CUTTING-EDGE TECHNOLOGY AND INNOVATIVE PROCESS FOR COMPLEX ARCHITECTURAL DESIGN SOLUTIONS

Project:
The Broad Museum, Los Angeles

Architects:
Diller Scofidio + Renfro
Gensler

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Vision – "The Veil and the Vault"

"The Veil and the Vault" by Diller Scofidio + Renfro (DS + R) is the phrase used to describe the concept of the new Broad Museum in Los Angeles – one of the most high profile projects to hit Los Angeles since Frank Ghery's Walt Disney Concert Hall. The veil is a honeycomb-like concrete shell that encloses the vault and provides much needed diffused natural light for the museum. It also supports the roof, allowing for a column-free exhibit space. All of the veil ports are angled and shaped so no direct sunlight enters the building.

The veil is lifted at one corner, opening the building to the street - an inviting gesture that welcomes visitors and commemorates a sense of arrival...as if the building captures the inhabitants. The main conference room of the museum is displayed on the outside, through the reshaping of the veil into what Elizabeth Diller calls "The Dimple," allowing an unobstructed view of the outside.

The proposed Veil construction was unprecedented in that the monolithic, compound-shaped perforated panels were made from structural precast concrete. When put together, the panels bear the weight of the entire roof of the building; this required a very high level of technology and precision to execute.

CTC was selected as a member of the team of companies contracted for production engineering and prototype fabrication, which would define how the veil of the museum would be built in precast concrete. All of the engineering and testing eventually resulted in a new production method for geometrically complex structural panels made of precast concrete.

CTC worked closely with the team, using CATIA software. While Diller Scofidio + Renfro were rationalizing the geometry of the panels to accommodate structural engineering requirements, CTC in tandem developed a new, highly complex production technology to bring their veil creation to fruition.


IMAGE BY: DILLER SCOFIDIO + RENFRO

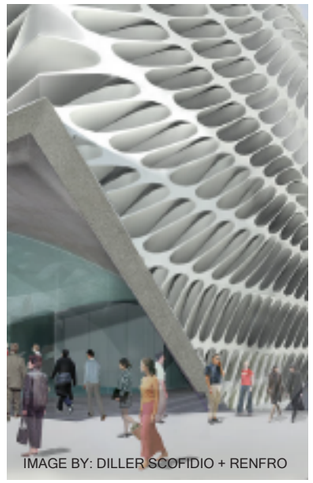
IMAGE BY: DILLER SCOFIDIO + RENFRO


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CTC Scope of Work

In this case, there was no pre-existing technology or process to create a precision load-bearing veil in concrete on such a grand scale. CTC was specifically brought in to bridge the multiple manufacturing and technical barriers needed to bring the vision to reality.

CTC independently developed the necessary formwork technology for manufacturing - and proved that the technology worked by producing a perfect prototype to a tolerance within 2mm. CTC also developed production budgets that would meet both the design and technology requirements. CTC also went so far as to develop value engineered proposals by slightly modifying the panel geometries in CATIA to achieve more repetitive panel designs (which reduced costs), while still maintaining 90% of the original light shading of the Veil ports.

The team consisted of Gehry Technologies, which executed the modeling of DS+R designs. The structural enginers were Nabih Youssef Associates. Production engineering and manufacturing was by CTC and a local precast company.

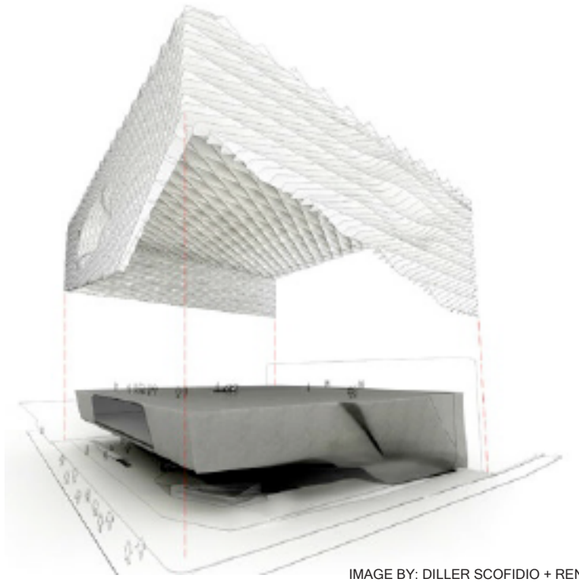


IMAGE BY: DILLER SCOFIDIO + RENFRO

The CTC team took responsibility and ownership for:

