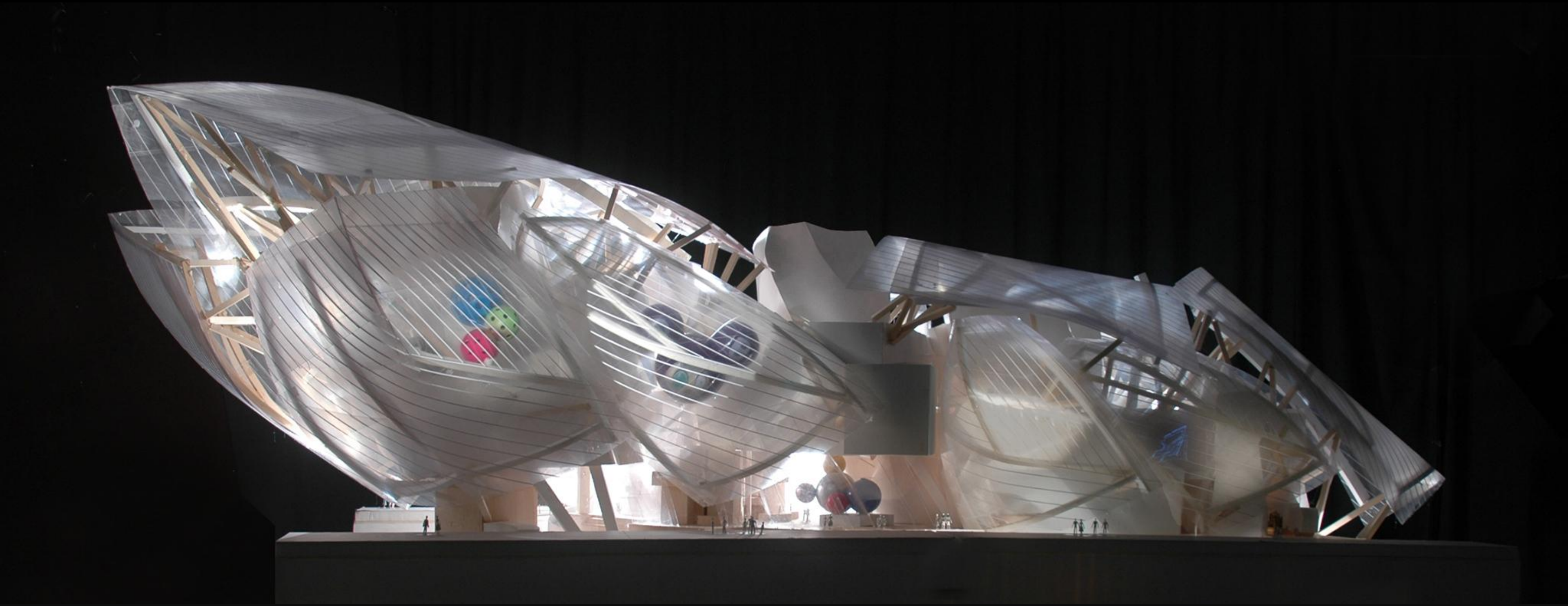
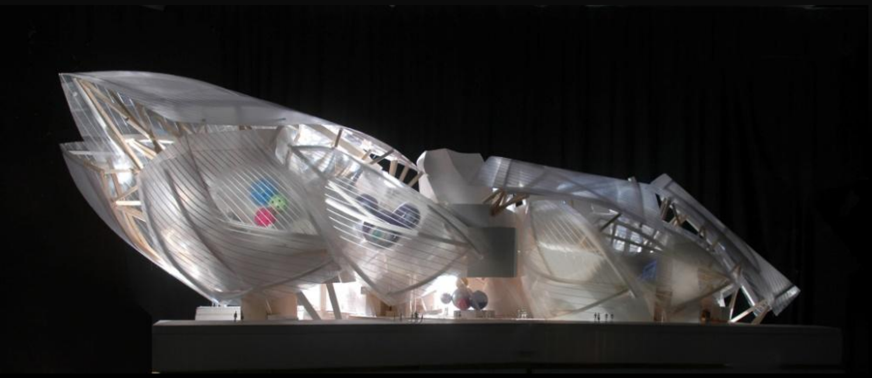
Building Information Evolved

Fondation Louis Vuitton



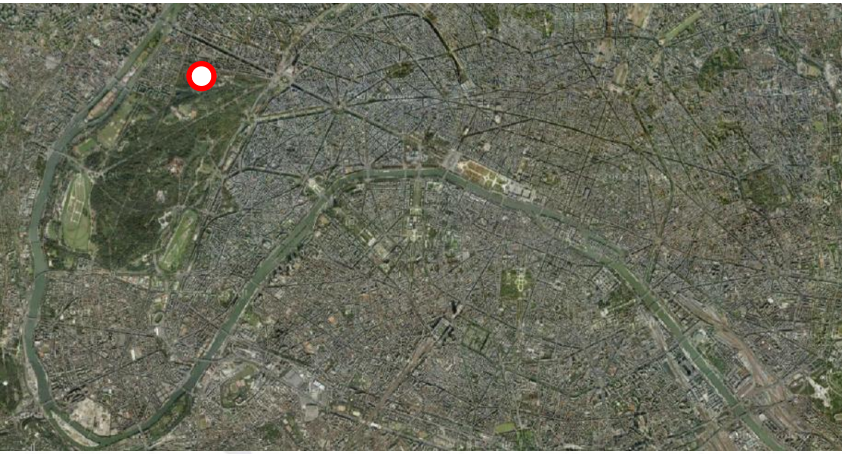
Fondation Louis Vuitton



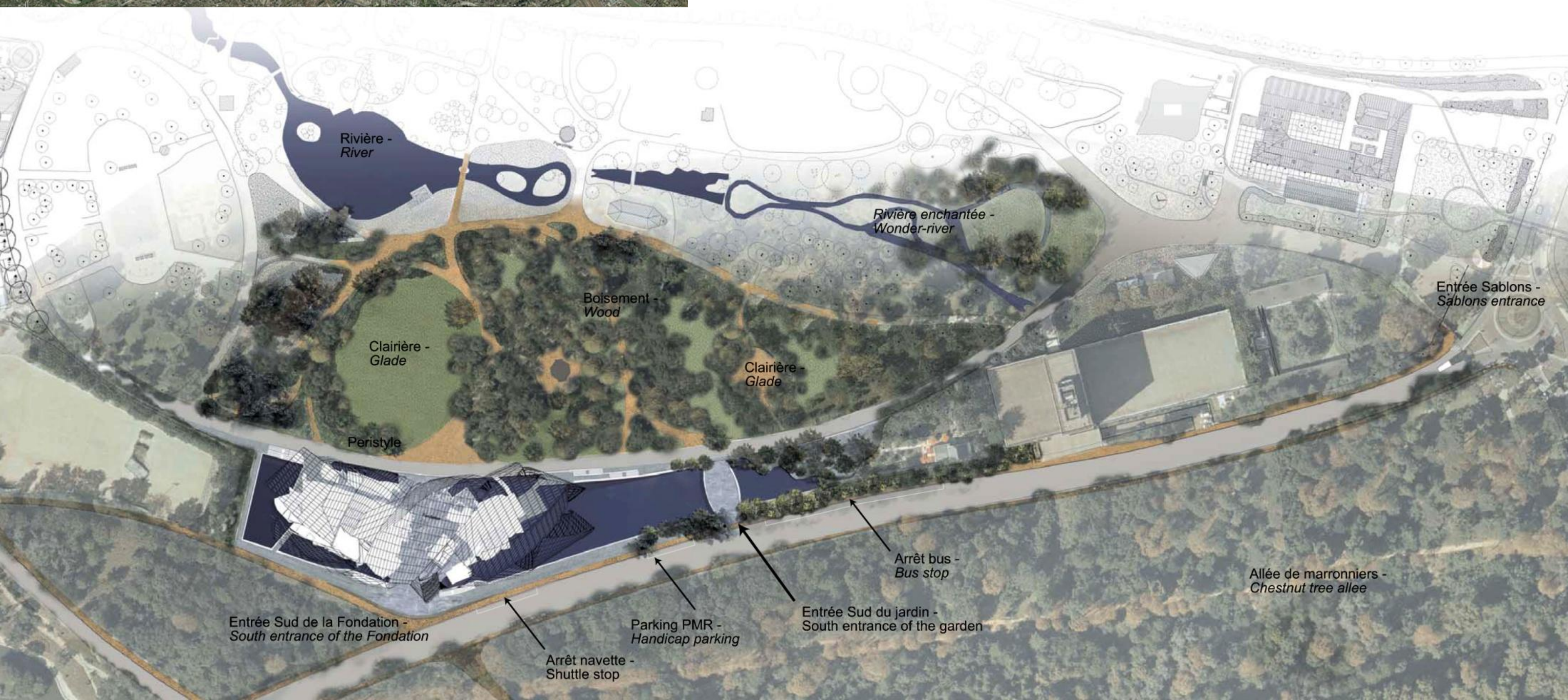
The Fondation Louis Vuitton is a major new Paris, France art museum. It is a showpiece – not only of art, but of design and technology. BIM formed the foundation; cloud model servers enabled concurrent design; advanced parametric methods brought the project to the next level; and an automated CNC process completed the fabrication chain.

- 15+ teams distributed world-wide
- Over 400 model users and collaborators
- Nearly 100Gigs of BIM model data
- Over 100,000 versioned iterations of the BIM
- 19,000 unique CNC-molded glass-reinforced concrete panels
- 3500 unique CNC-molded curved glass panels
- One unprecedented building

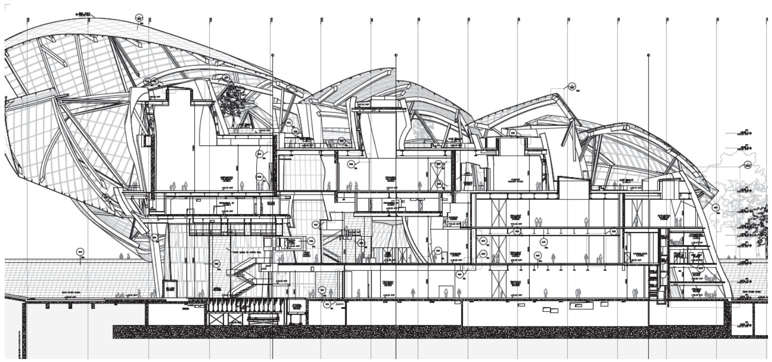
Architect’s Statement - Site



The Fondation Louis Vuitton design was driven by two important ambitions – an approach to the site, and a design ambition shared by the client and architect. The building serves as a gateway to the Jardin d’Acclimatation, an exceptional site within the Bois de Boulogne. The use of glass as the primary exterior material plays a principal role in the architecture of the Fondation Louis Vuitton. It is a reference and an ode to historical garden structures of 19th Century, structures built in harmony with nature while using the most innovative materials and systems of the time.



