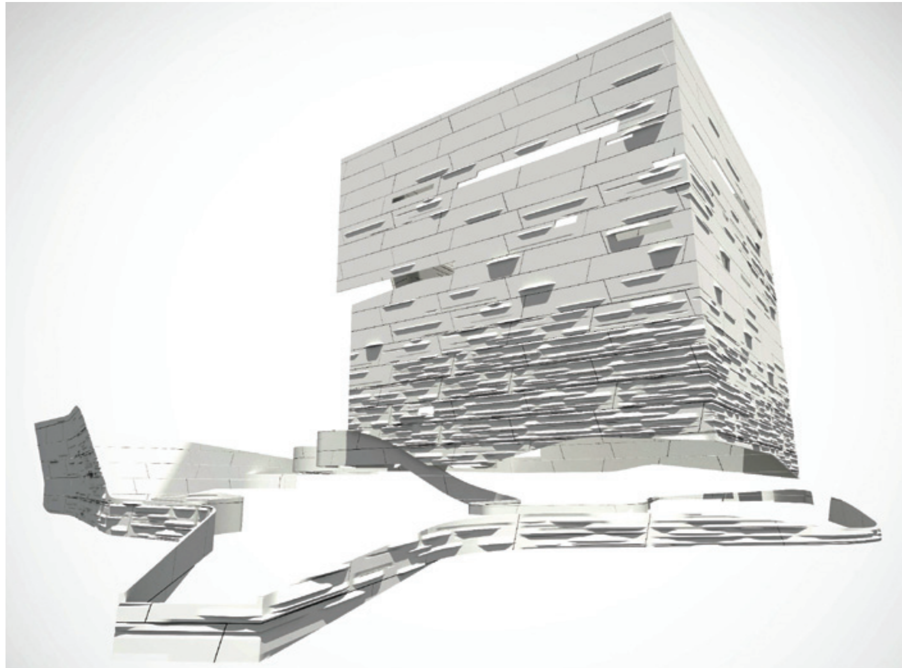


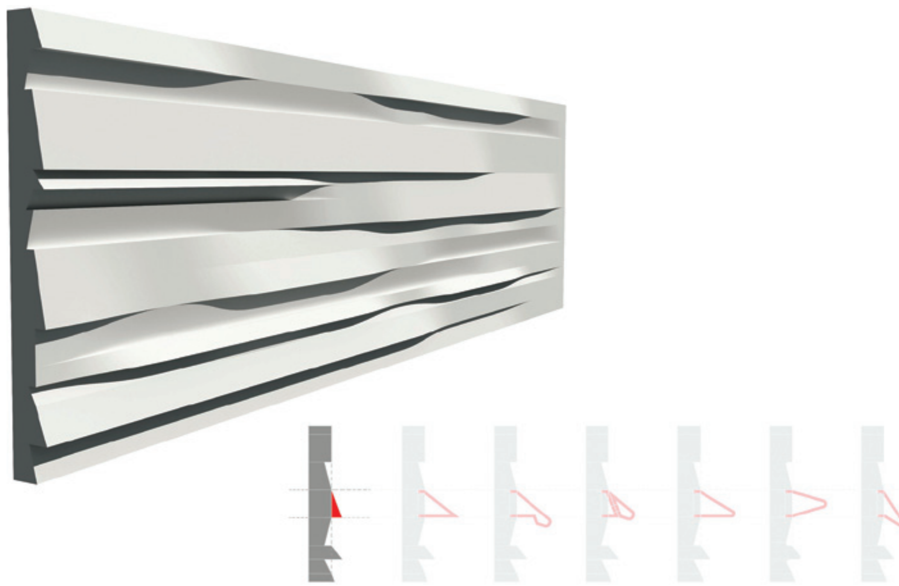
Panels and steel substructure grid

Workflow 4 (above left). Pattern Iterations. A custom script was designed to generate a series of unique iterations for the acoustic pattern, each of which relied on the attractor points while also satisfying the acoustic performance criteria for the space. The iterations were evaluated both for the density of perforations (which translated directly to fabrication time and cost) as well as overall qualitative effect.

Workflow 5 (above right). Refinement of Acoustic Pattern. The custom script was calibrated to respond to the existing building structure above the ceiling, as well as lights, sprinklers and AV equipment that would be integrated into the ceiling. The pattern generated from the acoustic analysis was modified by adding these rules to the parameters of the script:

1. All holes on 1 1/2in grid.
2. All holes can infinitely vary from 1in circles to 5/8in long ovals.
3. No holes within 1in of panel joint lines.
4. Any hole within 6in of panel joint lines must be less than 1/2in in diameter.
5. No holes within 1/2in of light/sprinkler cutouts.
6. Any hole within 6in of light/sprinkler cutouts must be less than 1/2in in diameter.
7. No holes within 1in of bend lines.





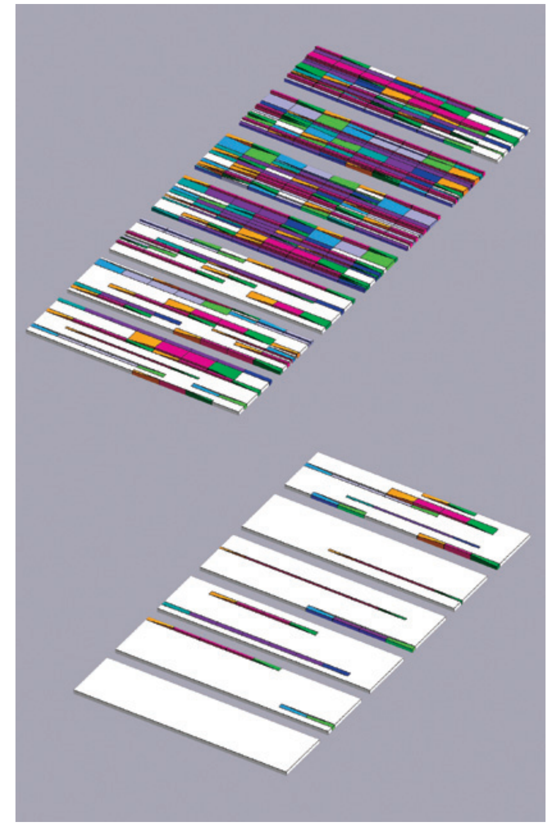
PEROT MUSEUM OF NATURE AND SCIENCE

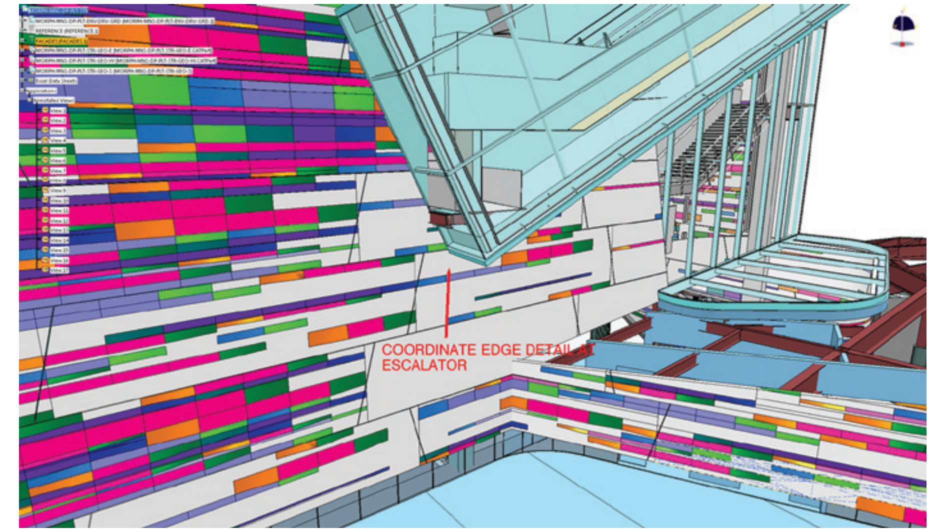
WORKFLOW CASE STUDY

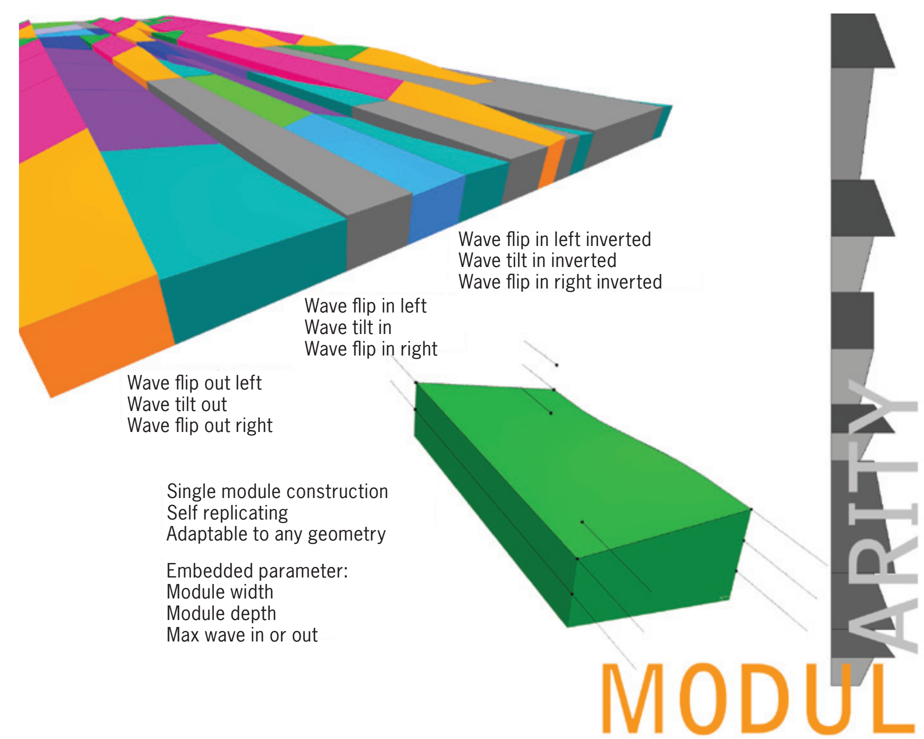
The Perot Museum of Nature and Science in Dallas demonstrates the selective use of digital techniques in conjunction with the skills of craftspeople to develop an innovative workflow in support of design. The building envelope evolved from working closely with a precast fabricator to develop casting techniques that would allow maximum design flexibility within economically feasible production methods. The building's exterior cladding includes 3D precast concrete panels with nominal surface variation ranging from flat to curved in two directions. The pattern of 3D features on the face of the panels varies to enable a gradient and give a more seamless appearance to the overall façade surfaces. The array of features is designed to optimize for increasing economy and increasing variation. Each panel is divided into a rectangular grid of identically sized modules. The design model embodies an economical system of making that translates directly to the precast contractor's fabrication and production methods.

Workflow 1 (top). Design study of the 3D precast panels of the Perot Museum of Nature and Science.

Workflow 2 (bottom). The panels include an array of 3D features on the exterior face of the panel. Designers utilize parametric tools to study variations in individual features, indicated with the red line.