1. **Final Veil Fitment:** This involved defining and validating a foolproof A to Z production method to hit the tolerance target, which in turn guaranteed the fitment of the approximately 350 individual precast panels. This began with inputting Gehry Technologies' CAD model, and then developing a strategy for precision interchangeable production tooling.

2. **Data:** In order for CTC to guarantee final fitment on the field, It was necessary for CTC to take responsibility of the CATIA data released from the architect and contractors. It then produced the final data set for production - after it had been thoroughly checked for fitment discrepancies and adjusted for production manufacturing.

3. **Innovation:** Creating new technology that led to the successful high-quality prototype, which proved the feasibility of the Veil design in precast concrete.

4. **Fabrication:** Fabrication of interchangeable high tolerance Precast Form Work to within 3 mm of CAD data.

5. **Budgets:** Providing multiple fixed budgets, including value-engineered options.

CTC – Innovative Approach to Design Solutions

Sketching innovations pen to paper in 2D, and then effectively translating those designs into 3D CAD software, is CTC's strength and key to their innovation process leading to design solutions.

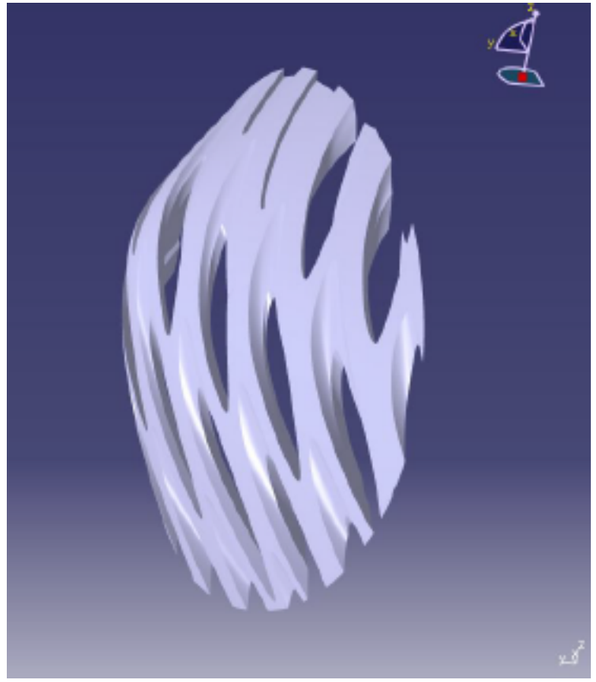
The CTC team has extensive experience working with a wide range of materials, including FRP, complex glass, resin, metal, and precast concrete - everything from titanium to concrete. Our knowledge base in this broad pallet of materials gives us maximum options to find innovative solutions for our clients.

CTC's CAD capabilities allow the company to adapt, utilize all types of data from architects, and translate their data into rationalized designs that are producible in an array of hybrid material choices.

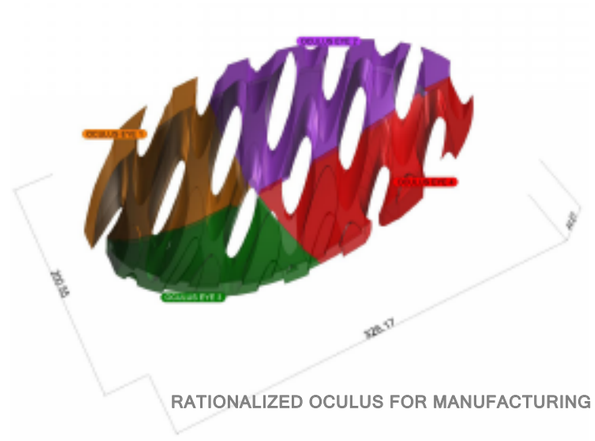
CTC specializes in digital fabrication; it has CNC and fabrication capabilities that can create geometrically complex shapes using different materials or media.