Architect's Statement - Design

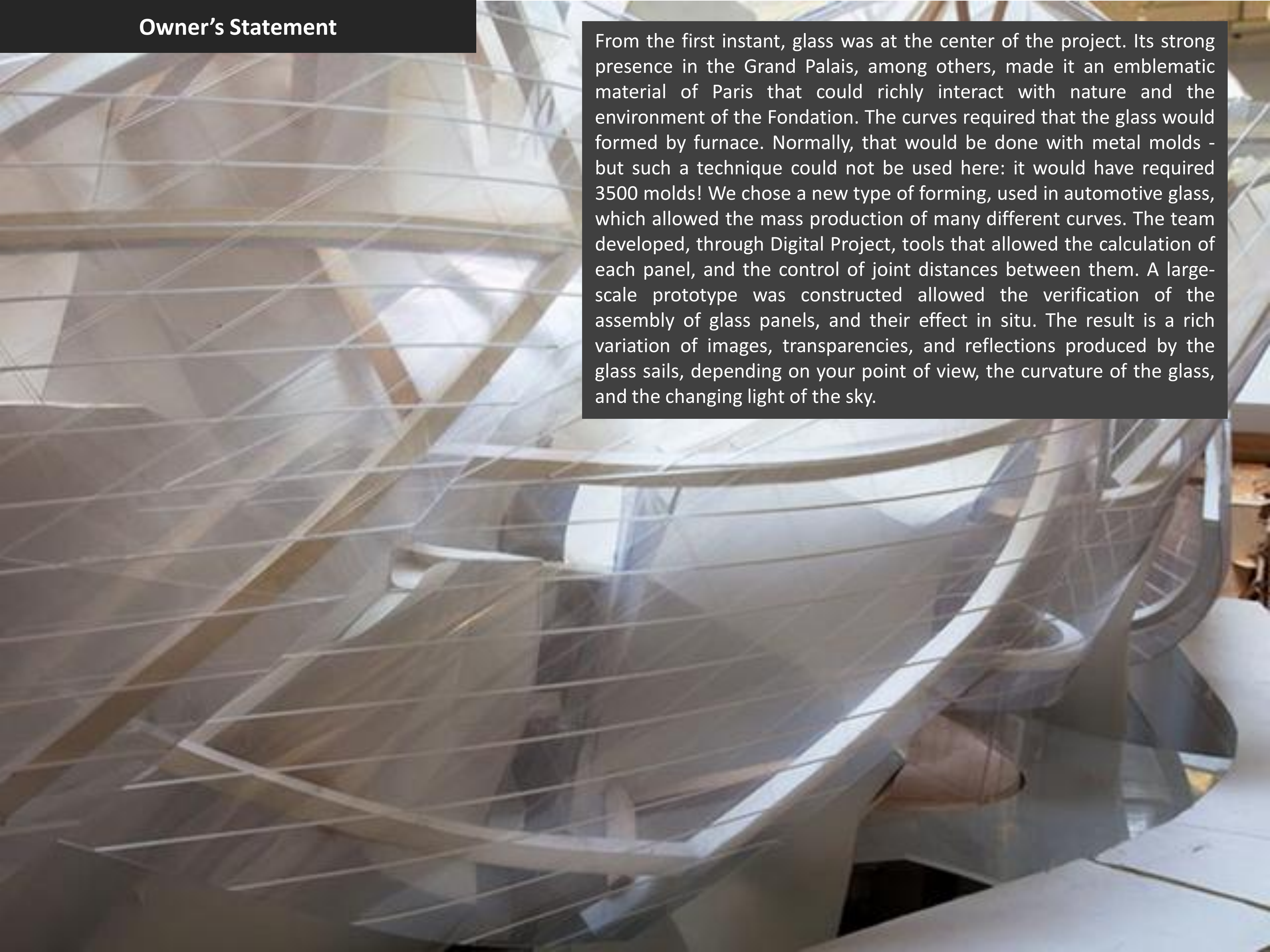


The technical processes behind the realization of the project extend these historical founded ambitions to incorporate today's digital technologies. The intention to lightness of structure and transparency was realized through tight design collaboration between the architect, engineers and fabricator, a process of continuous and concurrent design and engineering that involved ten firms and over 400 individuals working collaboratively in the development of the BIM model and ensuing fabrication processes.

More than a technical achievement, the ambitions of the project would not have been realized without the direct collaboration between the architect and client. The BIM model and communications technologies surrounding this shared model were critical to this relationship.

Owner's Statement

From the first instant, glass was at the center of the project. Its strong presence in the Grand Palais, among others, made it an emblematic material of Paris that could richly interact with nature and the environment of the Fondation. The curves required that the glass would formed by furnace. Normally, that would be done with metal molds - but such a technique could not be used here: it would have required 3500 molds! We chose a new type of forming, used in automotive glass, which allowed the mass production of many different curves. The team developed, through Digital Project, tools that allowed the calculation of each panel, and the control of joint distances between them. A large-scale prototype was constructed allowed the verification of the assembly of glass panels, and their effect in situ. The result is a rich variation of images, transparencies, and reflections produced by the glass sails, depending on your point of view, the curvature of the glass, and the changing light of the sky.



Contractor’s Statement

The operation performed by general contracting required for its architectural requirements, to master perfectly the basic referential construction. The digital model as the sole source was the solution and we had put in place procedures for managing and validating changes which are related to the design or implementation. The continuous updating of the model allowed to serve it to trade contract with the prime contractor.

This served as the sole basis for support to all technical studies and thus avoided the wasted time and errors common in phase studies due to poor knowledge of other lots or late integration of information. The contractual obligation to develop studies in 3D helped save time in managing the interfaces and in the manufacture of industrial components, which was conducted directly from the geometric data of the model. The phasing through 4D possible to optimize the exposure time, to pool resources for lifting or access and avoid the superposition of dangerous spots.

Running controlled media have summers in advance by Scanlaser, analyzed in relation to data and tolerances and corrections have been made in the factory on what to ask which saves time and quality.

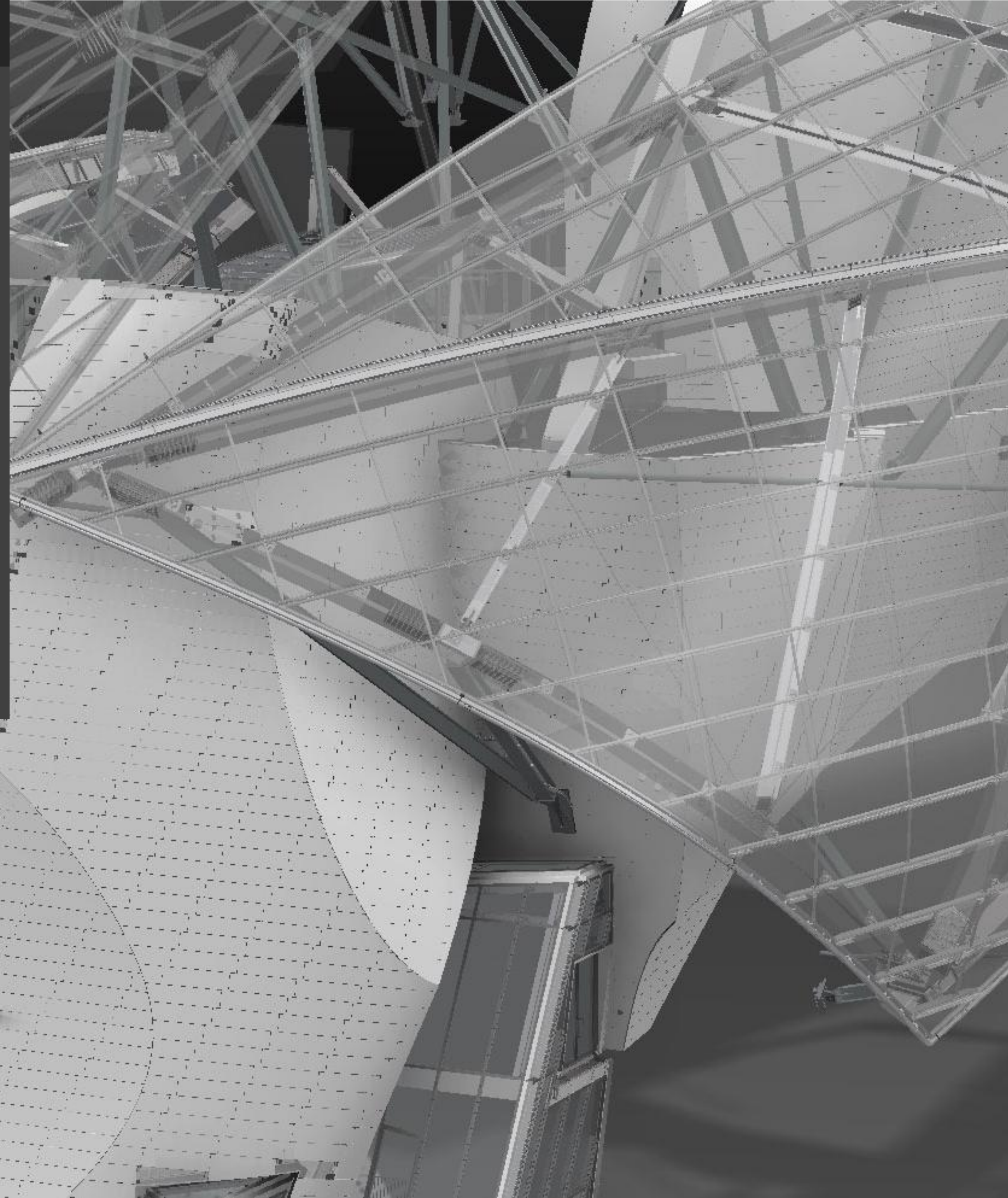
Integrated BIM Model

By combining advanced parametric models with custom collaboration tools, FLV evolved a structured new paradigm for collaboration on the cloud that enables radically new models of concurrent BIM and parametric design.

Interoperability

The core model consisted of a high-performance Digital Project master model, but the project used a range of other software, interopable through standard formats, custom tools, or the web platform.

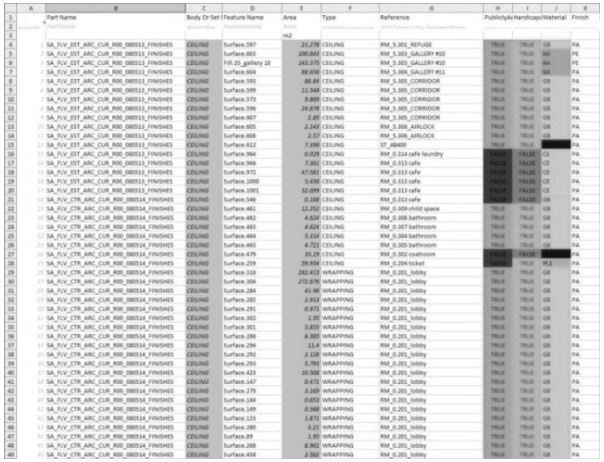
Digital Project
Tekla
Sketchup
AutoCAD
BoCAD
SolidWorks
ANSYS
STRAUSS
NASTRAN
Sofistik
3DVia Composer
Solibri