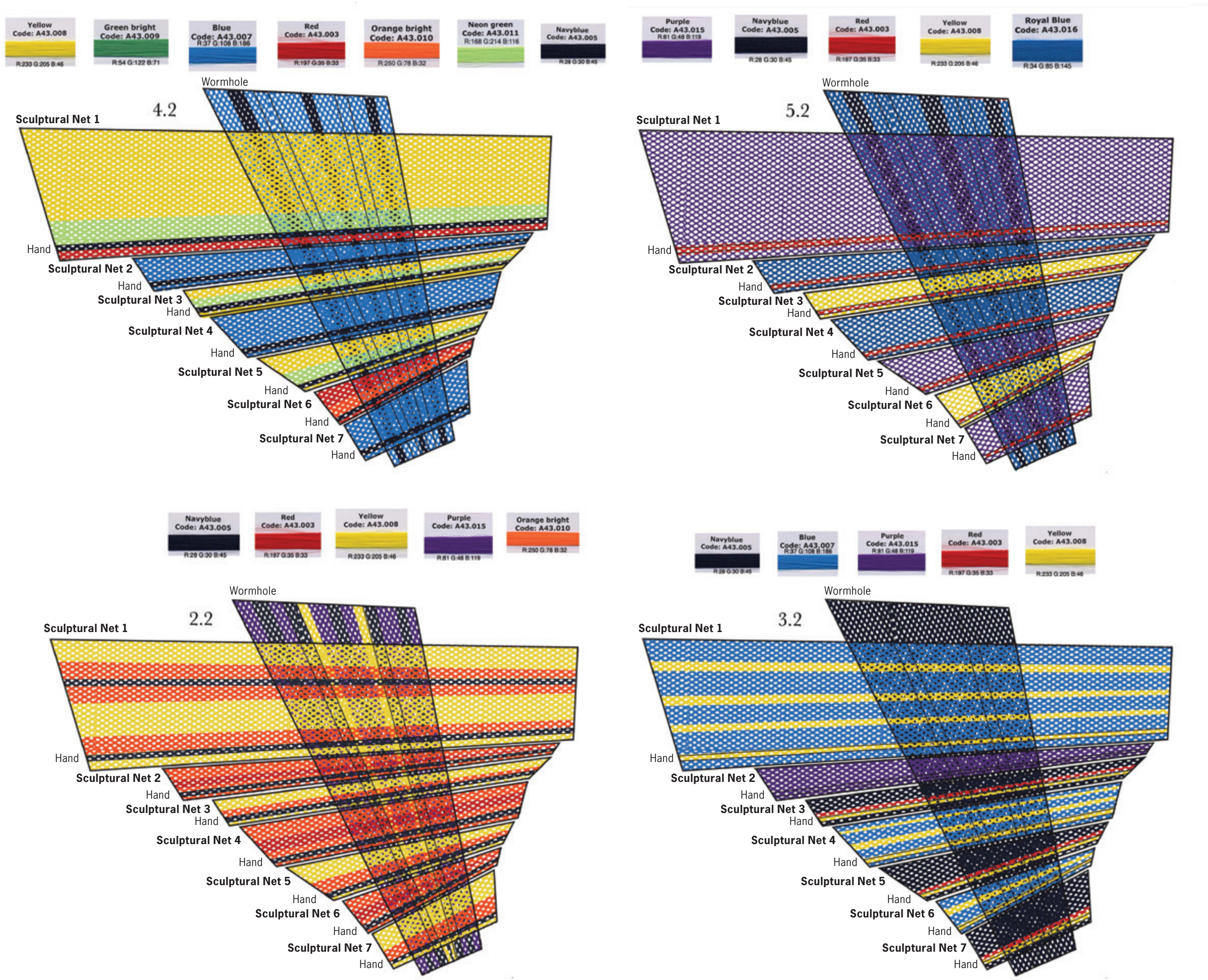




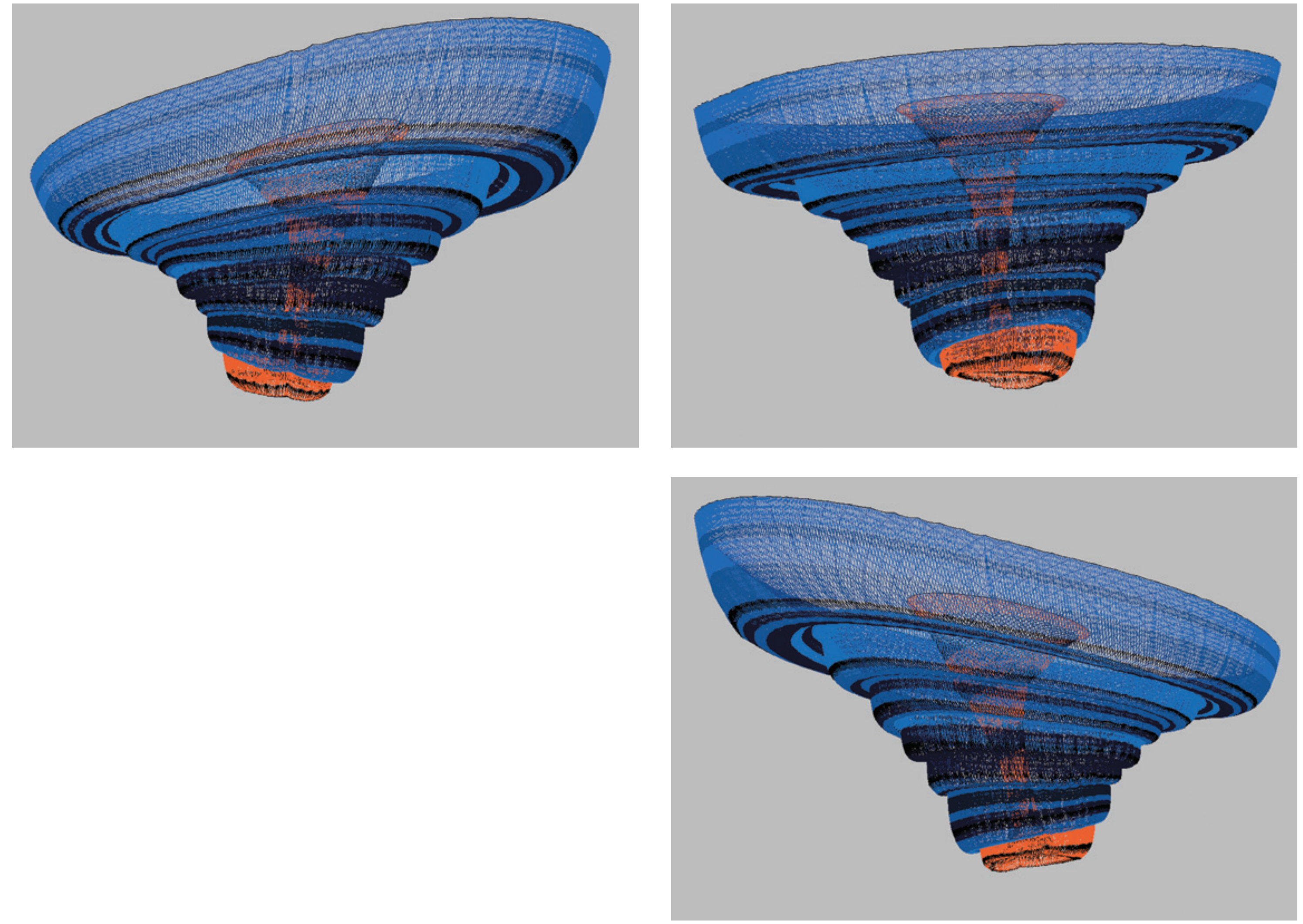
Workflow 3 (above left). Each panel is divided into a rectangular grid of identically sized modules. The white areas indicate a flat panel with no 3D features, whereas the colored areas represent grid modules where a form liner is placed to generate a 3D feature on the panel. Each color represents a different form liner.

Workflow 4 (top right). The design model indicates specific and unique conditions at the points where precast panels are coordinated with other building elements. The high level of technical detail in the model allows the design team to resolve constructability issues during the design process.

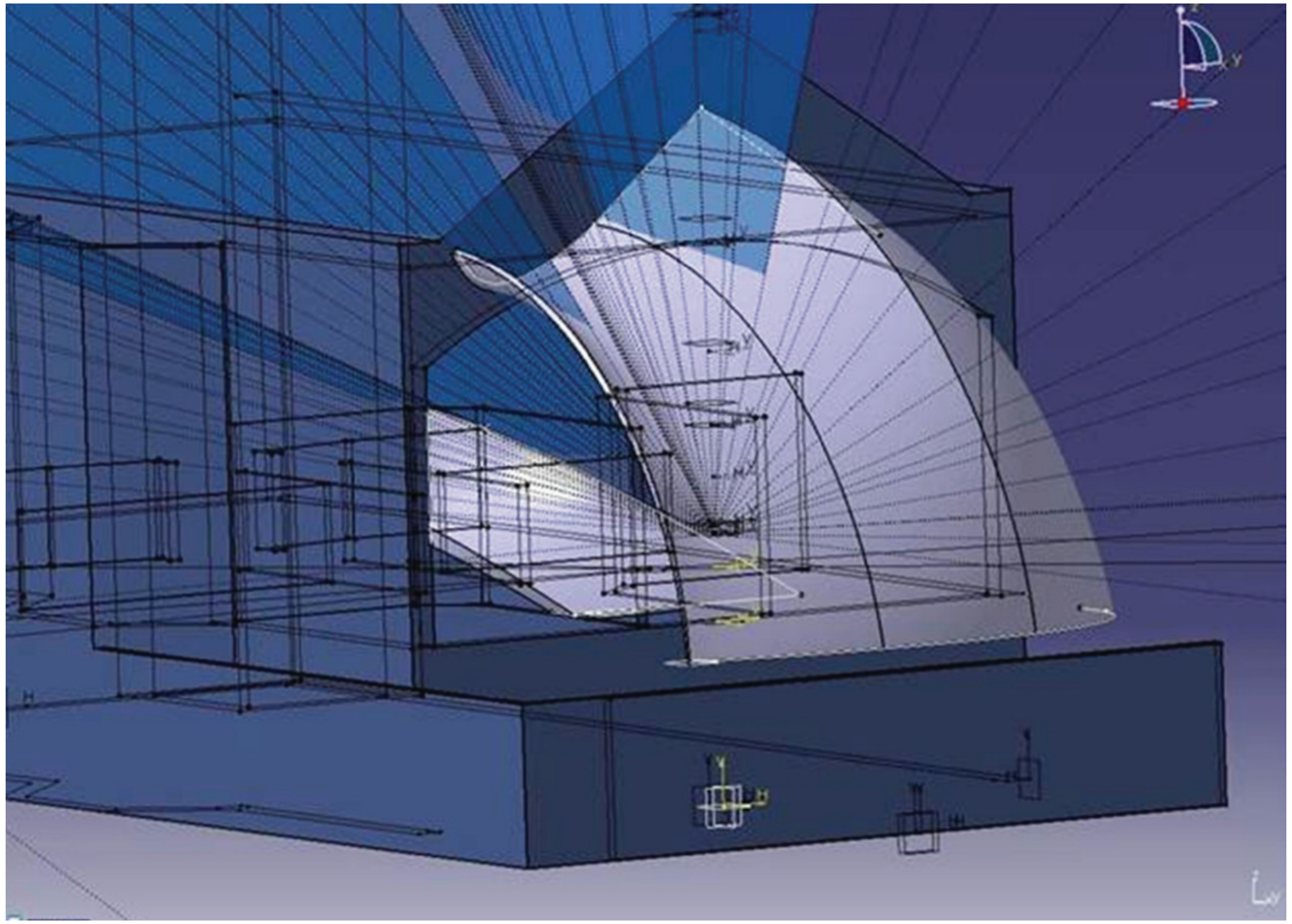
Workflow 5 (bottom right). A design study indicating the method of achieving modularity of the precast concrete panels. The colored blocks represent the solid geometry of a module of the precast panel. These solids will be created by casting their negative as a 3D form liner.



Workflow 5. Individual spool colors were mapped onto versions of the form found geometry so that the software could quickly iterate design options that included both shapes and color for the artist to evaluate.