The team is able to combine all these capabilities to rationalize complex designs, innovate if necessary, and create prototypes quickly - which ultimately bring the architects' visions into fruition.

In this project, CTC developed a new high tolerance formwork technology and a quality control system for manufacturing structural precast panels with complex surface geometry containing internal cable ducting.



27' X 17' DOUBLE COMPOUND CURVED OCULUS

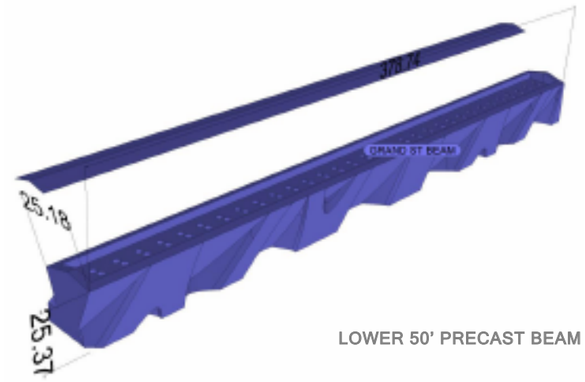


RATIONALIZED OCULUS FOR MANUFACTURING

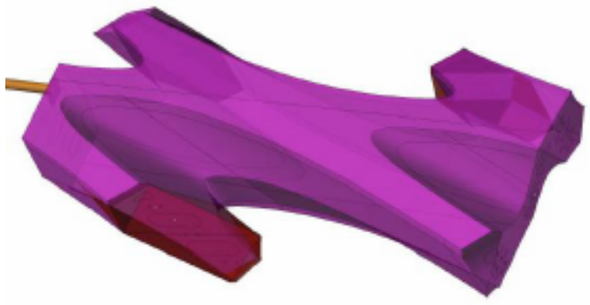
Design and Manufacturing of Precast Panels

The Veil consists of molded precast structural beams along the perimeters of each elevation (bottom, top, and corners). These beams are the hubs in which the post-tension cabling is attached. The perforated and solid panels were approximately 10'x20' with internal ducting that ran in a crisscross configuration through the entire elevation. For the system to work, all the cable ducting had to line up precisely so cables could be run through top to bottom, connecting the entire elevation. Furthermore, the gap between the extreme-angled panel edges needed to be constant within 3mm to avoid point load cracking of the panels (weighing 15K lbs. + each), as they were stacked over 100' high, end-to-end.

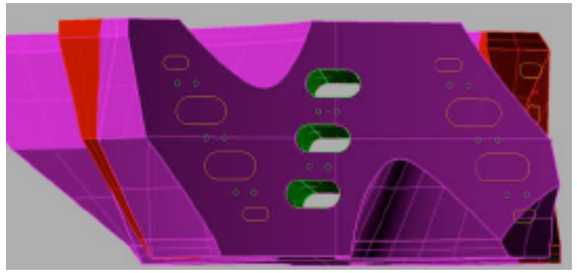
To achieve this feat, data management by CTC was the key to quality control of the tolerances throughout the 10 steps of production processing. If each step was not executed to perfection, it would have had a compounding negative effect, resulting in failure. For this reason, it was necessary for CTC to own the data once it was released from the architect.



LOWER 50' PRECAST BEAM



CTC PROTOTYPE CAD MODEL



CAD MODEL WITH CABLE DUCTS

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Overview of some of the steps involved:

1. **Rationalization:** The CTC team rationalized the design, making it producible. CTC decided how many different molds were needed and how to make them interchangeable - because each was unique where they intersected the corner beams. They accomplished all this while balancing a budget target.