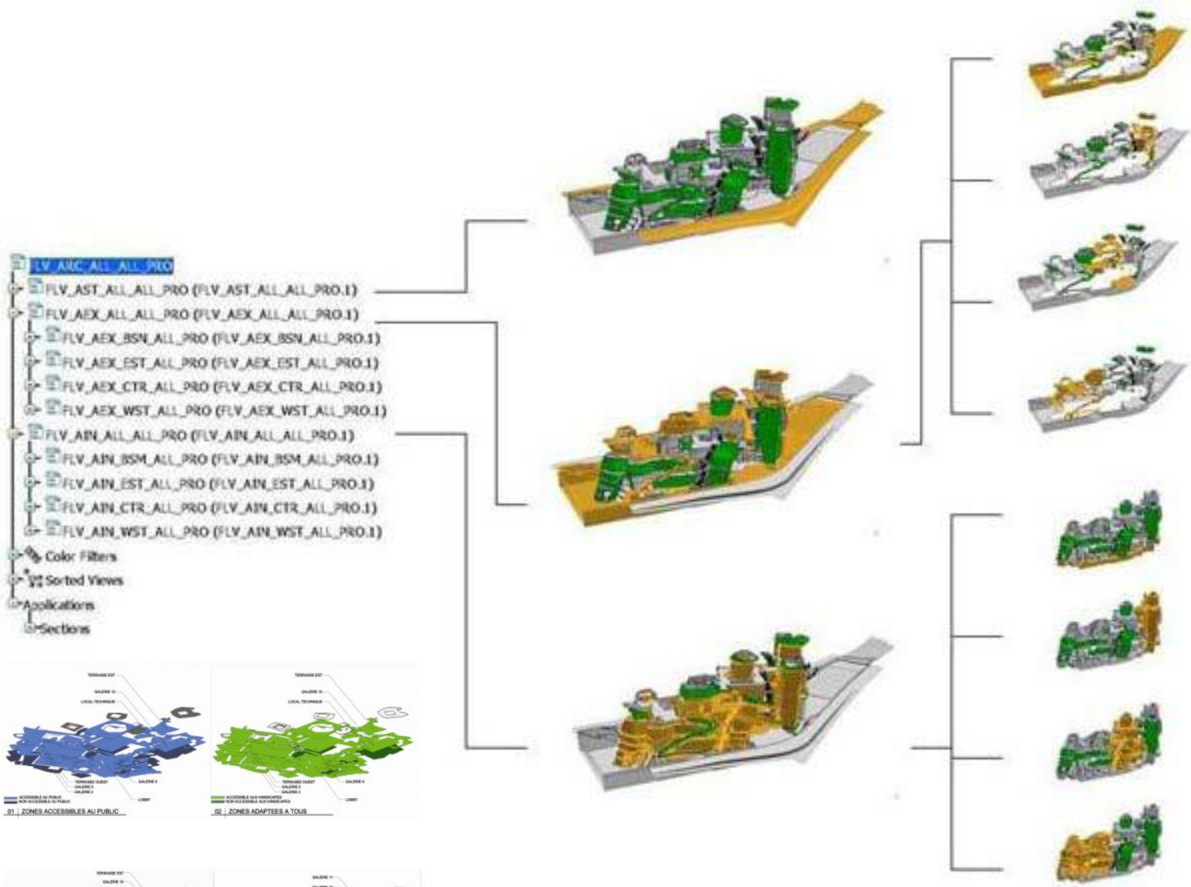


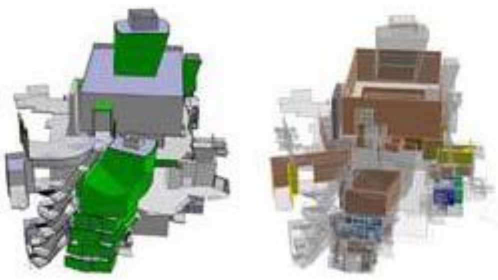
Mechanical Systems

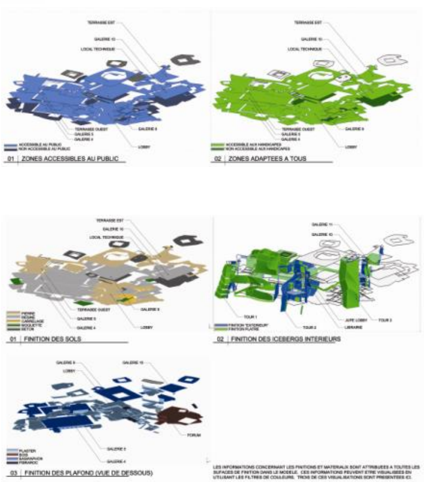
Architectural Finish Specification

All the usual BIM information – finish specifications, occupancy information, wall types, etc – was integrated into the model and extended with custom libraries.







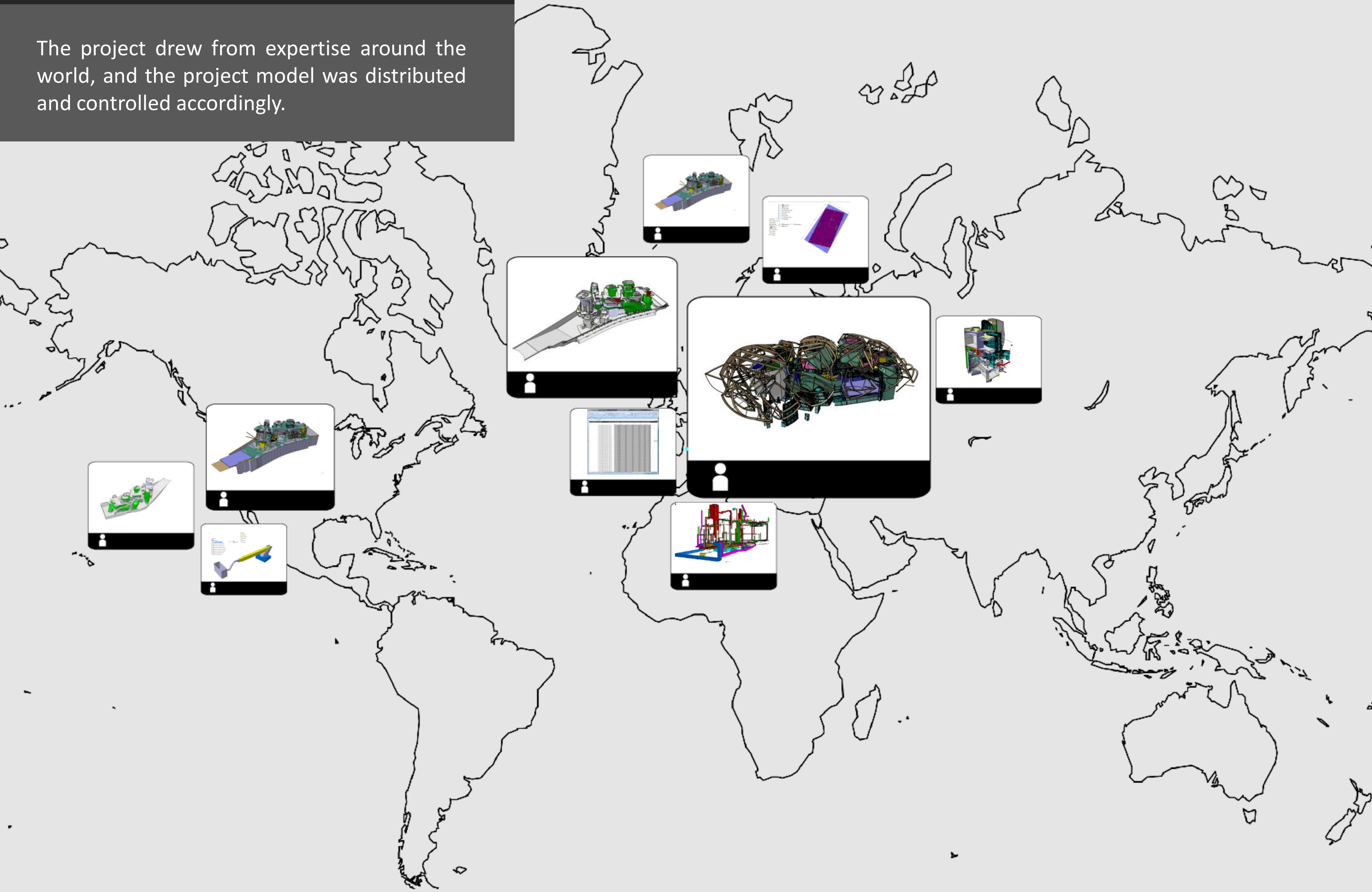


Global Collaboration

Project execution requires the collaboration among a spectrum of disciplines with specific technical and geometric intentions. This simultaneous definition of the project is concurrent design: many participants define the same project in a distributed way, simultaneously, on the same model.

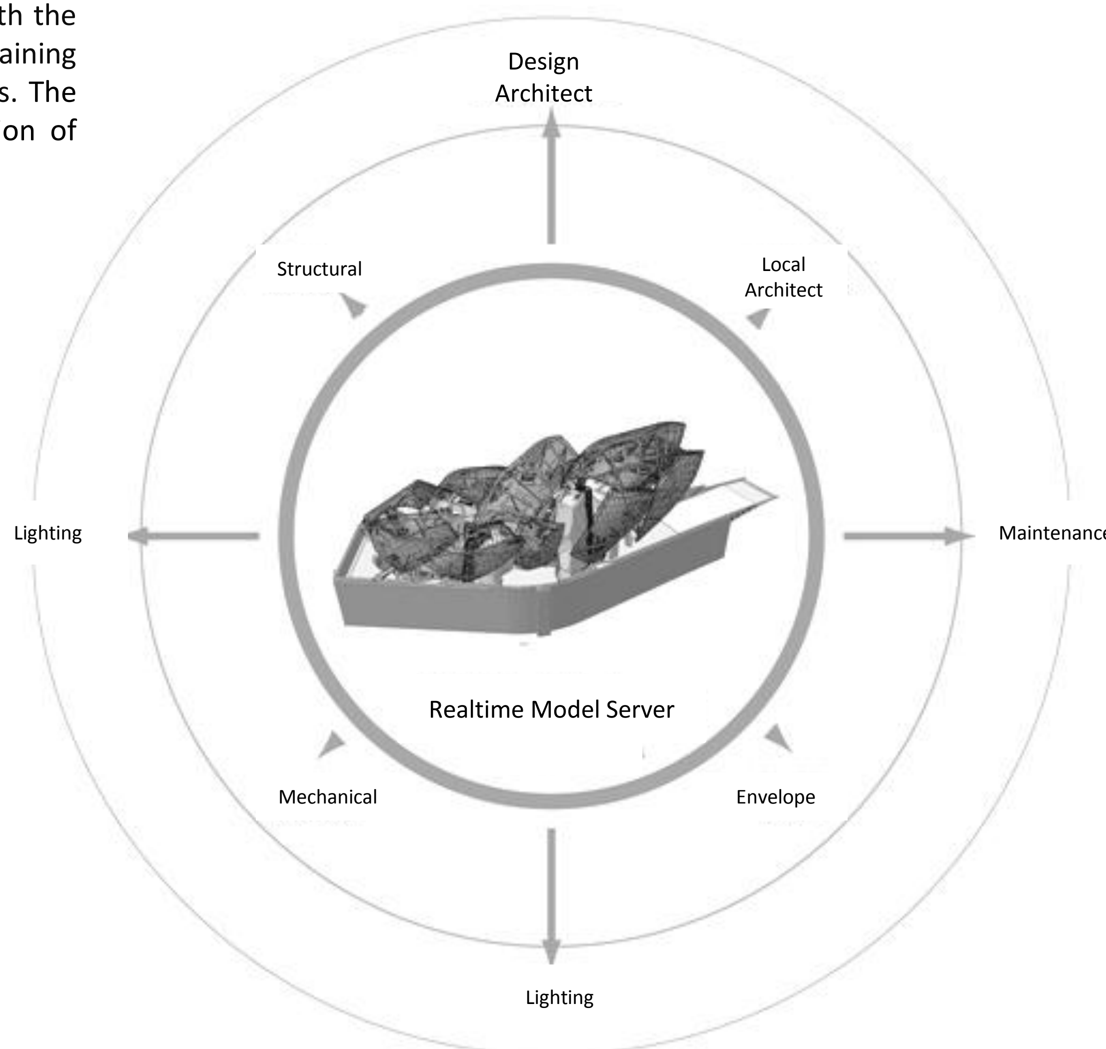
Global Project Distribution

The project drew from expertise around the world, and the project model was distributed and controlled accordingly.