Workflow 6. When completed, the tool could generate new sculptural geometry, run an analysis and output fabrication drawings in about four hours. During each successive iteration Buro Happold would refine the software while the artist was refining the design. This became a process of optimization analogous to the software engineering concept of refactoring, or the restructuring of code for maintainability, which enabled us to reutilize aspects of the software for future projects.

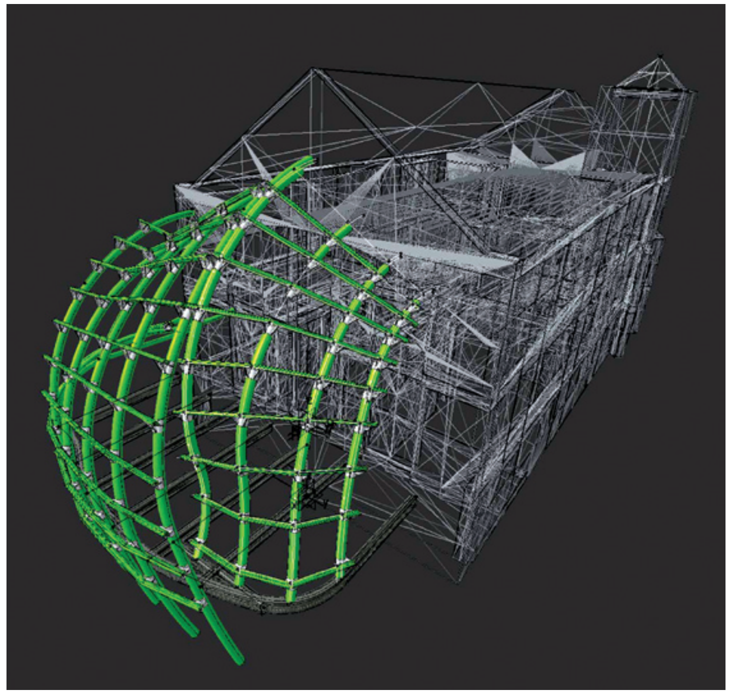


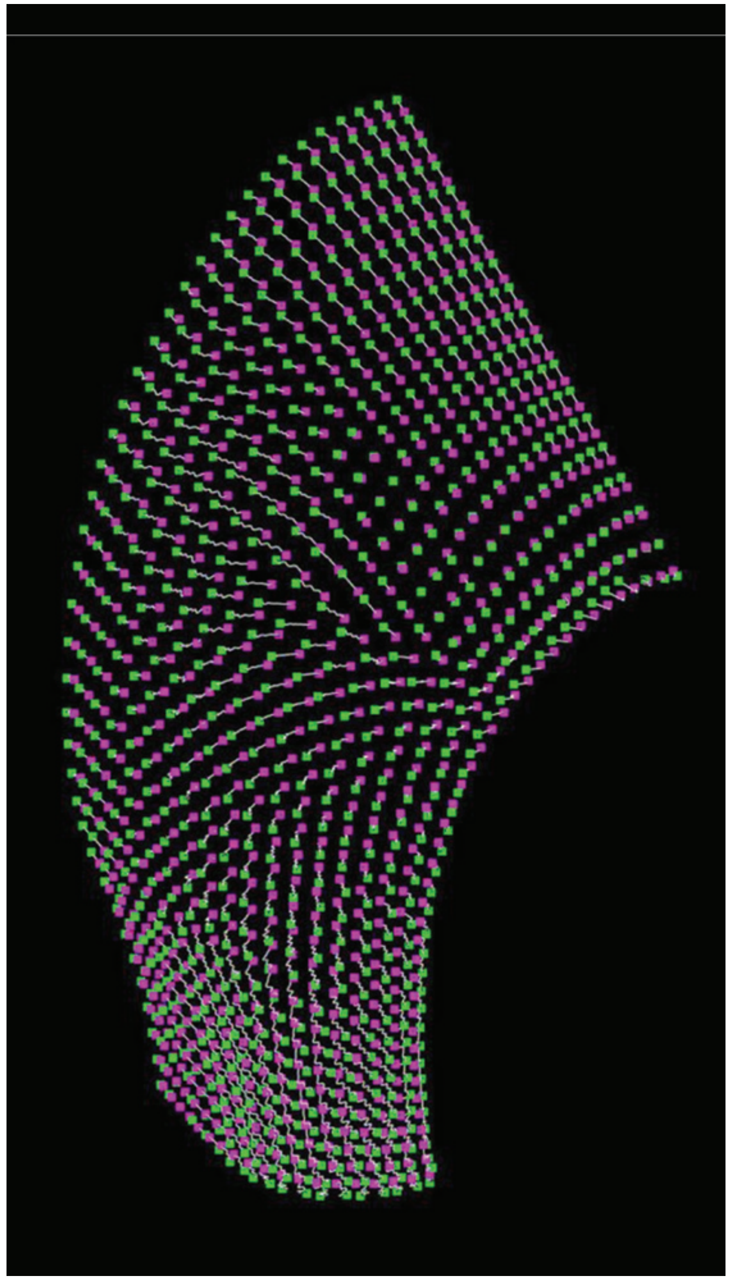
APSE CHURCH ADDITION

WORKFLOW CASE STUDY

This project was a collaboration between PAL students (Leanne Muscarella and Justin Nardone) and the architectural firm of Marchetto Architects on the design and fabrication of an apse church addition in Hoboken, New Jersey. The work spanned from conceptual design to project completion and incorporated content from coursework in parametric geometry, digital fabrication, environmental analysis, design optimization and interoperability.

Workflow 1. Surface model. During schematic design, a surface model of the Apse was generated in Catia with summer and winter sun angles integrated directly into the model as driving geometric parameters.





Workflow 2 (above left). Structural model. In addition, the model contained the full details and assembly sequences of structural steel components, including all radius information for each of the curved tubular columns and the flat steel rib plates.

Workflow 3 (above right). Curvature migration algorithm. This surface model contained a uniform point population that was altered and optimized by a scripted curvature migration algorithm. The script allowed each individual point to locate 12in square regions of minimal curvature based on a surface curvature analysis. This prepared the geometry to receive over 1,100 individual zinc shingles across the doubly curved geometric surface.

INTENTION TO ARTIFACT

PHIL BERNSTEIN

Phil Bernstein is an architect, a Vice President at software provider Autodesk, and teaches Professional Practice at the Yale School of Architecture.

In 1599 the British architect, surveyor and mason Robert Smythson created a beautiful and exacting drawing of a twelve-light rose window for one of his projects. Shown in a recent exhibition exploring the role of mathematics in architecture,[1] the drawing explains the architectural configuration, construction sequence and installation, and stone fabrication of the window in a corresponding curving wall, and it is precisely this conflation of outcomes that makes this image so provocative. [Figure 1] Designer-builders of Smythson's generation saw little distinction between descriptions of design intent and the resulting built artifact, and divisions between the creators and consumers of design information were largely irrelevant in the long era of project delivery by the "Master Builder" approach.

Four hundred years later, the relationship between the processes of design and construction is much changed. The roles of designer and builder have diverged, are acknowledged as different professional disciplines, and are heavily elaborated into hierarchies of architects, engineers, specialty consultants, construction managers, subcontractors, suppliers, fabricators, erectors and others. Even a simple construction project today might involve hundreds of such people, and the means of transiting the gulf from "design intent" to "construction execution" is regularly unpredictable and often worse. The separation is exacerbated by the structure and approach of project delivery itself. Architects and engineers are responsible for creating the intent of the design but ignore, to a certain extent, the means and methods of construction. This state is manifest in "construction documents" that describe, in the abstract two-dimensional language of plan/section/elevation, the highly complex interaction of pieces that form a building. Builders, burdened

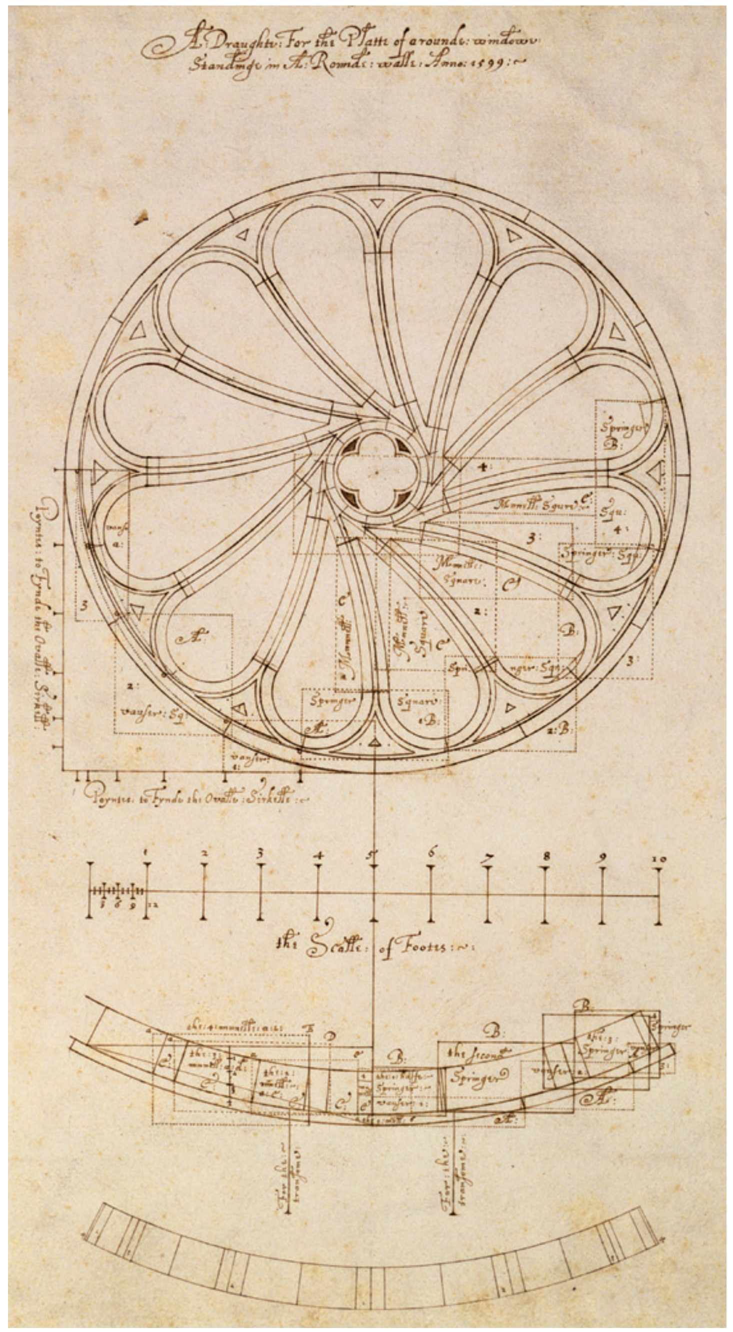


Figure 1. Drawing by Robert Smythson, circa 1599, "A Rounde Window Standinge in a Rounde Walle".