2. **Production strategy:** CTC determined the number of operations required to modify each mold to a specific shape, which determined the tool design. There was a production deadline, so the team determined the least amount of costly tools required to make the production schedule and developed the production sequencing for on-time delivery to the contractor.

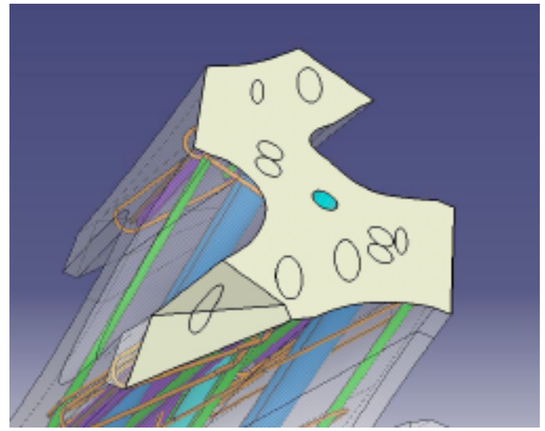
3. **Data cross check:** It was necessary to validate the CATIA files of each panel and cross-check each placement of the steel embedment ties that held the ducting in position during casting. This ensured the alignment of ducts from one panel to another.

4. **Engineering:** From that point, they went through CTC's tool engineering process, which required the team to recreate another CAD file incorporating their casting tool designs or Formwork Design. Each mold weighed over 8,000 lbs., combined with approximately 15,000 lbs. of concrete and steel inside the cavity tool that molded all sides of the panel (top and bottom). It required extensive structural engineering to guarantee the mold's ability to withstand that kind of pressure and hold to a 3mm +/- tolerance.

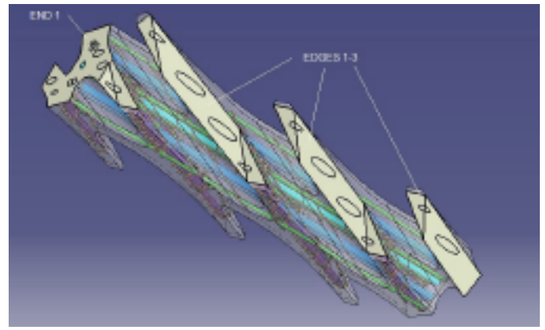
5. **Tool manufacturing:** The next step was the CAM department for 5-axis machining, where another data file was created to run the machines.

6. **Quality control:** After the preceding steps were completed, the project went through a quality control inspection process to check tolerances.

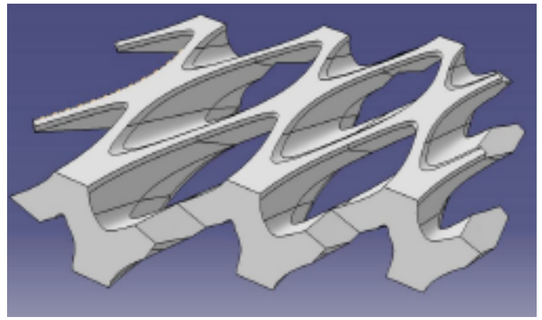
7. **Tool fabrication:** Then the project went to the Tool Fabrication department for final fabrication and assembly.