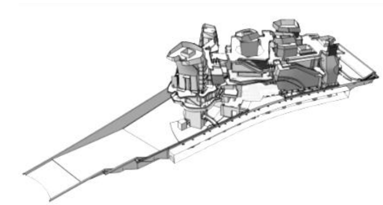
Model Server

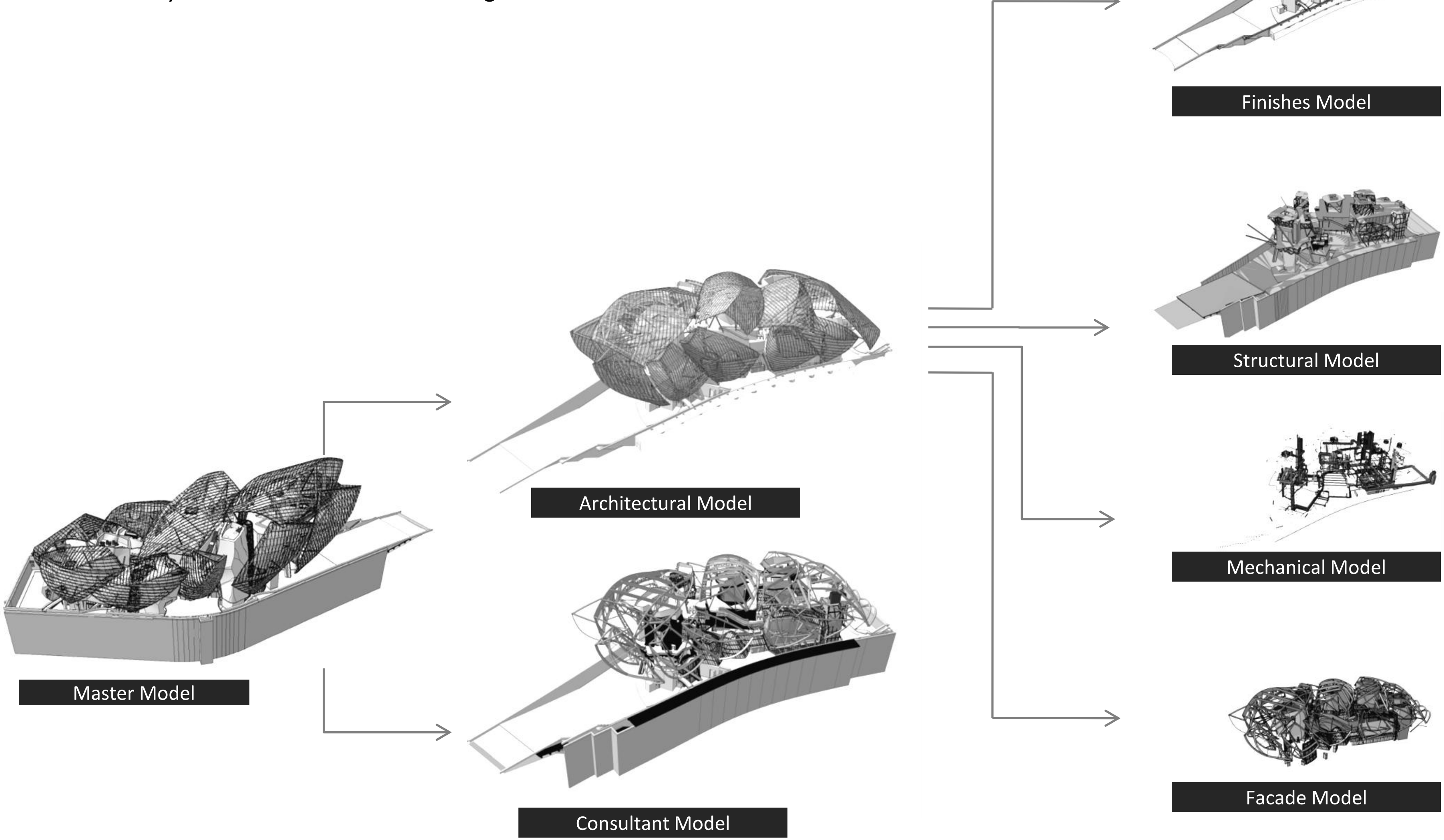
The project used a realtime, centralized model server. The server was synced to individual computers and allowed for users to work with the actual model files transparently, while maintaining coherence and consistency across all authors. The process helped accelerate the communication of project data dramatically.



Work Breakdown Structure as Model Structure

The organization chart of the project was mapped onto the model structure to become the work packaging plan. This product structure has a natural mapping to a file organization, which is ultimately connected to cloud versioning tools.

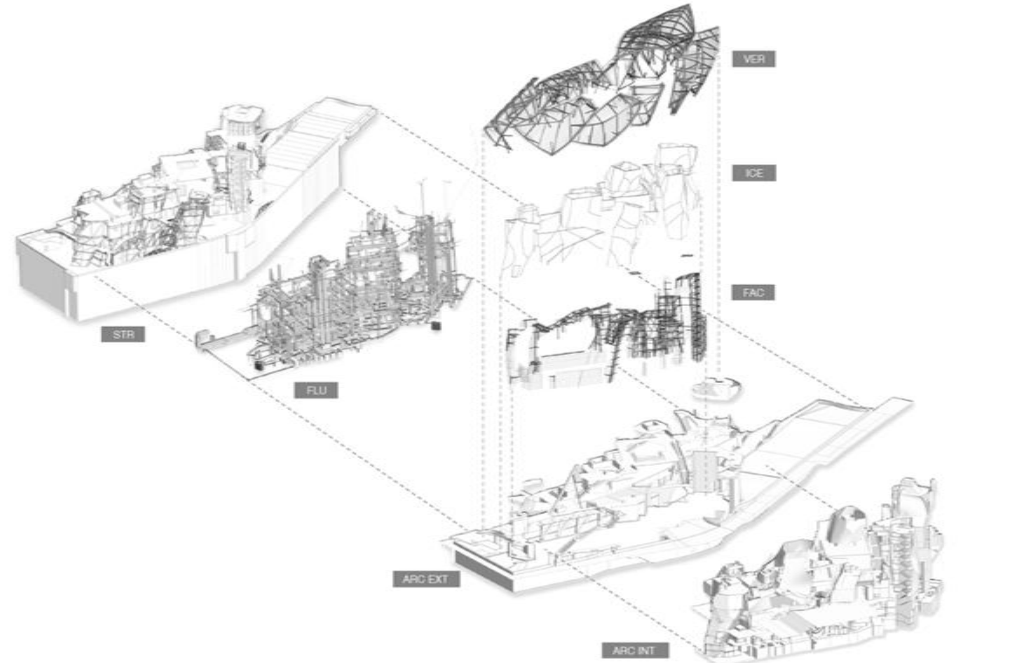


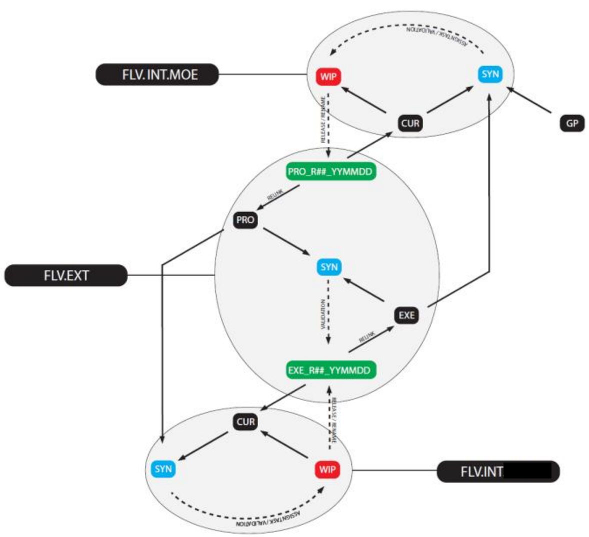


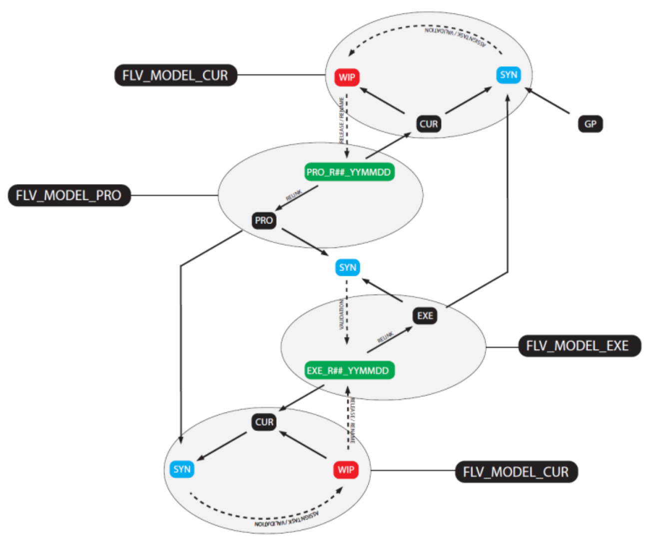
Systemic Model Submissions

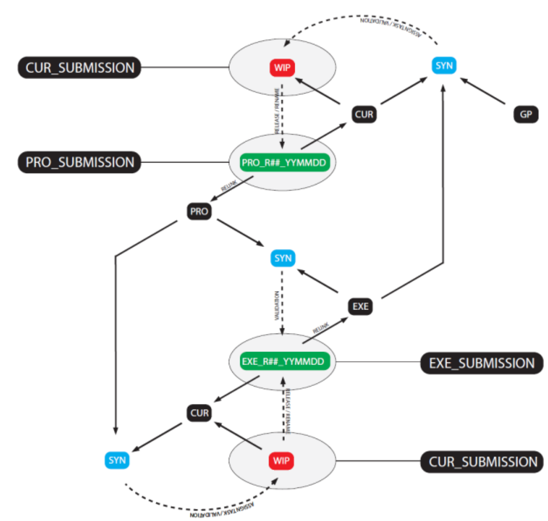
In effect, there became three major models:

• PRO: The design team's authoritative document.
• INT: The contractor's realtime, working model.
• EXE: The high-fidelity synthesis of the two, used for construction.





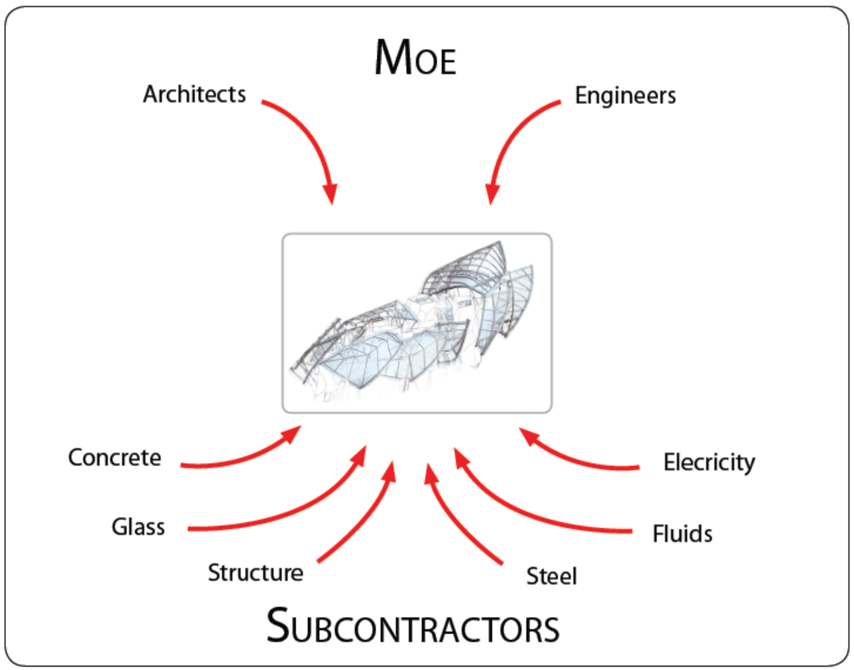




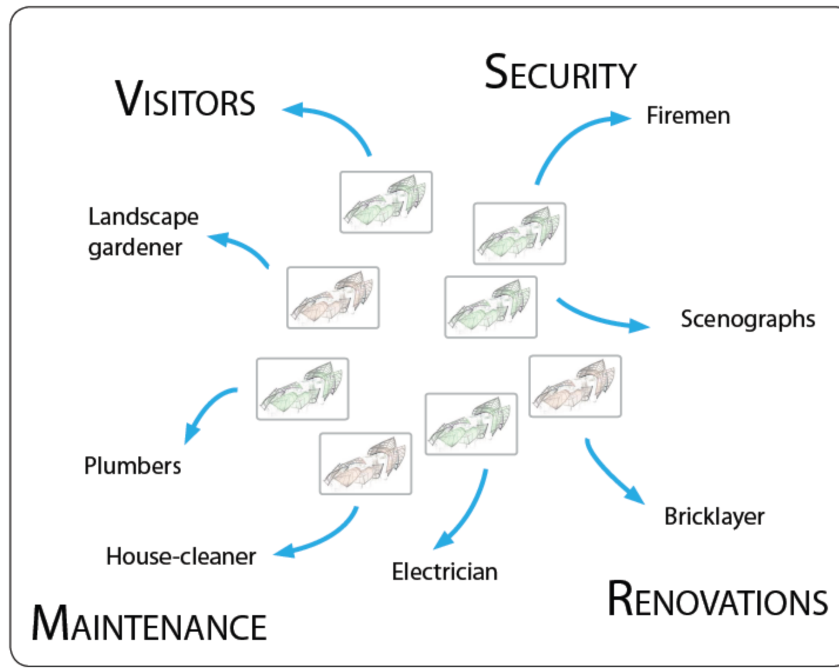
Data Aggregation, Data Distribution

Consultants and subcontractors integrated not only geometry but adaptive engineering intelligence into the model. Each of the maintenance trades will benefit from the complete 3D BIM model, including museum curators and visitors.