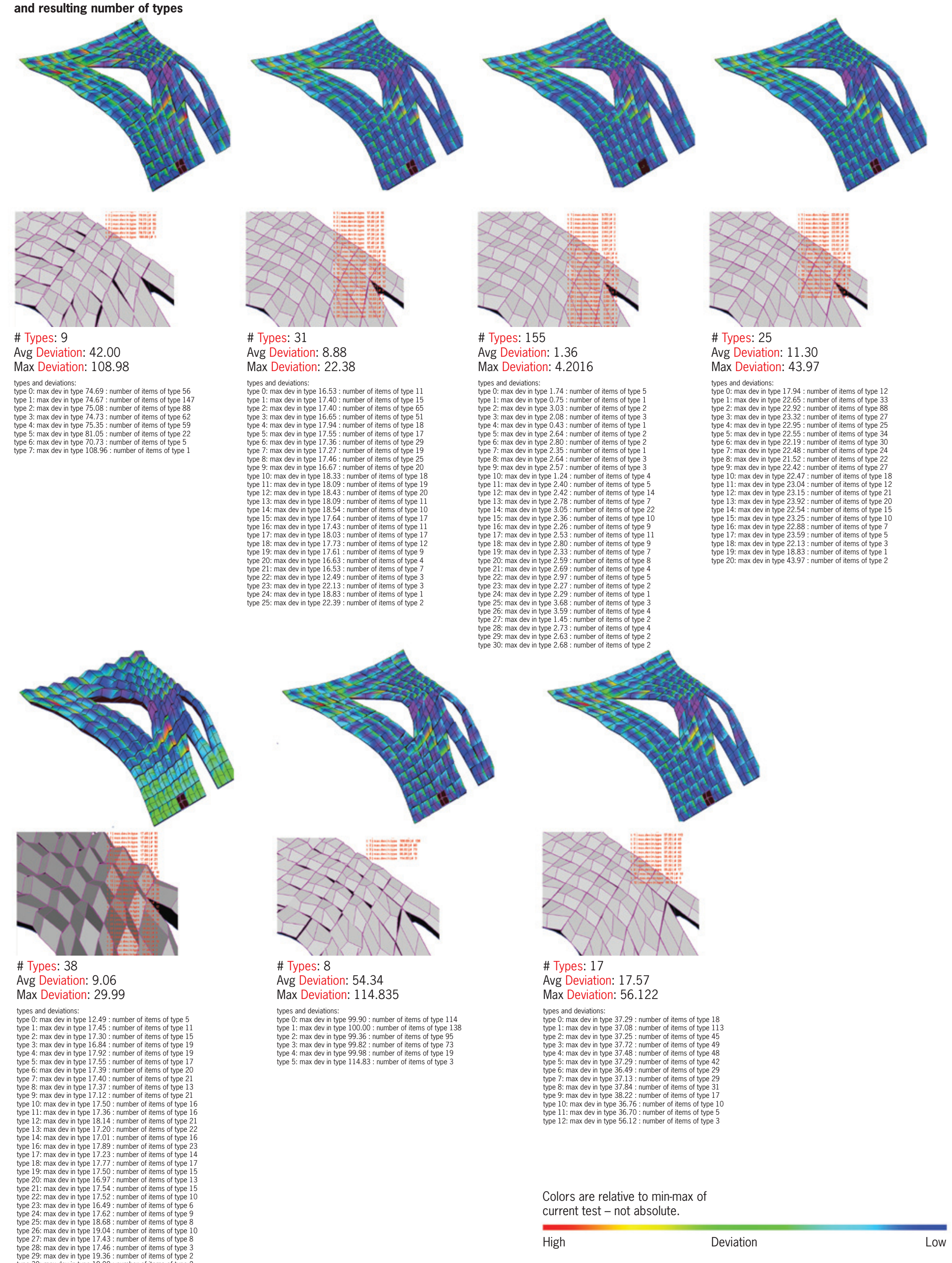
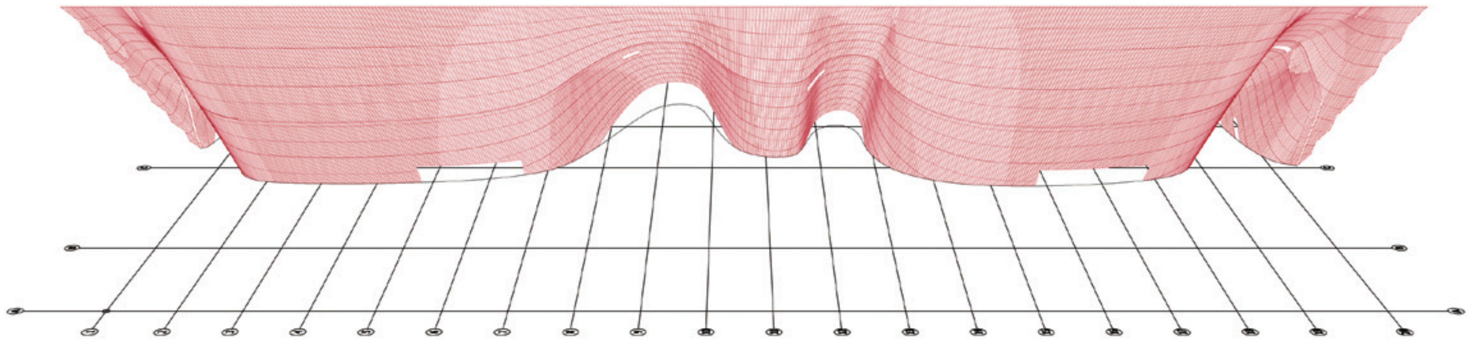
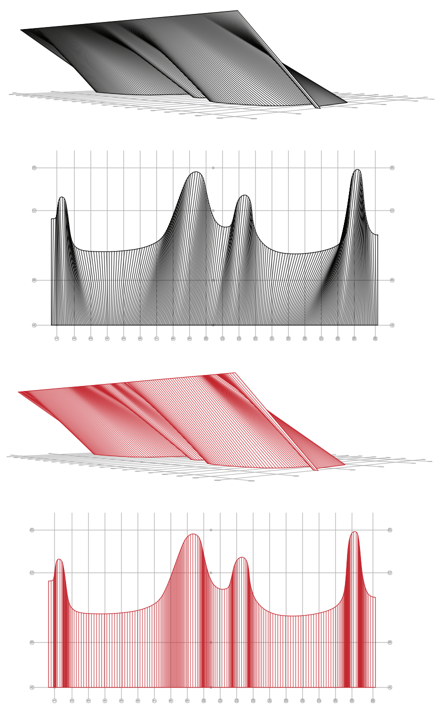
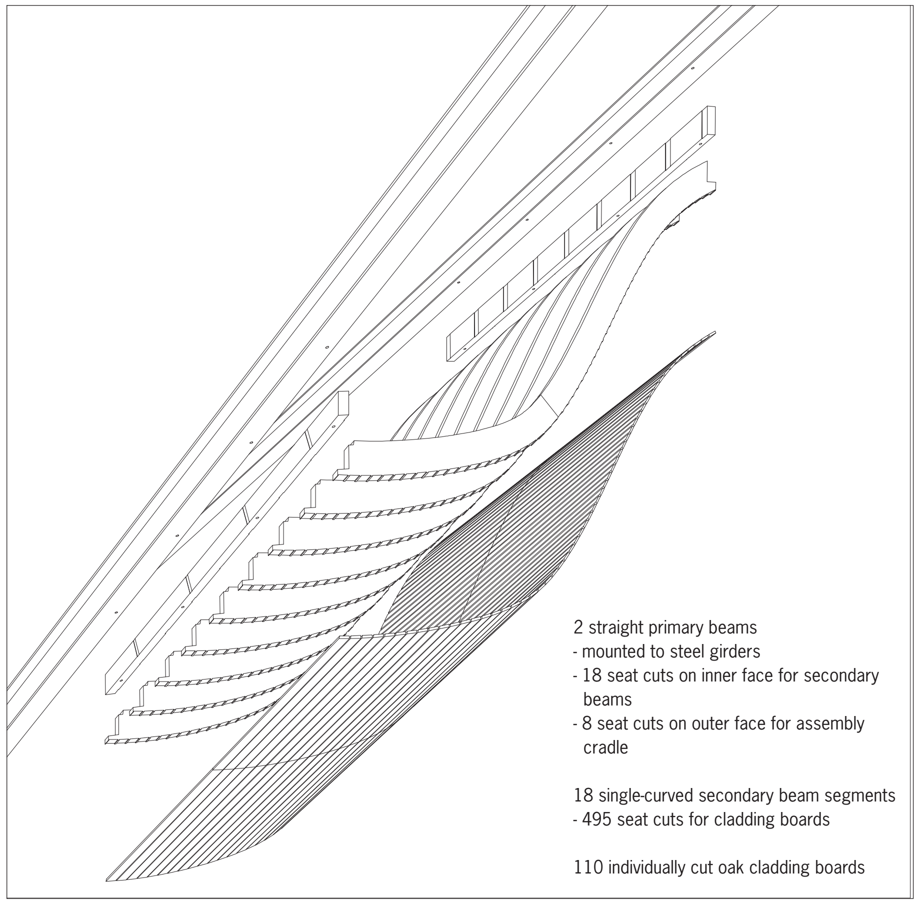


Figure 2. Zaha Hadid Architects, scripted parametric geometry generation.