INTERNAL STEEL AND CABLE EMBEDMENTS



UNIQUE END CONDITIONS FOR PANELS



10' X 20' PANEL

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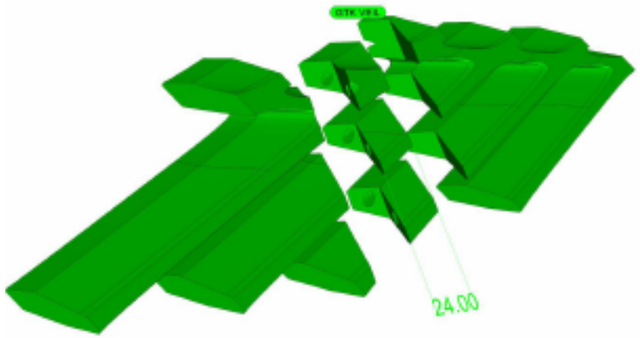
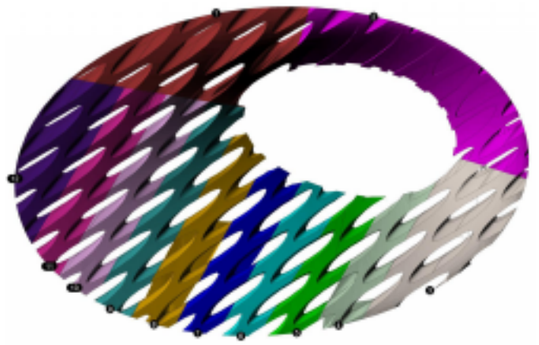
In the end, all the pieces of the puzzle needed to be a guaranteed fit - which ultimately dictated the manufacturing process CTC created. The ultimate goal was that when the 10'x20', 15,000 lbs. puzzle piece was craned into position, it would drop into place perfectly within 3mm +/- tolerance. CTC had to know - prior to installation - everything would fit; there was absolutely no room for error.

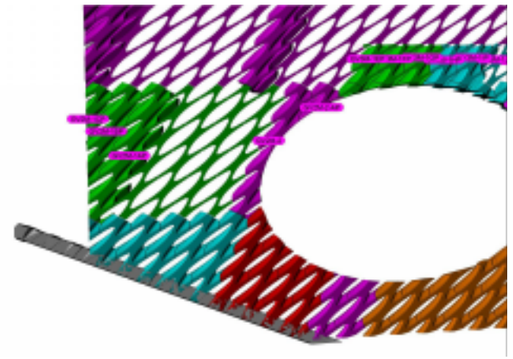
"CTC has a unique set of capabilities to take on complex architectural projects like this," says Eric Adickes, President of CTC. "With the Broad Museum, we took on the challenge knowing we had the technology and the track record to pull it off. As the program progressed, the immense weight from the casting forces posed big challenges which we eventually overcame."