BUILDING INFORMATION

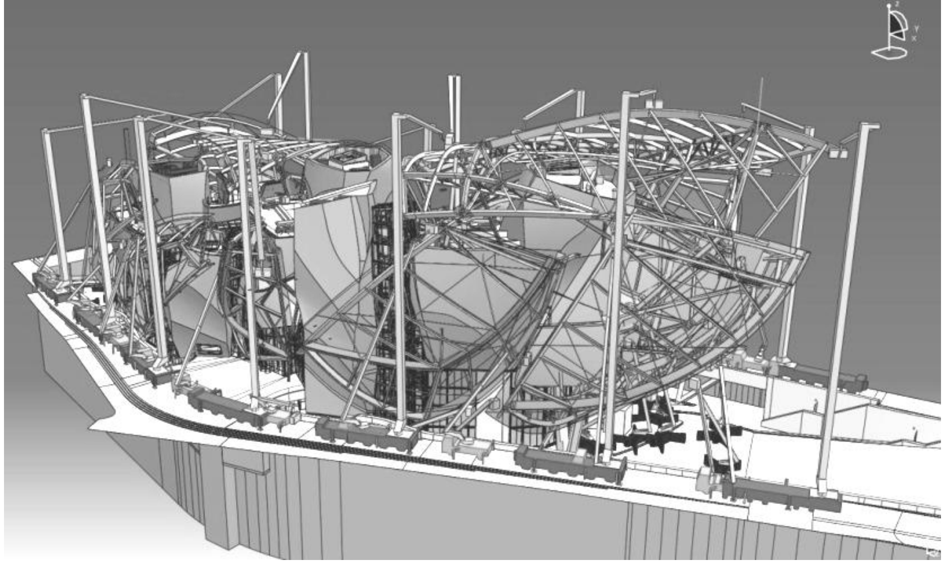


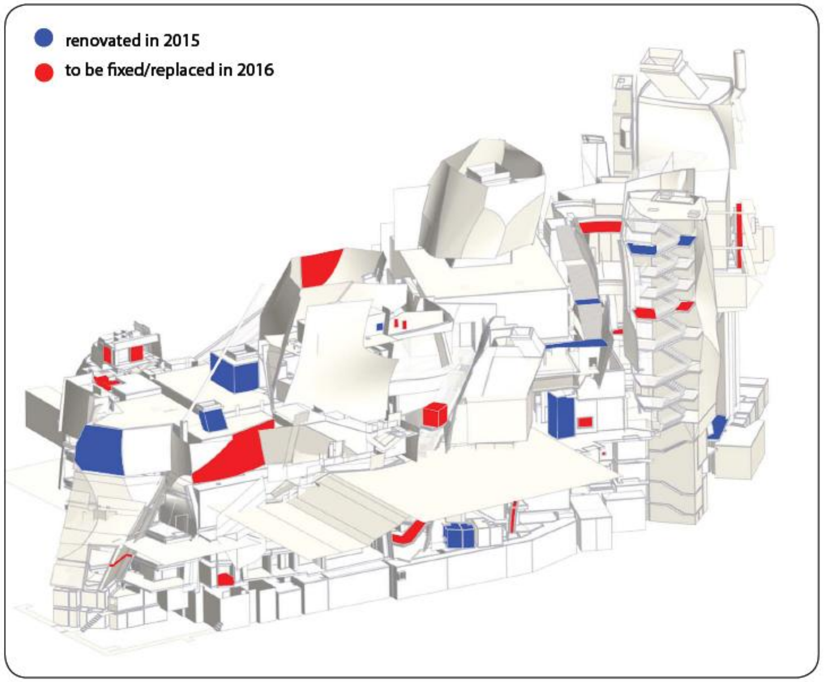
EXTRACTING INFORMATION

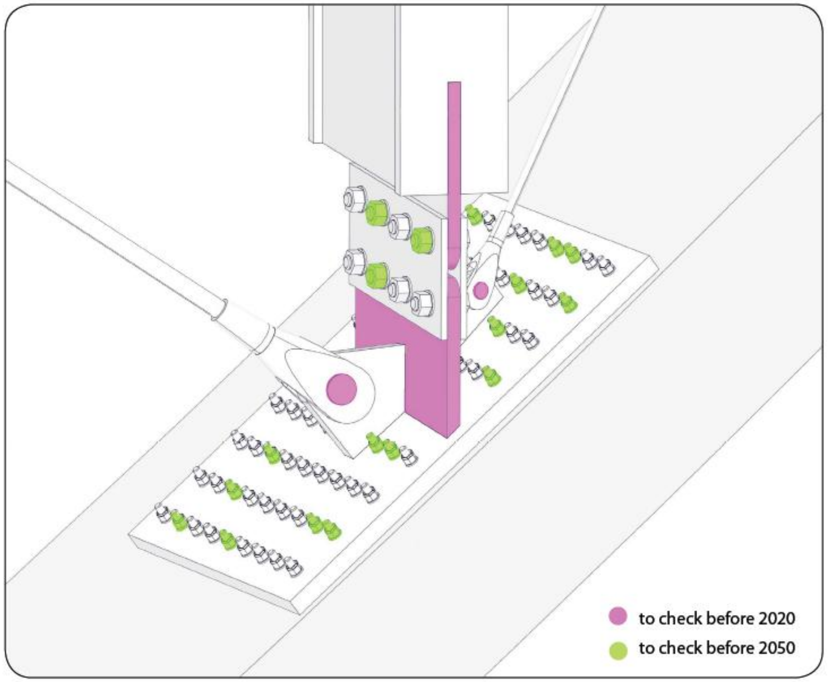


Anticipatory Maintenance Database

Data about routine maintenance includes predictive information around material and facility lifecycle.





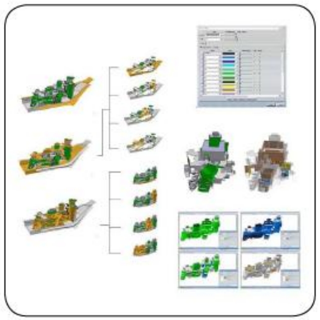


There was a separate project consulting team specifically tasked with accelerating the adoption of digital process.

BIM Strategic Resource Team

TRAININGS

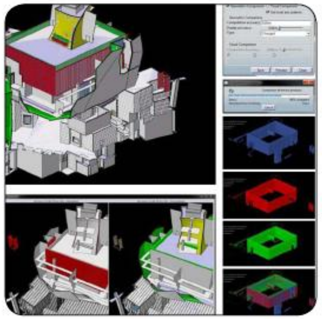
CUSTOMIZED TOOLS



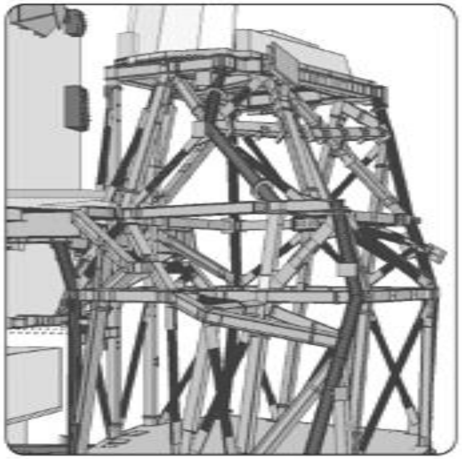
TUTORIALS

DAY TO DAY ADVISES

NEW TOOLS



Construction-Level Concurrency Process

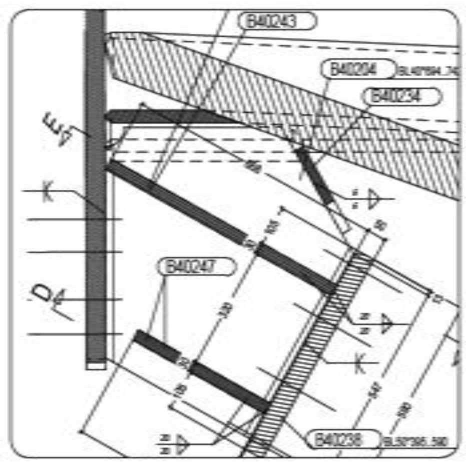


Integration of construction modifications in the 3D Model

- List all different particular procedures depending on different trades / subcontractors - rationalized them, limit the differences.
- Revise the status of PRO & EXE model : which level of details? Which legal status? EXE = DOE?
- Which future for the models that are not updates anymore?

Optimize 2D-3D links

Reset hierarchy : for some parts of the building, 3D is the most recent and advanced reference - but for some others, 2D is the reference, and has to be integrated in 3D.