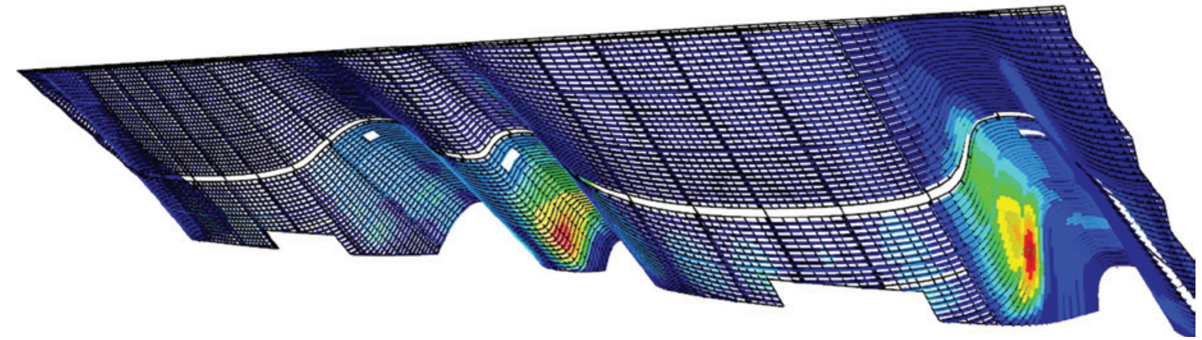


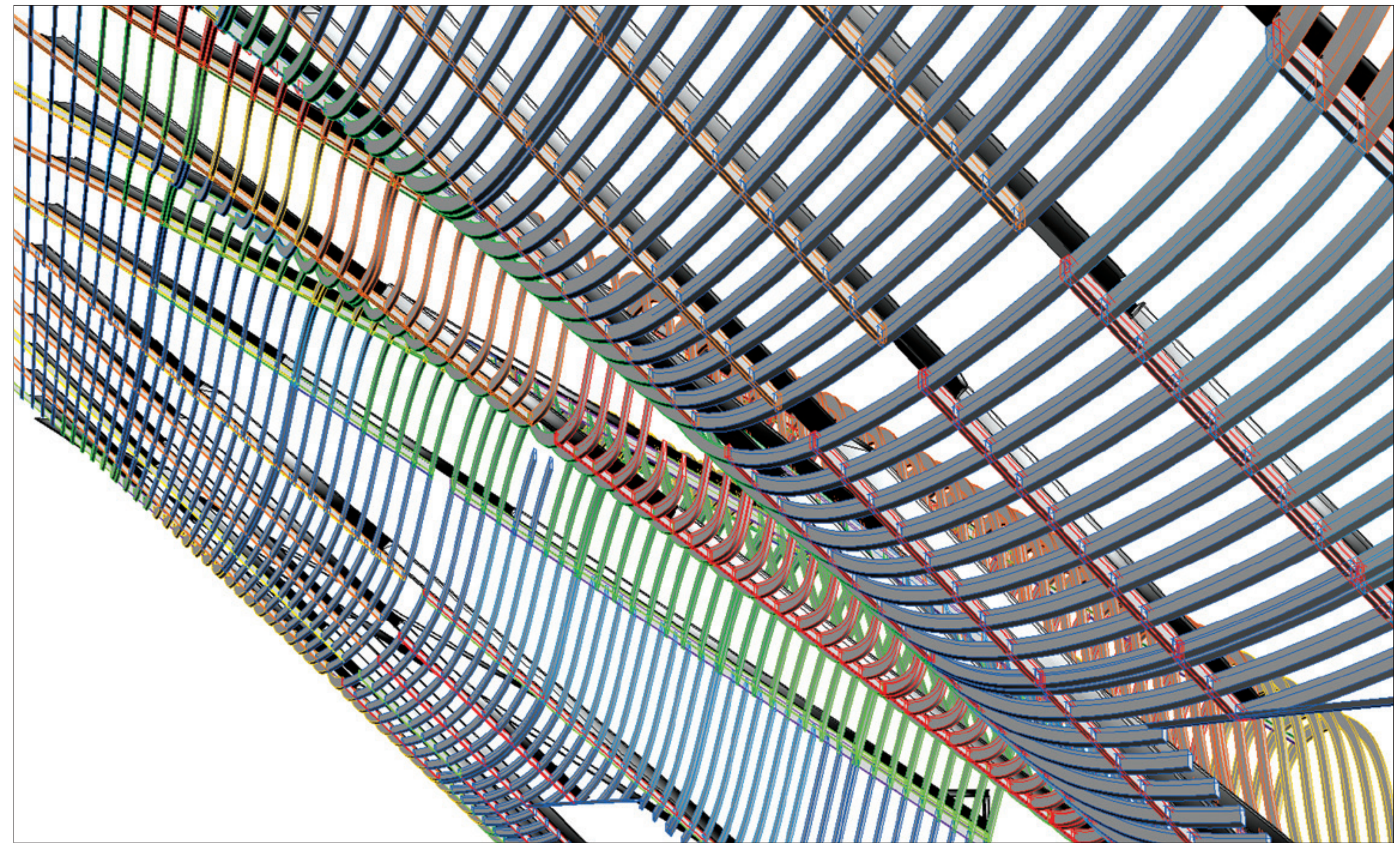
KILDEN PERFORMING ARTS CENTRE

WORKFLOW CASE STUDY ▶

Working in close collaboration with the architect, engineer and timber specialists, designtoproduction developed a fabrication and assembly concept for the curved wooden façade of the Kilden Performing Arts Centre in Kristiansand. The workflow consisted of refining the design geometry from the architect in response to fabrication and assembly logics and then developing a parametric 3D model. The model contained data for 14,309 glue-laminated girders and locally sourced oak cladding that were then output from this model and delivered to the timber fabricator for CNC fabrication. This was one of several timber projects realized through a refined workflow, where the structural engineering of complex timber structures, provided by SJB Kempter Fitze, and the craft and digital timber fabrication skills of Lehmann Timber Construction were integrated through the parametric modeling of designtoproduction.

Workflow 1 (top). The initial model provided by the architects for the Kilden Performing Arts Centre seemed to be a simple ruled surface. However, varying undulations in the surface created unresolved geometry that was impossible to detail, fabricate and construct.





Workflow 2 (facing page, left). designtoproduction rationalized the surface so that it used similar-sized planks and reduced the gaps and pinching of the original mesh.

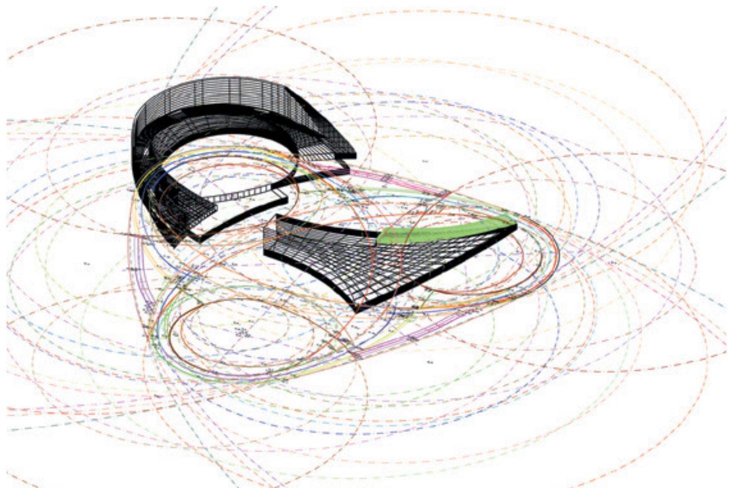
Workflow 3 (facing page, right). The design goal was to create an underlayment system of ribs onto which the finished oak cladding boards would be fixed. The model included "seat cuts" that were CNC milled into the underlying ribs to make installation both easier and faster.

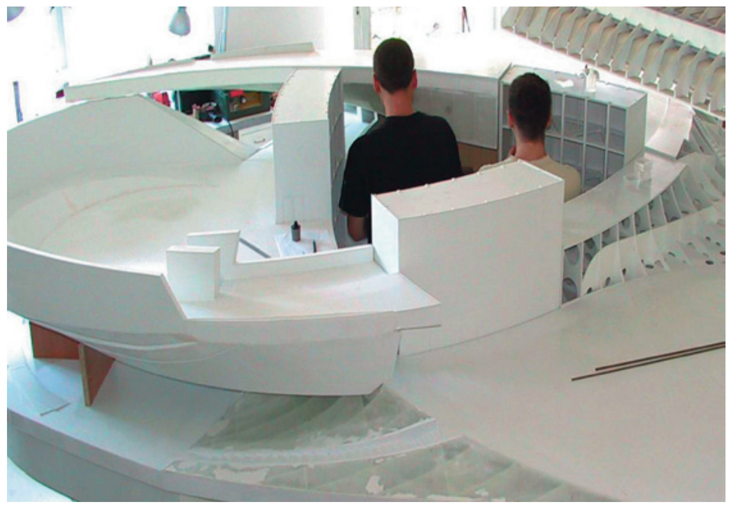
Workflow 4 (bottom), 5 (top). Developing the model parametrically allowed the designers to push and pull certain areas of the façade and get updates on the constructability of the system in real time.

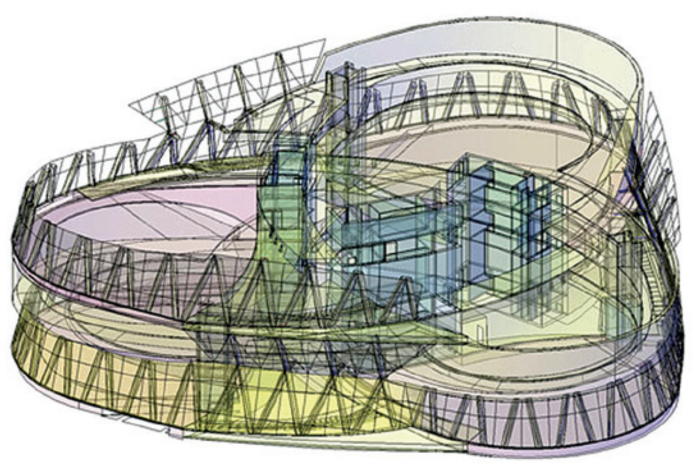
very interested in the idea of how to proportion information to guide design. Where before we proportioned “mass”, we now proportion “information” in the architecture, but we have to know where, what and how much value to give to the information, based on the parameters we are working with. In a way it is strange to call it proportioning of information because we used to proportion geometry and forms, but these can be combined with information. Indeed, information can now inform the geometry, it can inform the form.

SM: Imagination has been part of your work for a very long time. What do you see as the relationship between imagination and computation? While they could be seen as opposites in that one is qualitative and the other quantitative, it is also true that for developments at high levels of computation through fields like artificial intelligence, the brain has regularly been used as a model. There is a very interesting reciprocal relationship between human imagination and rational computation. What are your thoughts on this relationship relative to the design process?

BvB: I often have long discussions with my friend, Robert van Lier, from the Donders Institute for Brain, Cognition and Behaviour in Nijmegen on this topic. What I have discovered in these conversations in relation to our design process is that all of my intuitions related to the development of the Möbius House—repetition, the ways you could start to play with double images, the suggestiveness of the figurative versus the abstract—were not learned through the use of the computer but rather by trying to intuitively articulate new forms of spatial aesthetics. And that is only possible by using your imagination and experience to formulate a vision of something and always be ahead of the computer. If digital techniques become more important than the thinking process, a bizarre condition develops where just because







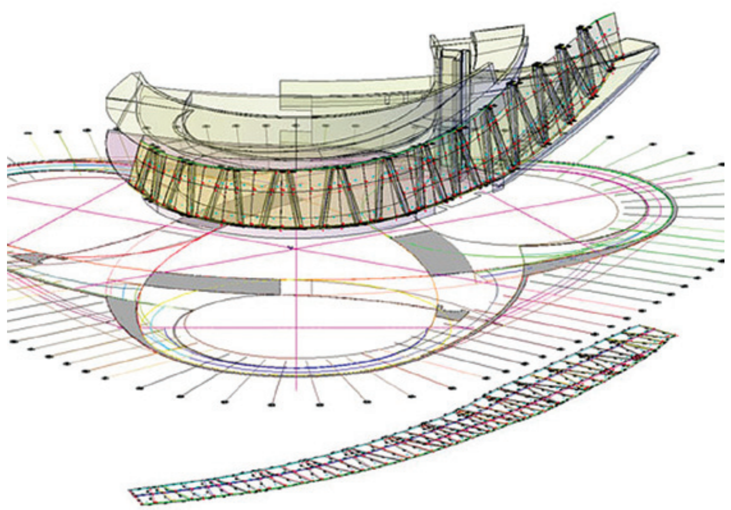


Figure 5 (top left, bottom left, bottom right). UNStudio's Mercedes-Benz Museum, Stuttgart. The underlying geometry of the building consists of tangentially interlocked circles and arcs. This system was programmed into the mother model (an early version of BIM), with the idea that local changes could easily be carried through the entire building while still controlling the overall geometry.

Figure 6 (top right). Model showing a section of the Mercedes-Benz Museum. Regularly stepping out of a digital workflow serves as a reminder to distinguish between information used to design and information used to manage.

something can be modeled on the computer, it can get built, which is what is now happening around the world. While we know that it is possible to attain highly diverse architecture with computational design, we have lost sight of how important it is to keep thinking. We need to stimulate our imagination and renew architecture through the rethinking of the disciplines of geometry, building, how you work with infrastructure and other realities of construction. [Figure 4]

SM: This is a perfect segue into the relationship between “Designing Design” and “Designing Industry”, because the design model for you seems to serve the purpose of bridging the gap between more abstract thinking and more concrete realities. You also speak of “mother model”, primarily in reference to the construction of the Mercedes-Benz Museum. Is the design model and the mother model the same? Or is the mother model a more specific version of a design model? How do you see those two models relating?

BvB: The mother model is a further extension of the design model. The design model encompasses the theoretical or mathematical principles of a project, and then the mother model is the actual 3D model that is constantly in flux and being changed as the project develops. It is adaptable and linked to all of the consultants and team members working on the project. We have discovered over the last few years that the mother model can control quick digital exchange and better manage and integrate all of the information of the design team. In one day, you can exchange information with dozens of specialty consultants and have updated information back the next day in the same model. This was a very new process in 2004 when we were working on the Mercedes-Benz Museum and brought the first programmers into our office. We didn't even have BIM software at that

Figure 7. Mercedes-Benz Museum. Sixteen months into construction.

THE SCENT OF THE SYSTEM

JESSE REISER & NANAKO UMEMOTO

Jesse Reiser and Nanako Umemoto are Principals of Reiser + Umemoto RUR Architecture. Jesse Reiser is Professor of Architecture at Princeton University.