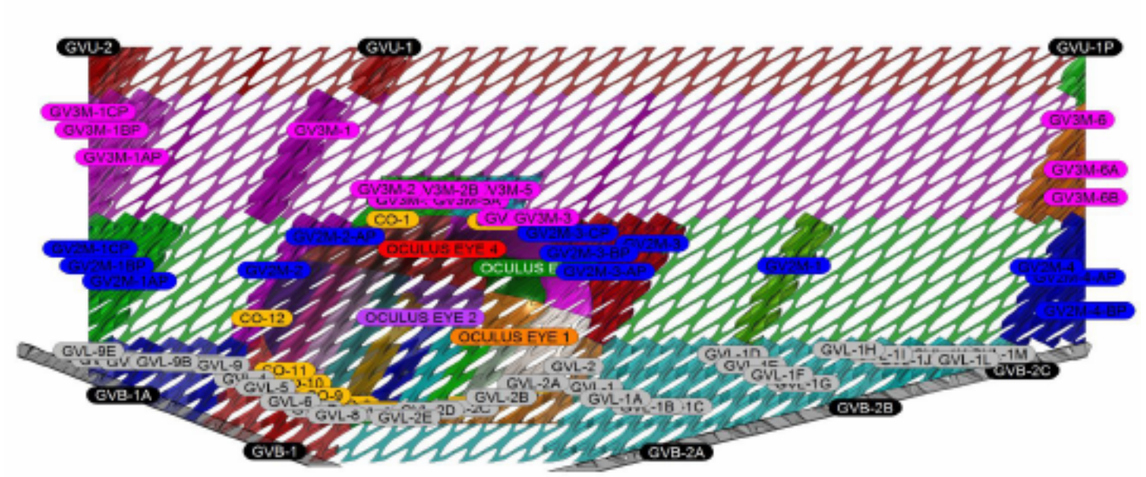


INTERCHANGEABLE TOOLING

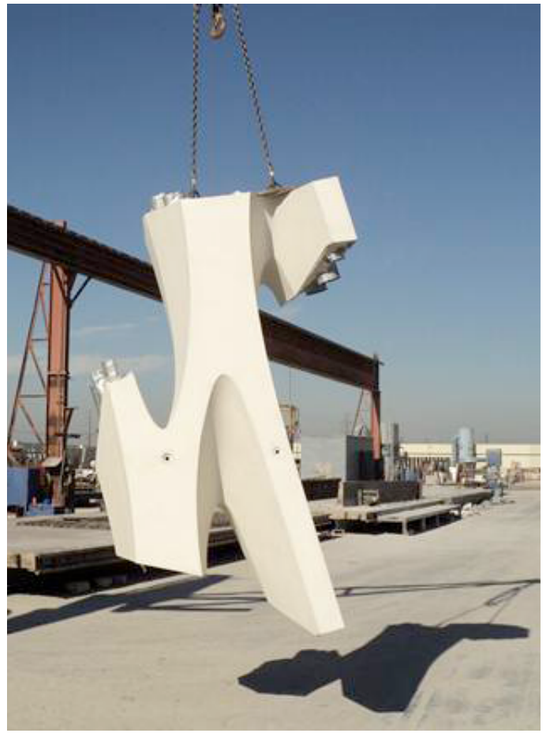
10' HIGH VERTICAL CORNER COLUMN



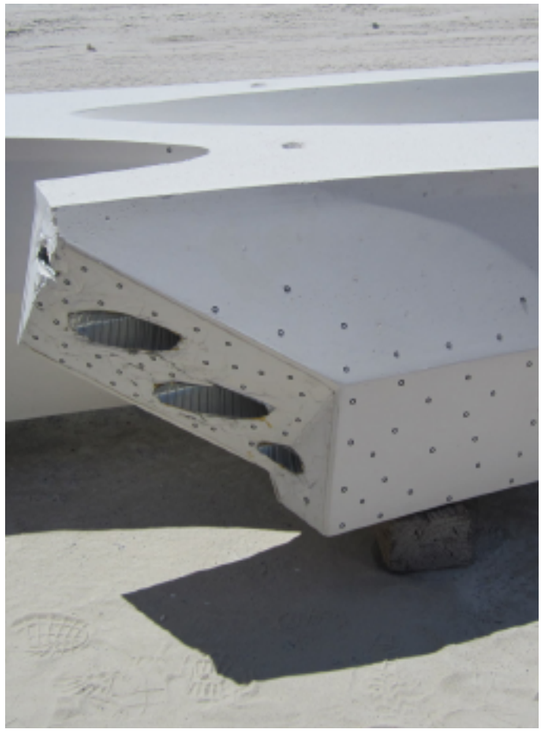




RATIONALIZATION OF REPEATING AND UNIQUE PANELS FOR PRODUCTION ENGINEERING



CTC PROTOTYPE



LASER SCAN VALIDATED PROTOTYPE. TOLERANCE WAS WITHIN 2 MM OF CAD DATA

Result

The CTC team innovated a totally new precast concrete production process that has multiple applications for constructing buildings with complex geometries.

Eric Adickes says: “The CTC team is always at the forefront of technology. Before we worked in architecture, we were experts in automotive and aerospace design and fabrication. Over the years we have successfully transferred technologies between these industries, generating innovative fabrication processes along the way. With our technology base and willingness to take risks and innovate, we have been able to engineer and fabricate some of the most innovative projects in architecture. One project that paralleled the Broad Museum in technical complexity and difficulty was Frank Gehry’s Conde Naste Cafeteria. The project consisted of over 80 unique compound curved glass panels 16’ tall, weighing 1,000 lbs. each. Like the Broad precast challenge, CTC innovated unprecedented compound curved safety glass technology, which mirrored the CAD file to exacting tolerances. Our knowledge base in all types of materials is so broad and our technical experience in digital manufacturing is so in-depth, there’s not much we can’t take on.”

CTC SUCCESSFUL PROTOTYPE