Clean Batiwork-3D Links

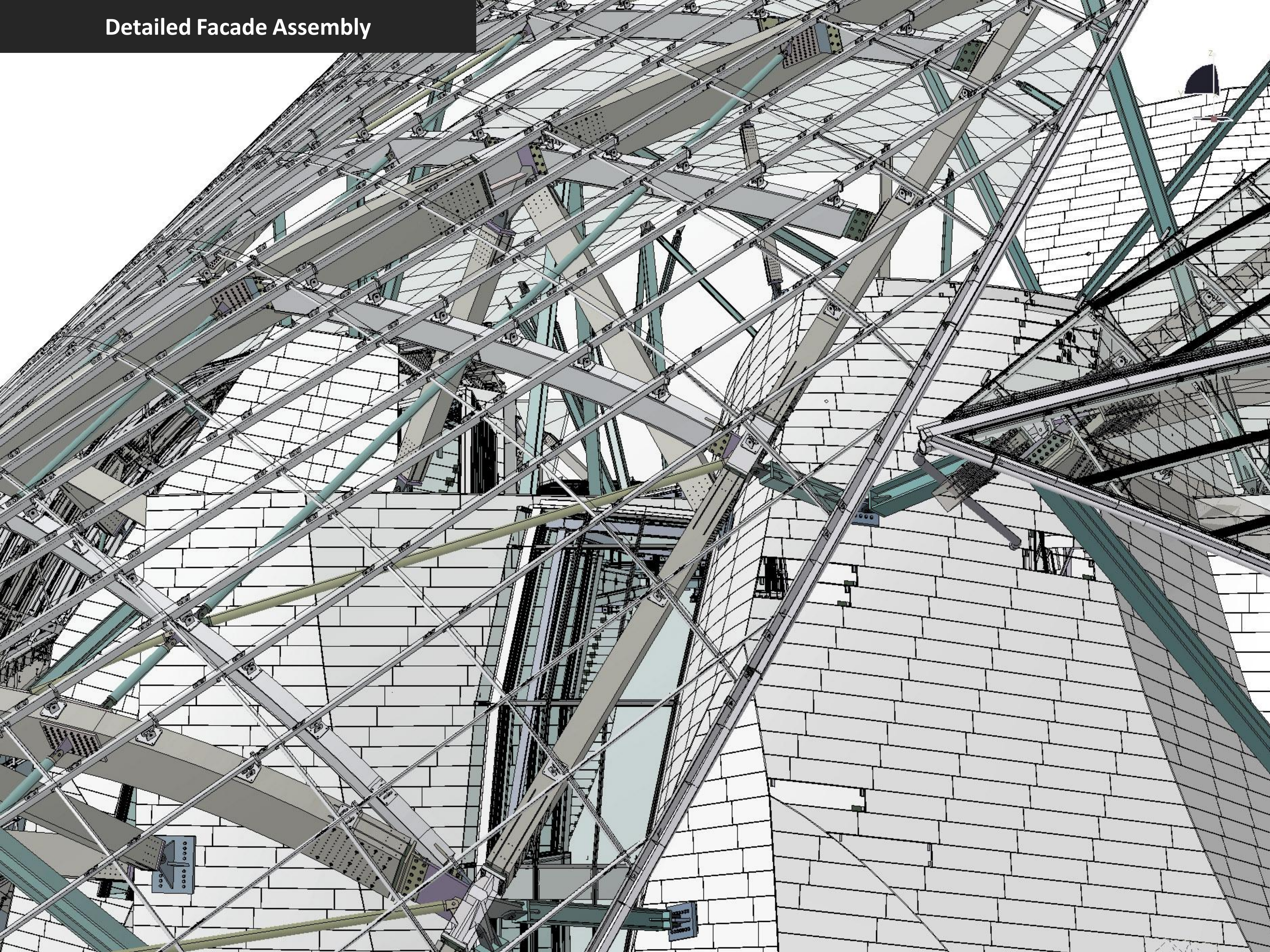
- Automate some links between 2D approval process (Batiwork) and 3D validation process.
- Index 2D naming convention (different than 3D naming convention).

Façade Structure, Under Construction

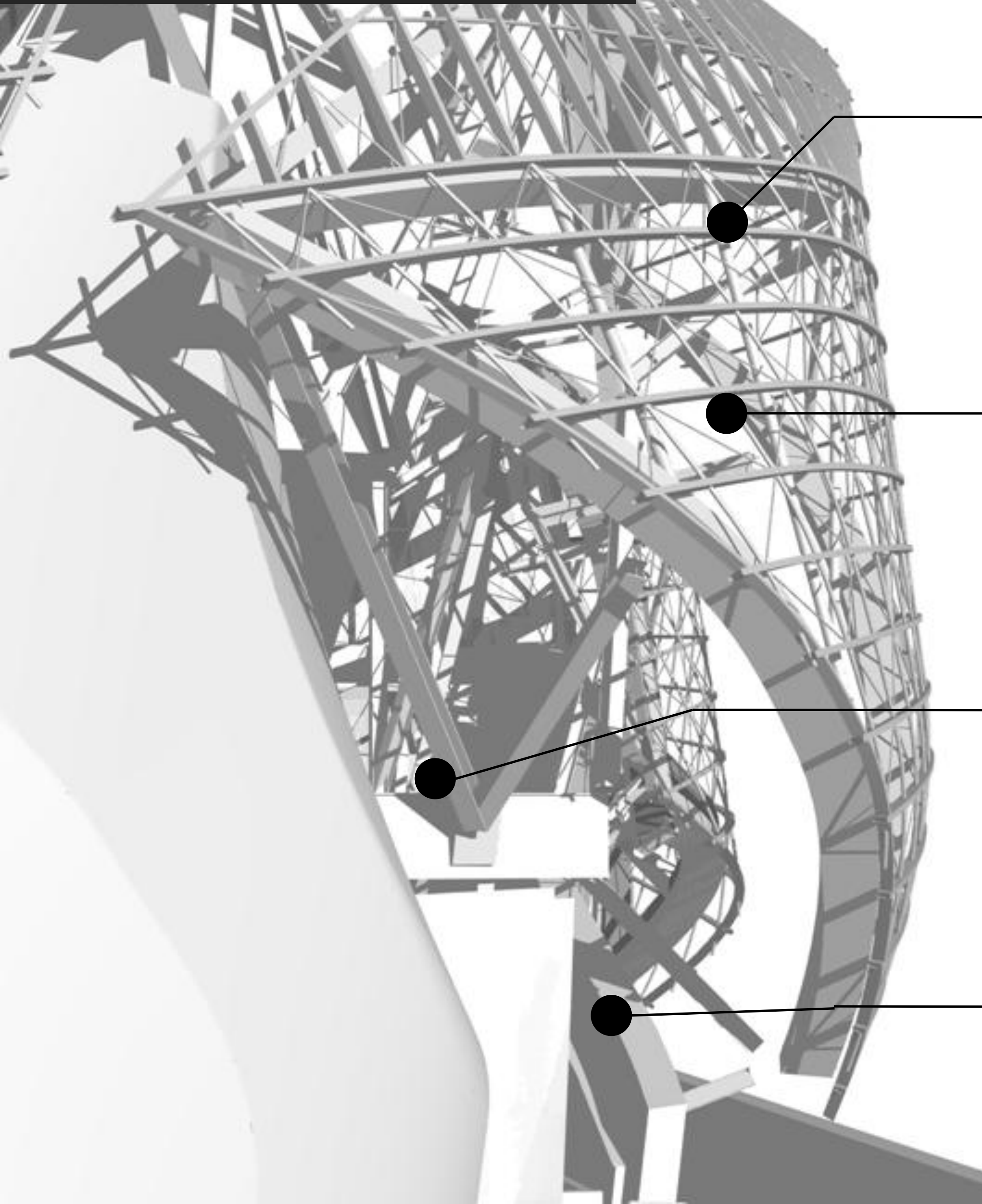
Generative Detailing

The building demanded extensive mass-customization techniques for nonstandard components: over 200 intelligent reusable modules to validate details and produce individual shop drawings automatically and generatively.