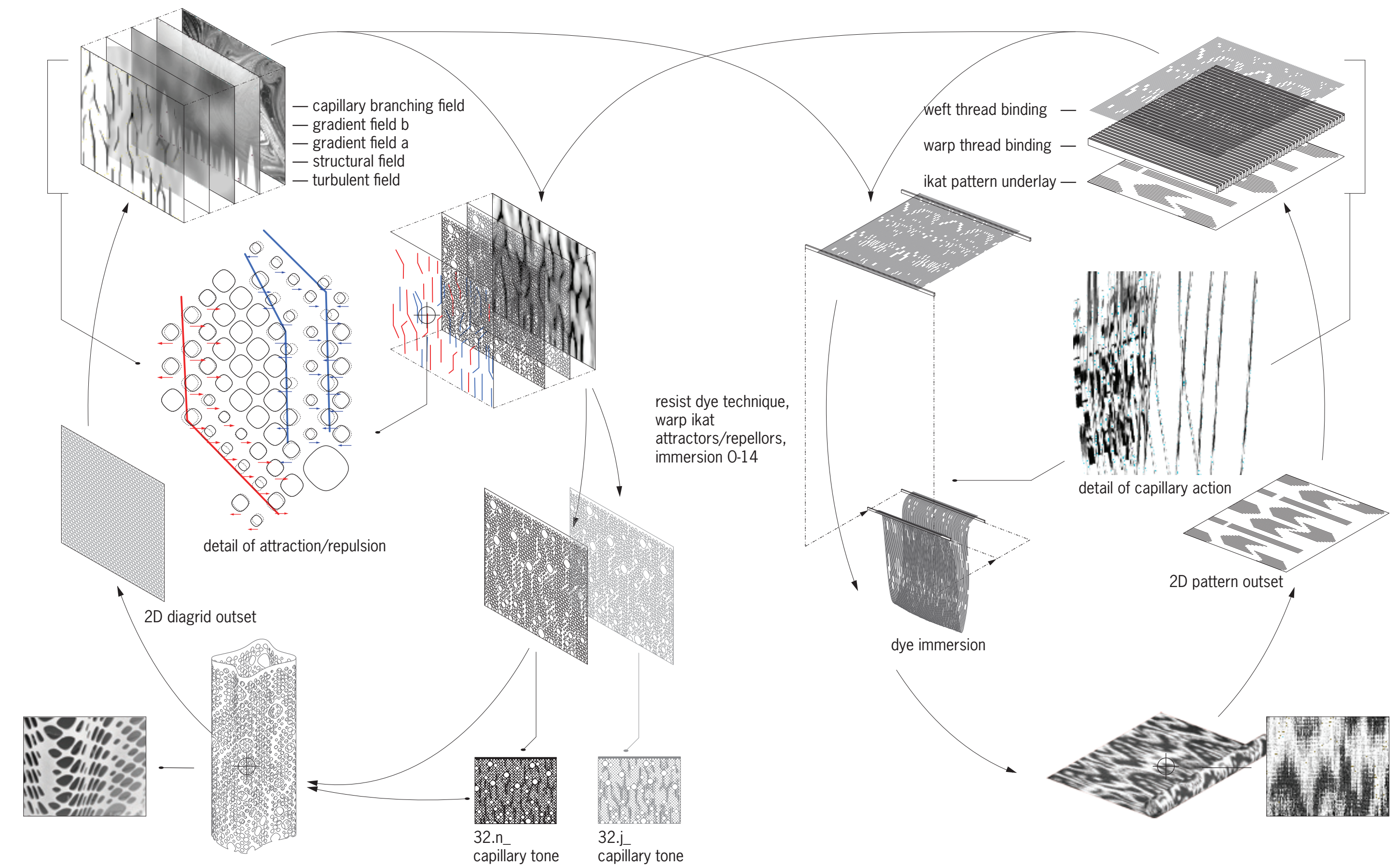
It is widely assumed that the architectural innovation of the 1990s was made possible by the computer, but this is only a partial truth. Certainly, new technologies made possible linkages between design and the economics of production that had never before existed, yet the real breakthroughs were conceptual and aesthetic before they were technological. The politico-aesthetic ground was laid in the aftermath of exhausted strategies to produce architectural difference (deconstruction and collage) over and against modernism's homogeneity, through Deleuzian concepts like continuous variation and corresponding architectural models such as Jeffrey Kipnis's theory of intensive coherence.[1] In short, the architectural desire to produce difference through similarity pre-dated its technological employments.

Today's current infatuation with scripting is no exception, where in the name of bespoke algorithms practitioners hope for an architecture that will be, at long last, more fully intentional, tractable and rigorous. To be sure, scripting is a useful addition to the digital toolbox when it is used to explore well-defined design concepts, but in the worst case it becomes a substitute for active judgment. Inertia takes over and architects fool themselves into thinking that repetition—simple or complex—is a form of rational thought. There are many aspects and applications of computational design and analysis that are becoming common today; the risk is that the seduction of these tools creates an illusion of rigor that obscures the role of active critical assessment. The challenge for the future development of computation in architecture is the use of discretion to know when and how it should be applied to design.

In our work, computation is used as a tool to work through aesthetic and architectural agendas. One of the primary benefits of using digital tools during the design process is the increase in speed of feedback—of being able to visualize changes quickly. The use of scripts allows us to speed up the design process to a point where we can streamline mechanical processes and complete the project with a small team. However, there is a limit to what computation as a design tool can achieve before the results become mechanical.

With this in mind, we can discuss our design for O-14, our recently completed office tower in Dubai, and its particular relationship to design, analysis and fabrication methods. The design began with a primarily aesthetic desire to see drifts of forces flowing down the building—these could have been painted or sketched—but as we attempted to develop scripts to simulate selective modulation, the desired effect was lost. We tested ways to automate the effects of the building's gradient hole pattern but the result was not responsive enough and became too mechanical—you could smell the system through the unthinking inertia of the script. When these design ideas were turned into rules, the rules necessary to produce the local conditions became so numerous and specific that the time needed to generate each iteration was no longer efficient, so eventually this approach was abandoned.

We were much more interested in the sensitive shifts and continually changing gradients that could be produced in a watercolor wash or charcoal drawing as an expression of the painter. These effects would be more localized and precise. In the end, the shell geometry, subjected to the iterative process of structural



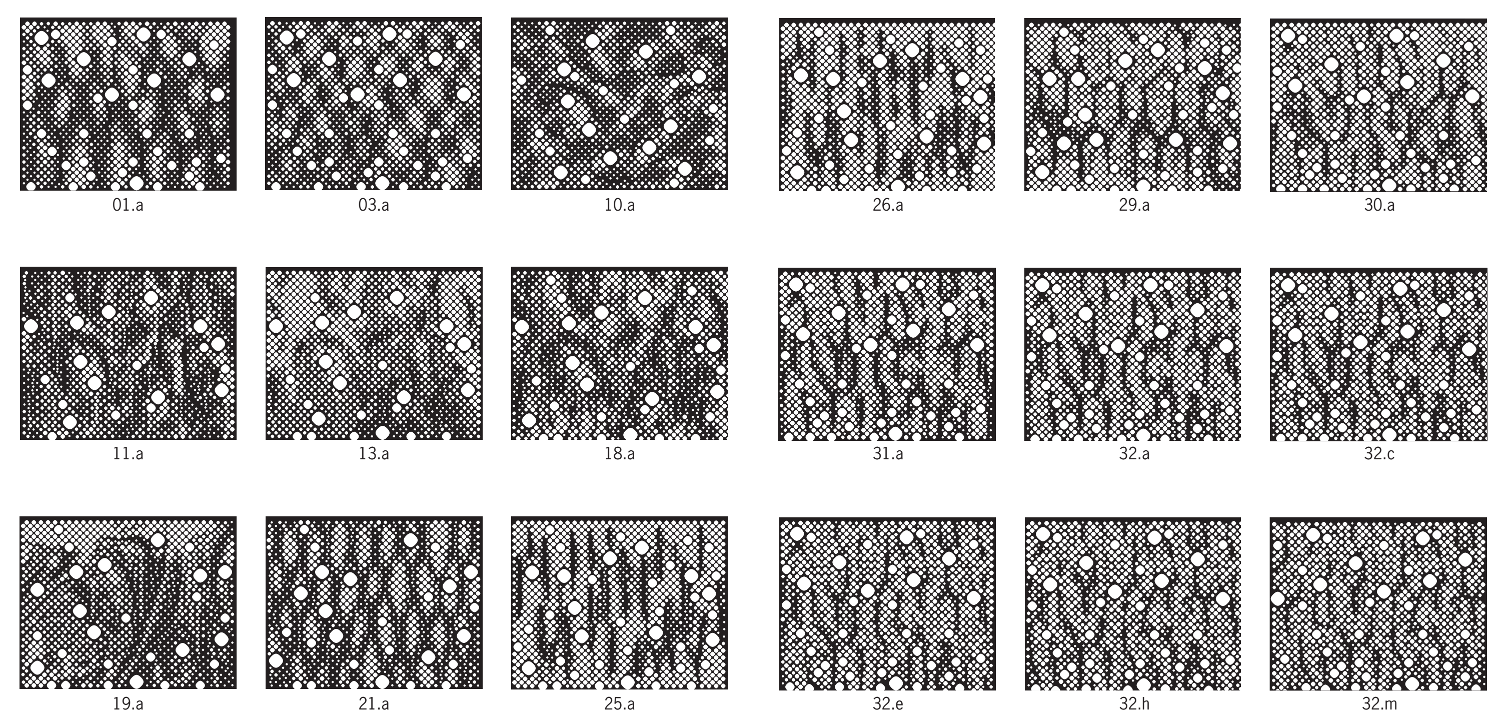
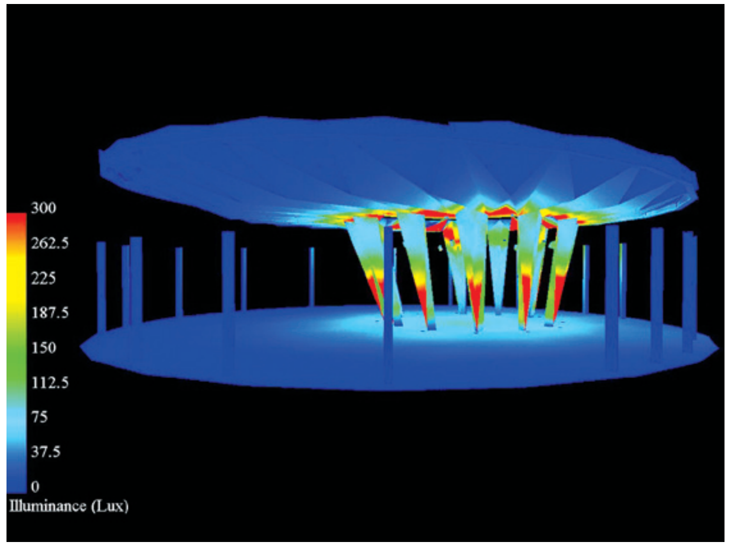
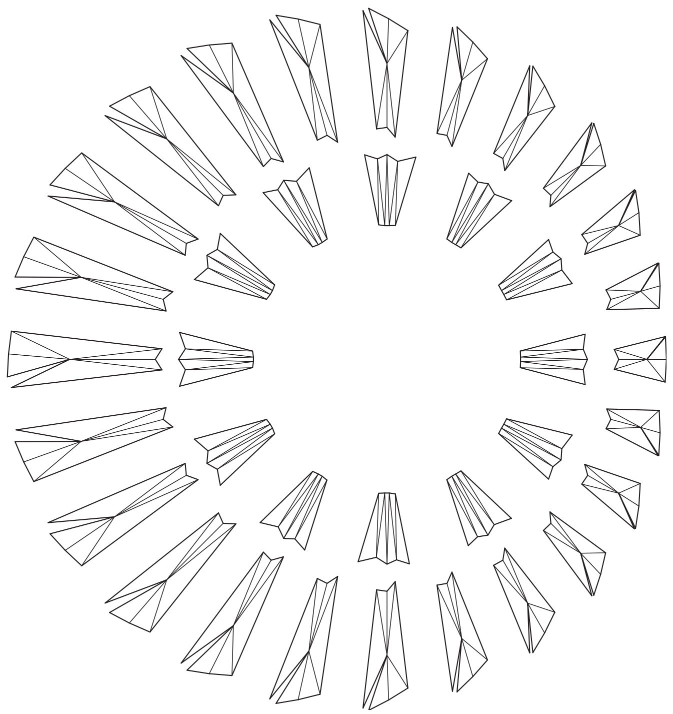
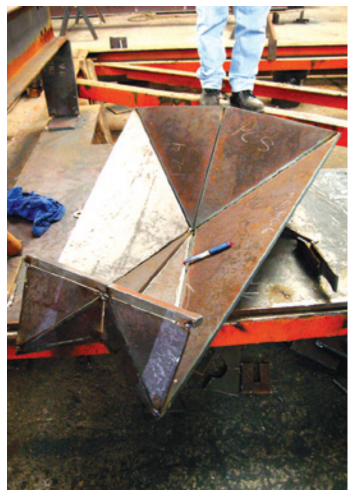


Figure 1a (top). The development and recombination of the O-14 tower shell pattern, as compared with the layering processes of Japanese Ikat weaving techniques.

Figure 1b (bottom). O-14 shell development, highlighting in sequential order 14 of the primary 32 families of perforation iterations, thereby further emphasizing that the design of O-14 is not tied to the overall regulating geometry. The pattern seeks to attenuate the monotony, while still preserving the sense of the sublime and the monumental.





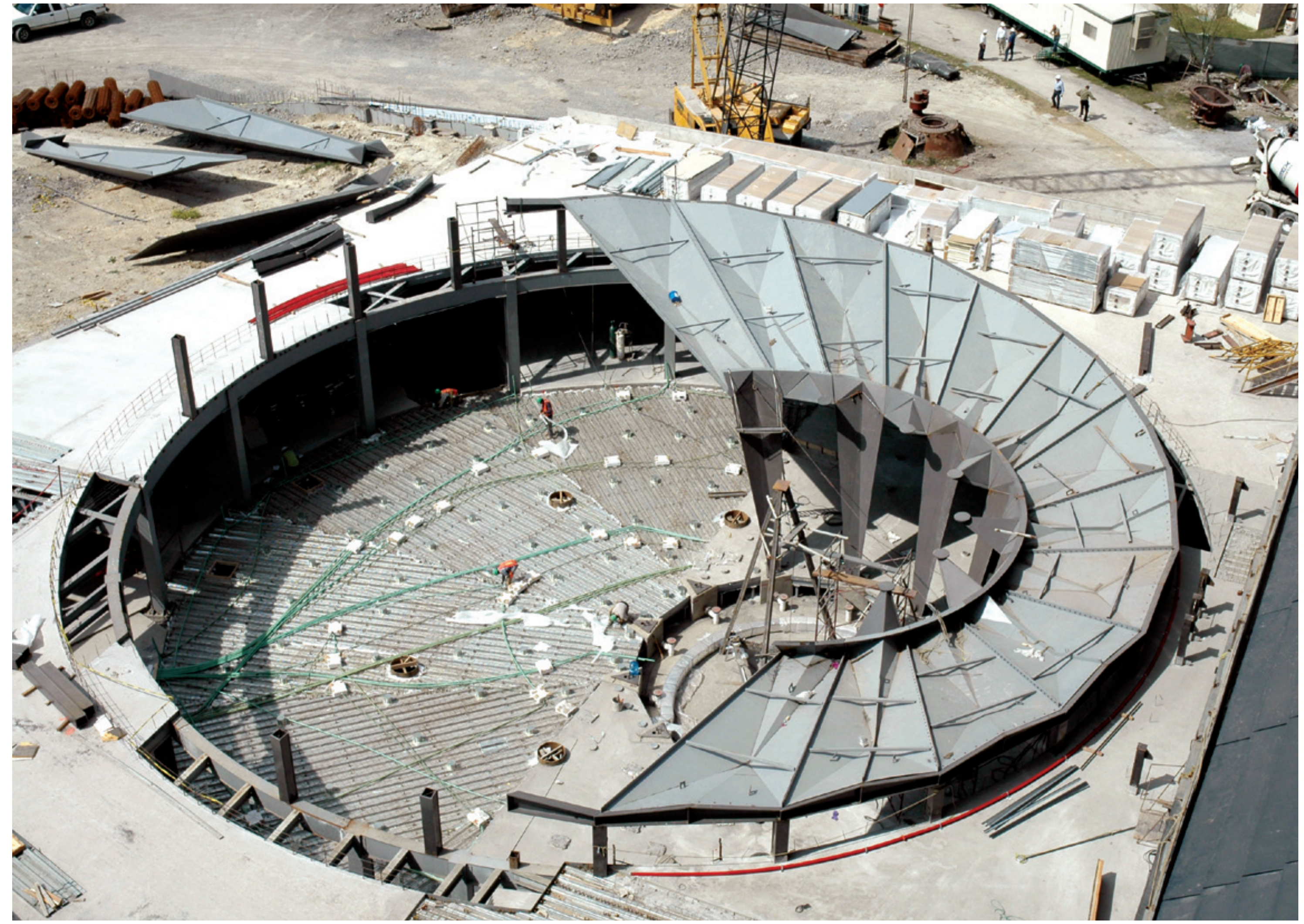


Workflow 3 (top left). The same model could also be exported out and tested in an artificial illumination and acoustics simulation to determine the lighting and sound attenuation requirements.

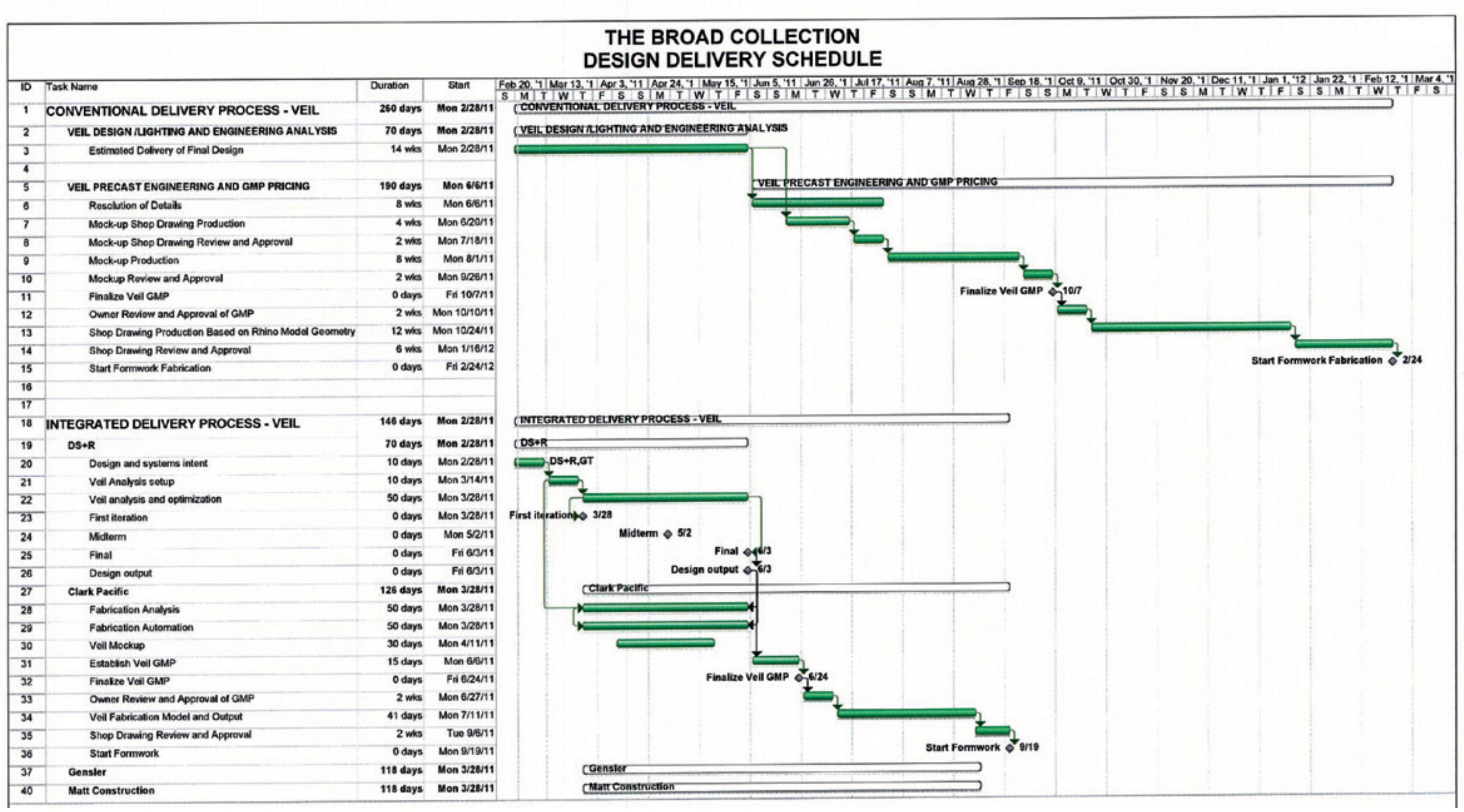
Workflow 4 (bottom left). The model was then broken apart into buildable components and the geometry could be unfolded to be developed for fabrication.

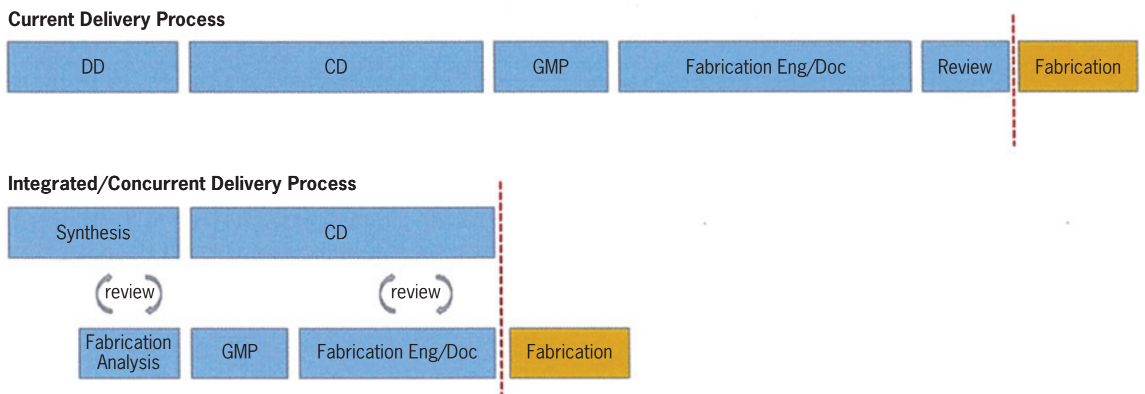
Workflow 5 (top right). The gallery addition and louvered facade under construction.

Workflow 6 (bottom right). The patterns for the folded metal plates were developed directly from the unfolded model and fabrication mock-ups were produced at smaller scales to check the structural integrity.