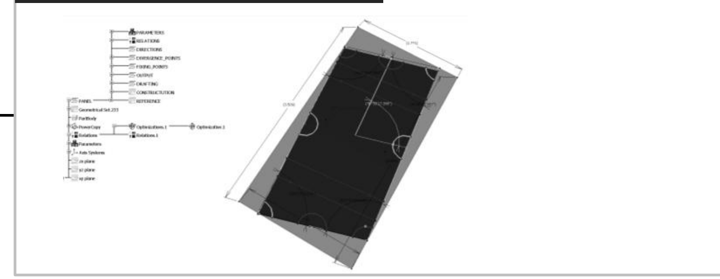
Detailed Facade Assembly



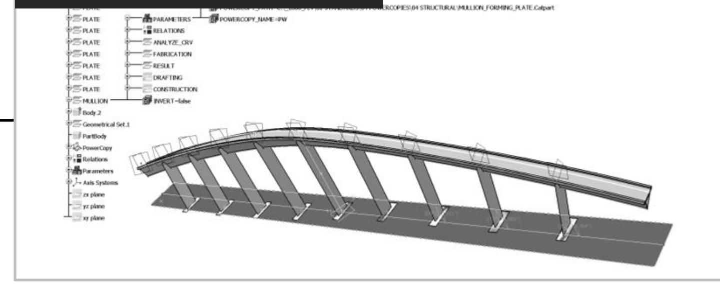
Examples of Generative Details



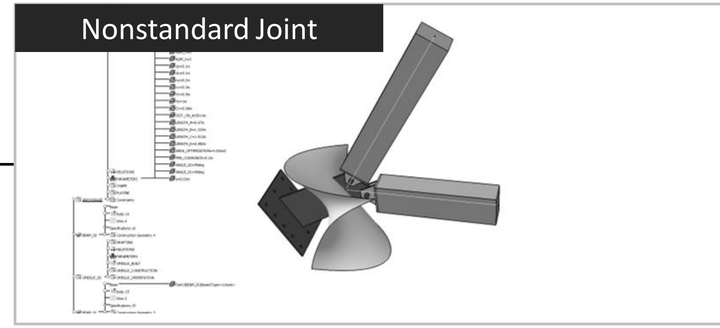
Glass Façade Panel



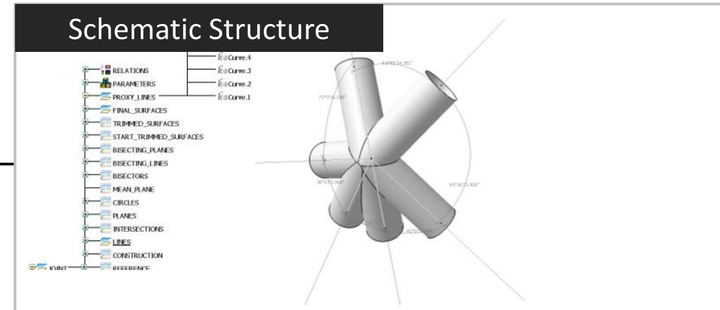
Curved Extrusion



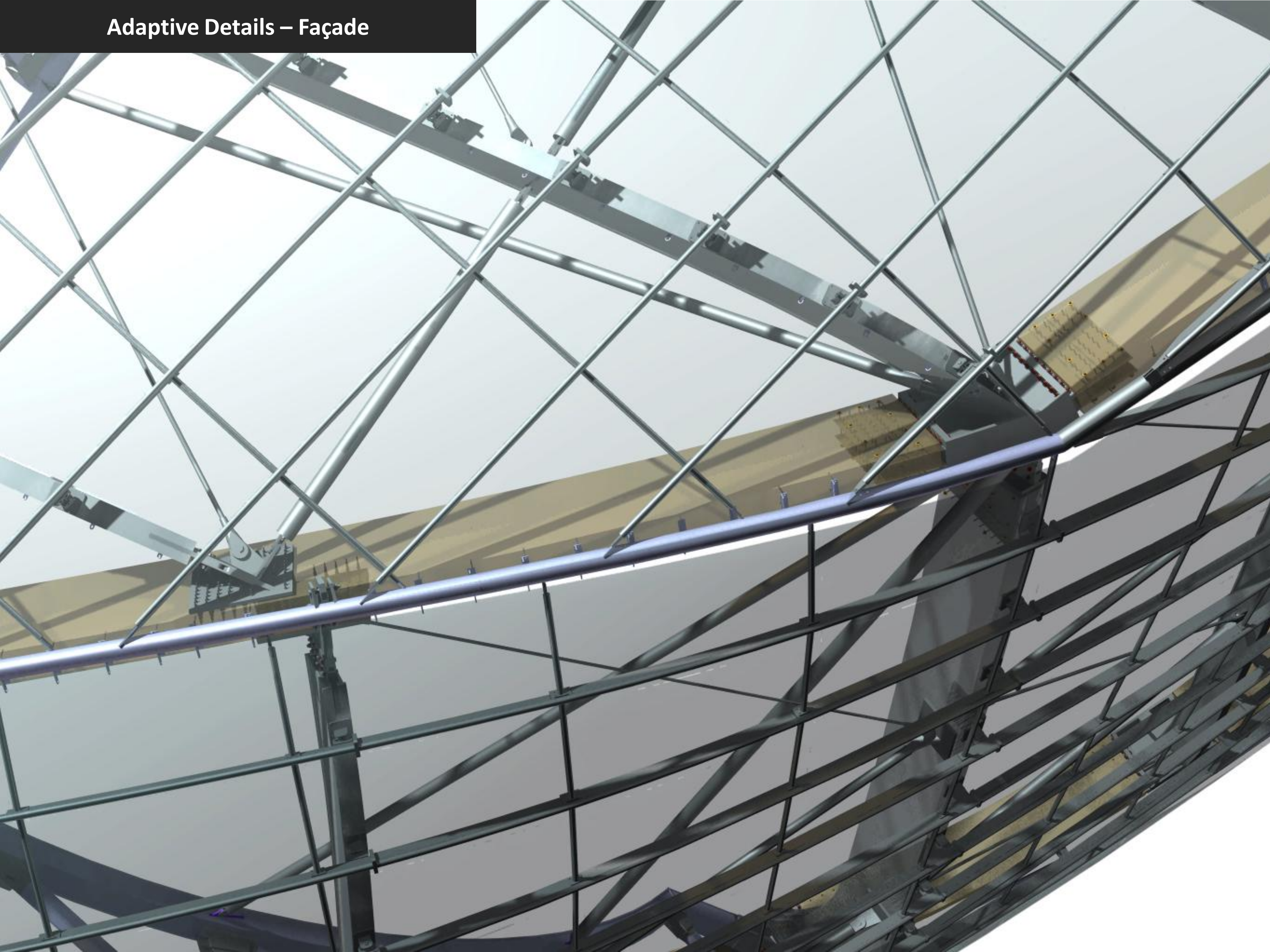
Nonstandard Joint



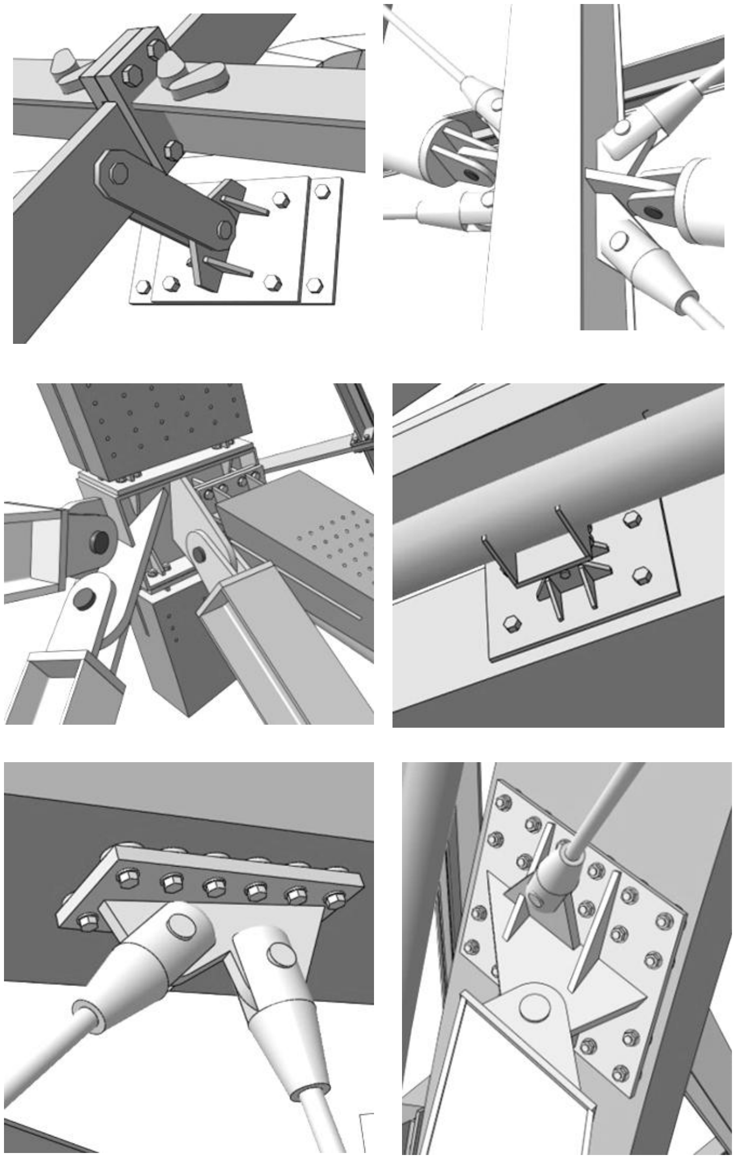
Schematic Structure



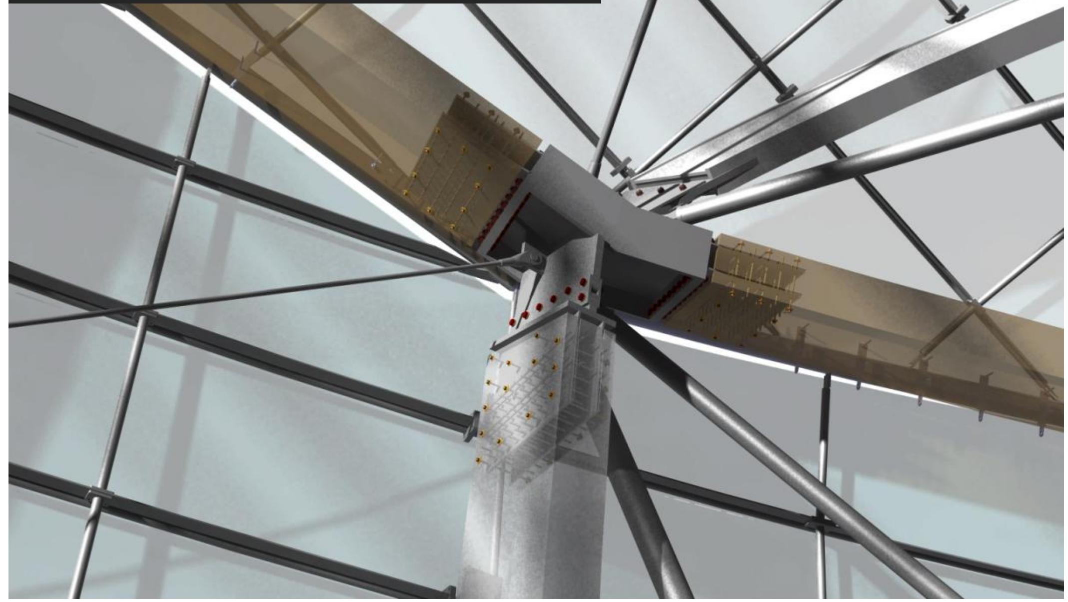
Adaptive Details – Façade



Adaptive Details – Façade



BIM Model – Generative Detail

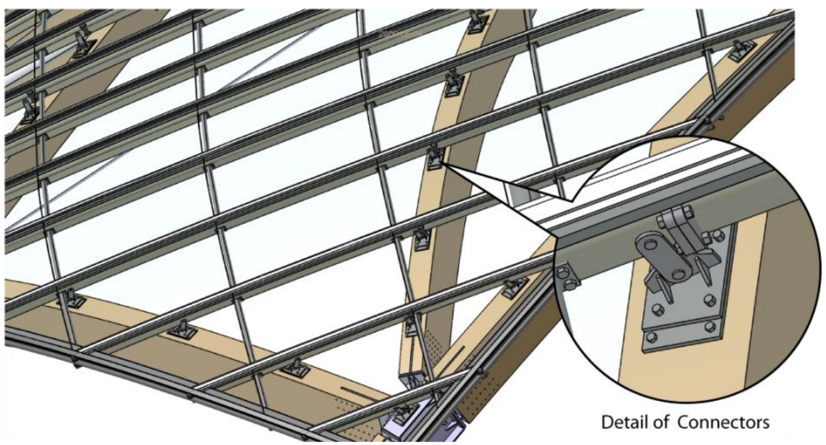


Fabricated Joint

CNC Custom Fabrication of Extrusions

Computer-controlled fabrication processes were used extensively. Every extrusion was custom CNC cut, made to order from the BIM.

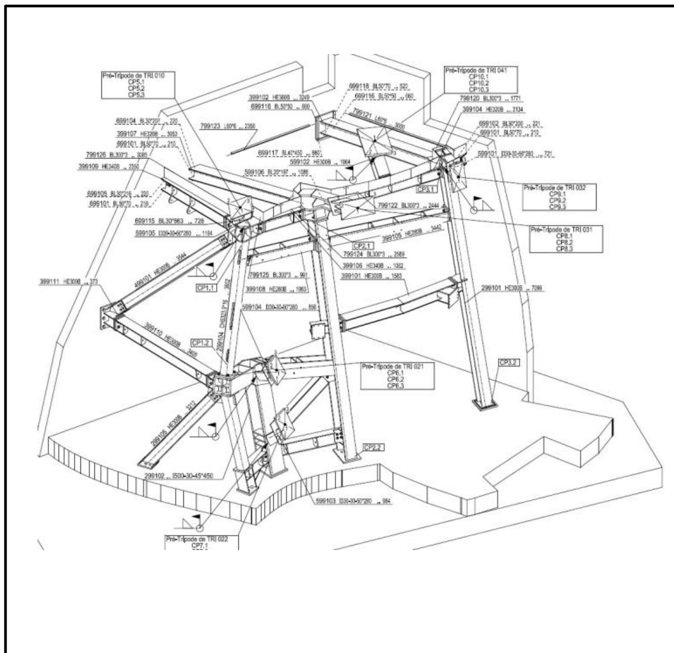
RESULT: Tertiary to Secondary Connections



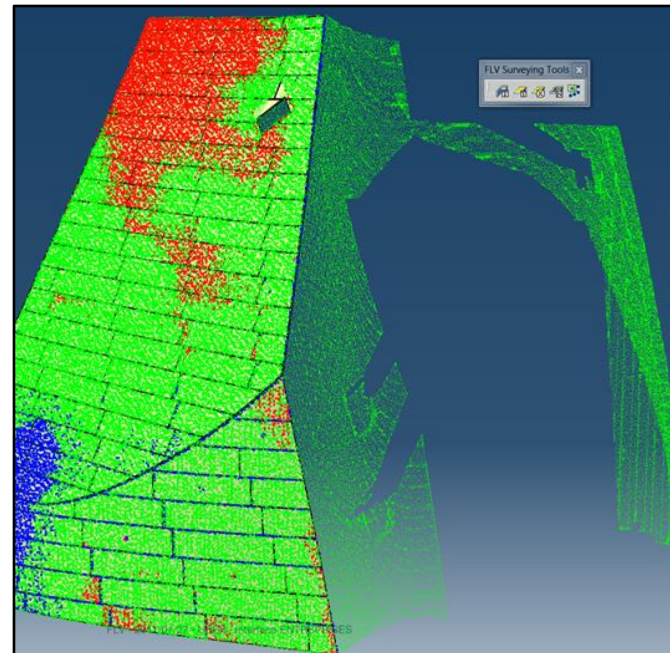
Primary Structure, Under Construction

Survey Verification, from Model

Construction quality was monitored with on-site with laser equipment, and round-tripped back into the model.