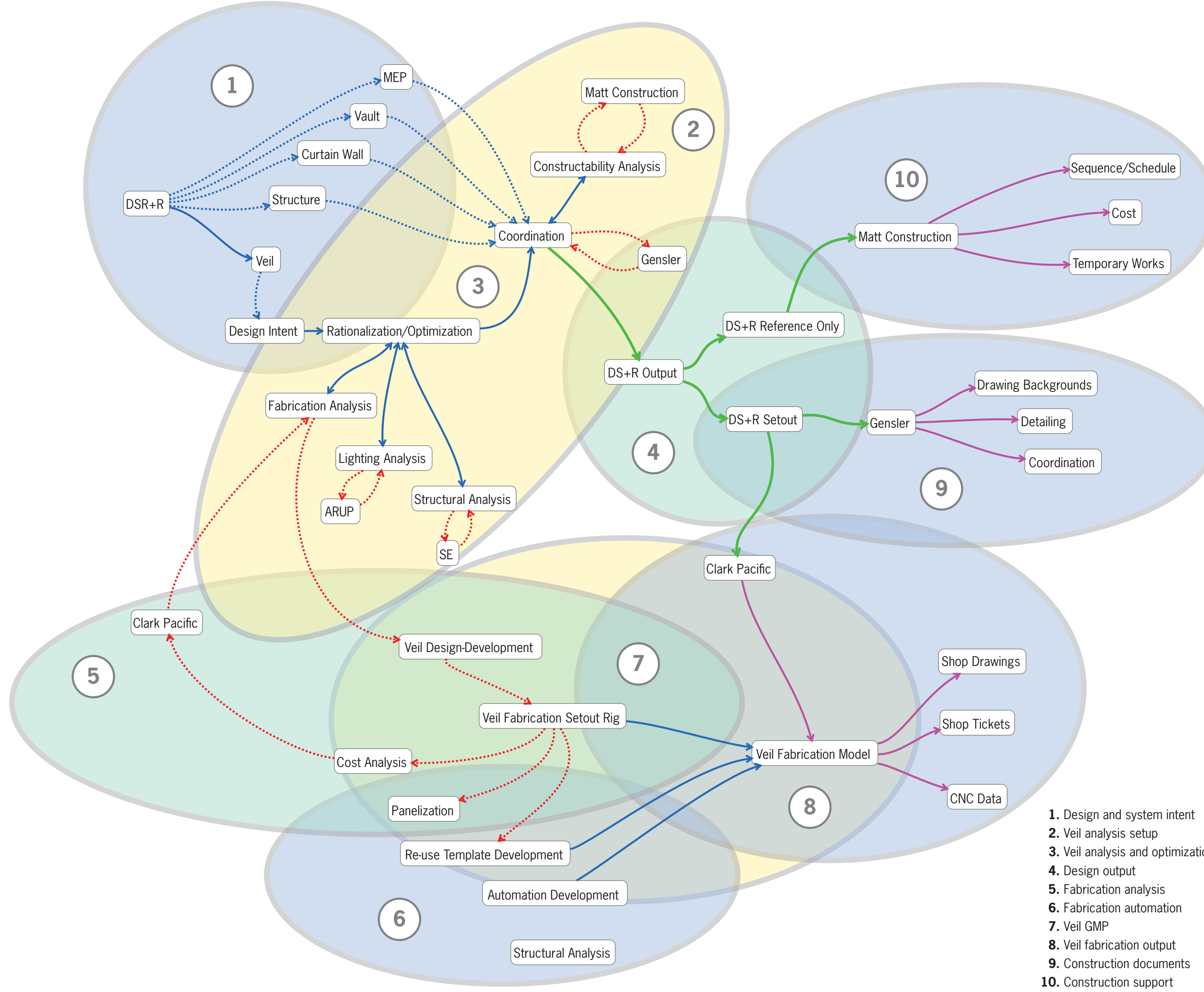
Workflow 7. The folded metal plate assembly became both structure and roof. Construction on site proceeded with temporary structural members in place until the assembly was situated properly and could become self-supporting.





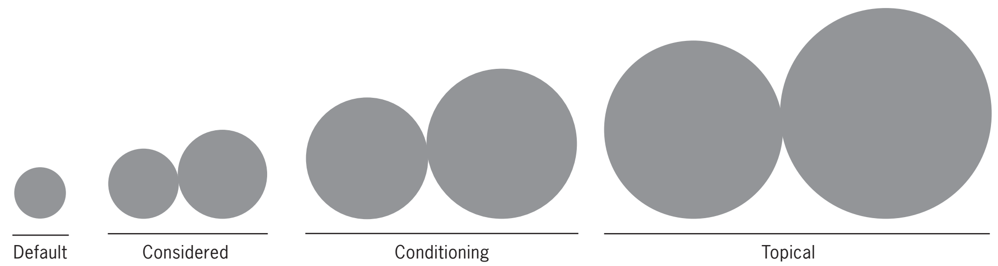
Workflow 3 (top). The initial schedule (top), derived from a conventional delivery process, created significant perceived risk because many high-risk tasks would not be occurring until late in the schedule, when any change would have greater consequences.

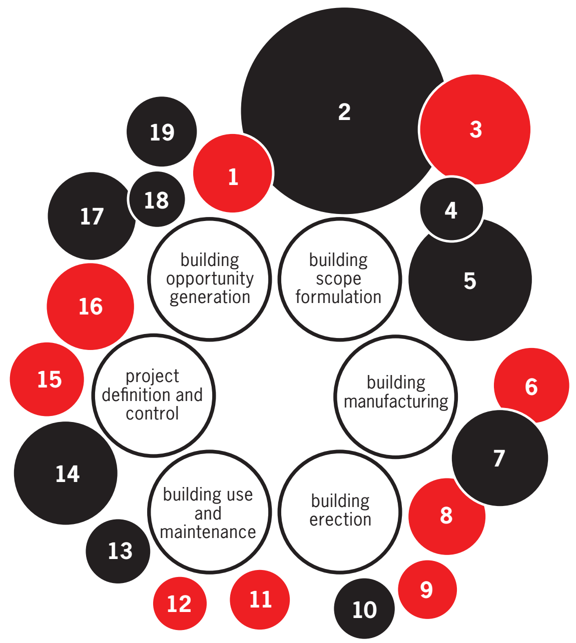
Workflow 4 (bottom). Developed after a month-long buy-in process where all team members met and voiced their concerns, an integrated delivery process (bottom) front-loaded critical fabrication and constructability steps that would inform the design and avoid later changes. The accelerated schedule summary emphasized the overlaps between the various team members.



Workflow 5. During this buy-in process, a workflow diagram of a concurrent design, engineering and fabrication process facilitated the discussion among the team members. For instance, during the design development of the veil around lighting and structural issues, information is being sent to the precast subcontractor to develop their fabrication processes and perform real-time cost analysis. The workflow was broken down into ten tasks as represented by the shaded ovals. The blue lines indicate design information; the red lines indicate fabrication and pre-construction information; and the green lines indicate the delivery of construction documents.

Indicative hierarchy of specific design dimensions in the economy of the project (default—considered—conditioning—topical, from smaller to larger diameters). Red circles identify design dimensions with important mutual relationships for project procurement and outcome.





1. Program
2. Spatial/visual
3. Performance
4. Specifications
5. Materials/systems
6. Tectonics
7. Fabrication
8. Testing
9. Assembly
10. Site
11. Use
12. Maintenance
13. Change
14. Coalition
15. Operations
16. Procurement
17. Resources
18. Stakeholders
19. Goals

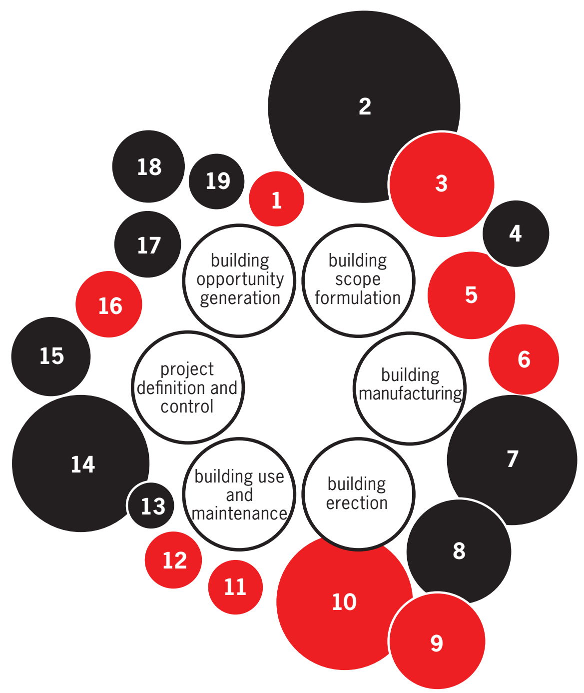


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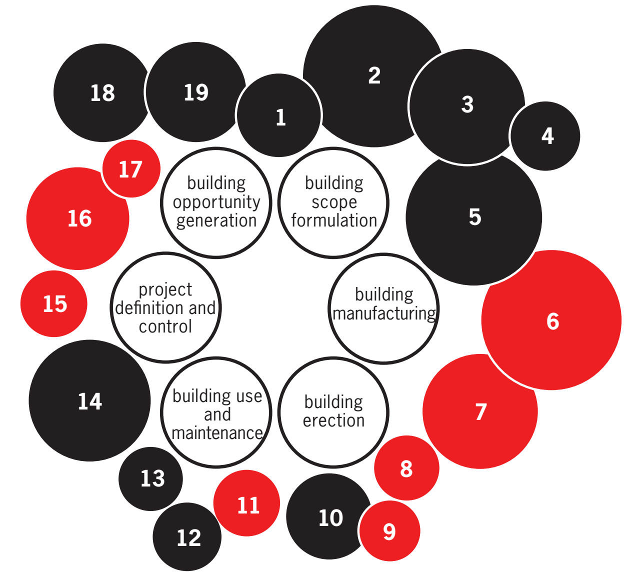
Figure 7 (top). Ara Pacis Museum, Rome, completed 2006. Main design consultant: Richard Meier & Associates; main contractor: Maire Engineering.

Figure 8 (bottom). Federation Square, Melbourne, completed 2002. Main design consultants: Lab/Bates Smart; main contractor: Multiplex Construction.



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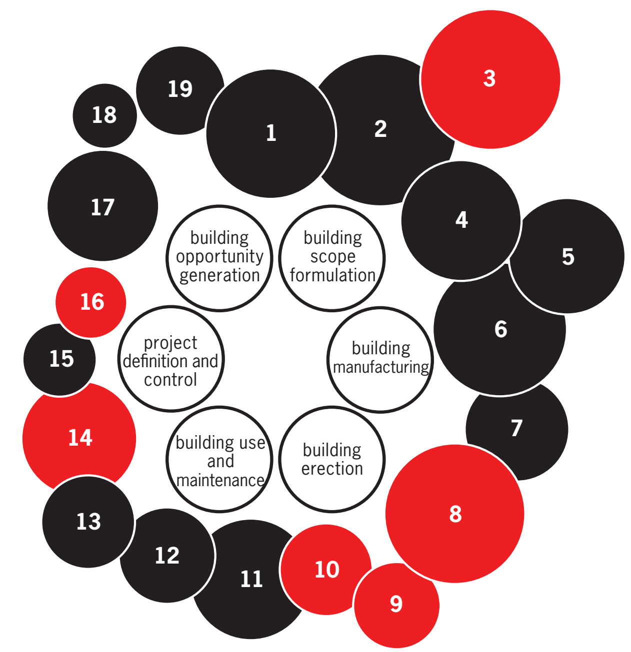

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Figure 9 (top). Simmons Hall, Cambridge, Mass., completed 2002. Main design consultants: Steven Holl Architects, Arup, Nordenson & Associates; main contractor: Daniel O'Connell & Sons.

Figure 10 (bottom). Southern Cross Station, Melbourne, completed 2006. Main design consultant: Grimshaw Jackson JV; main contractor: Leighton Contractors.