Predicted Coordinate Extraction


Site Survey

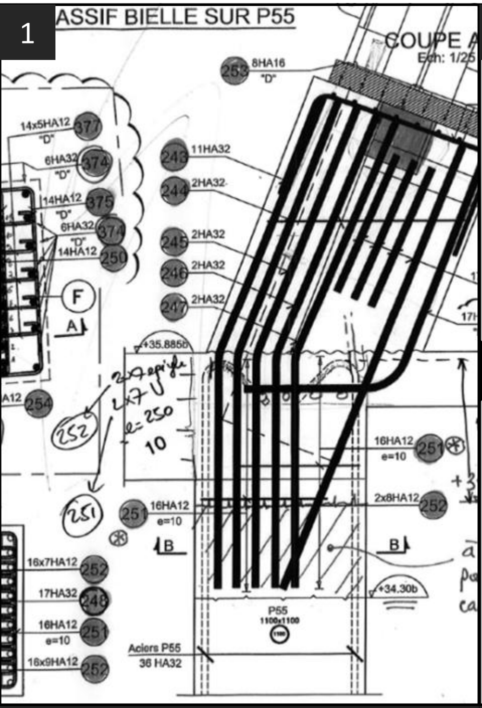


Point Cloud Confirmation

Generative Rebar and Embeds

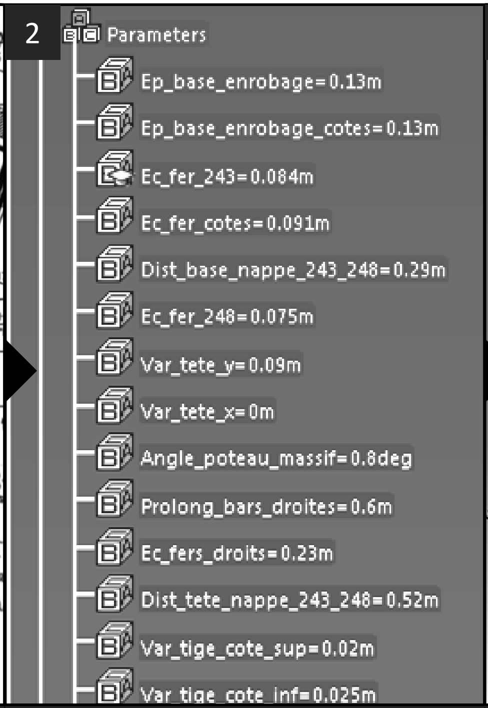
Difficult rebar configurations were designed as self-adapting, parametrically-driven modules that automatically adjusted 20 variables necessary for the concrete design.

1



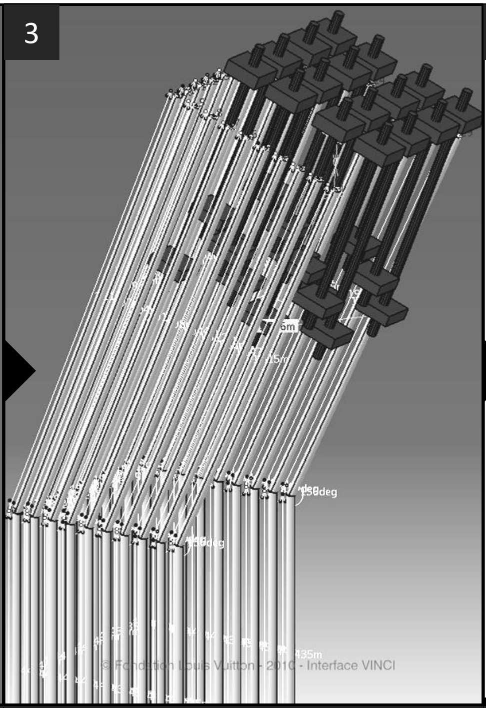
Initial Rebar Drawings

2



Parametric Constraints

3

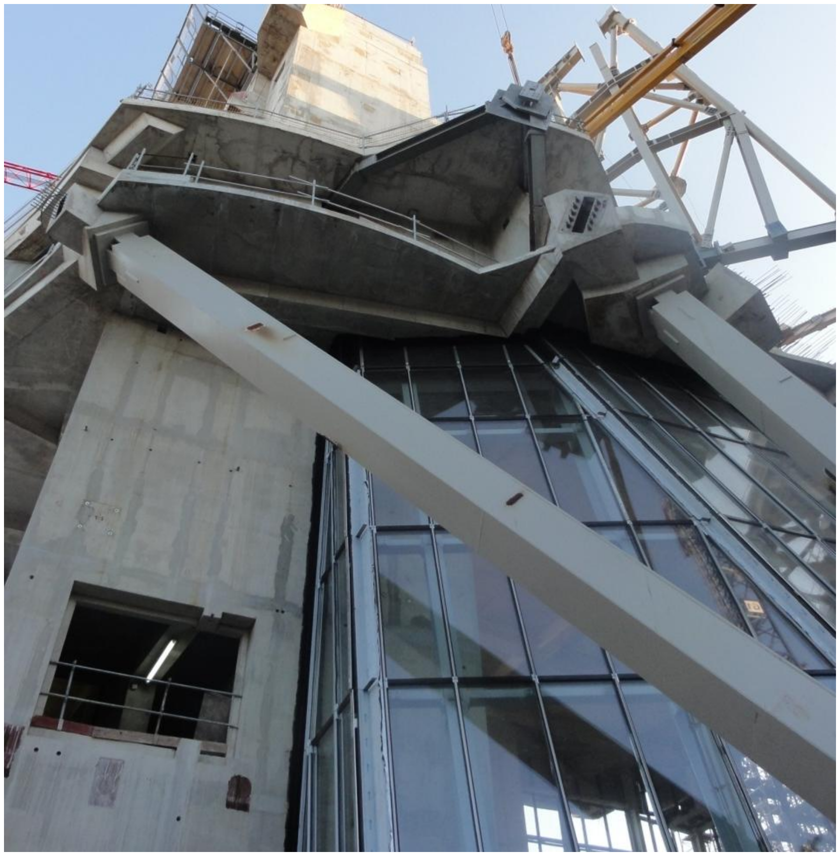


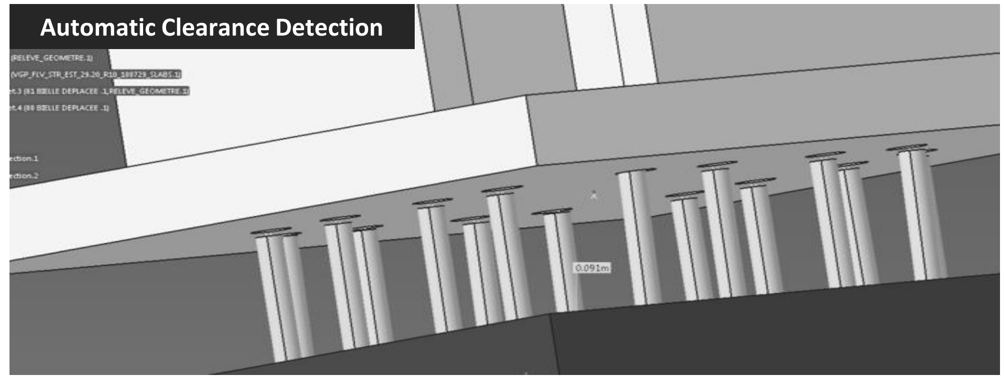
Generative Rebar

4

On-Site Assembly

Bracing Structure, Under Construction





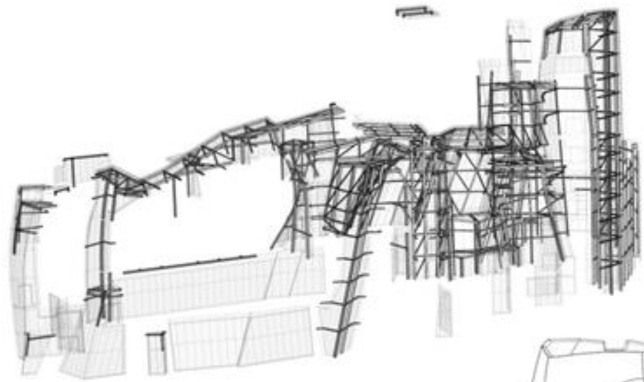
Automatic Clearance Detection

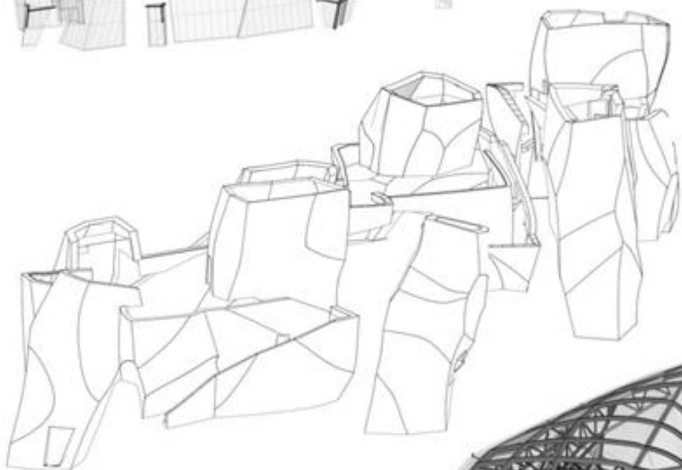
Site Installation, from 3D

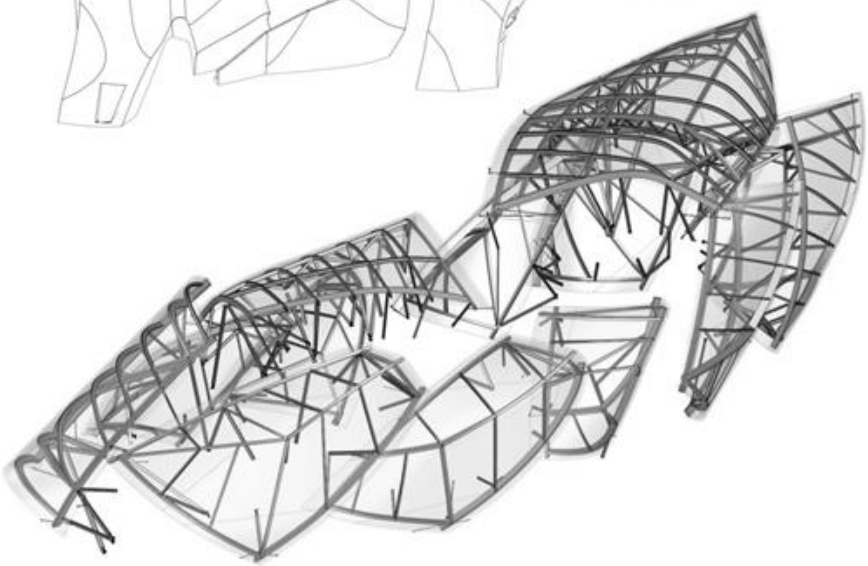
Material Optimization

Several building systems required computer optimized solutions. The team embedded self-configuring optimizations in the BIM objects themselves, which tested millions of configurations to compute a best solution.

Façade Element Types







Enclosure Glass

Even the flat enclosure glass was custom-cut along the unusual edge conditions.

“Iceberg” Cladding

The molds for these panels were custom CNC cut, from the BIM, for a precise and exact fit.

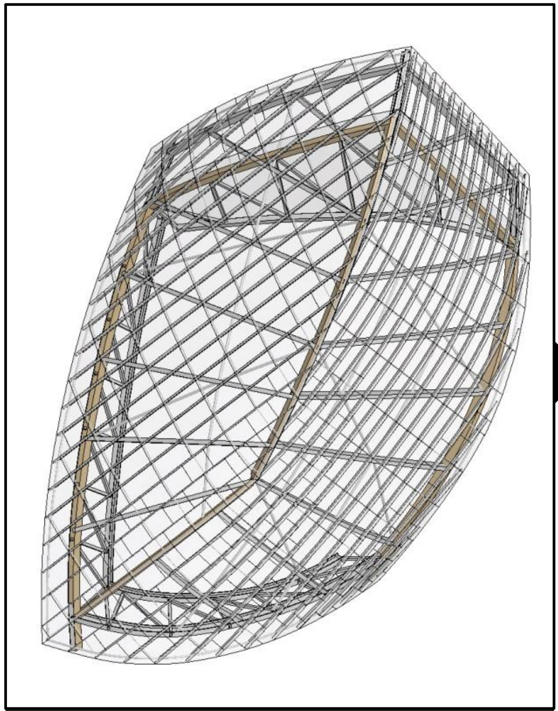
Canopy Glass

Each of the 3500 panels was custom formed to a cylinder shape by a CNC mold machine.

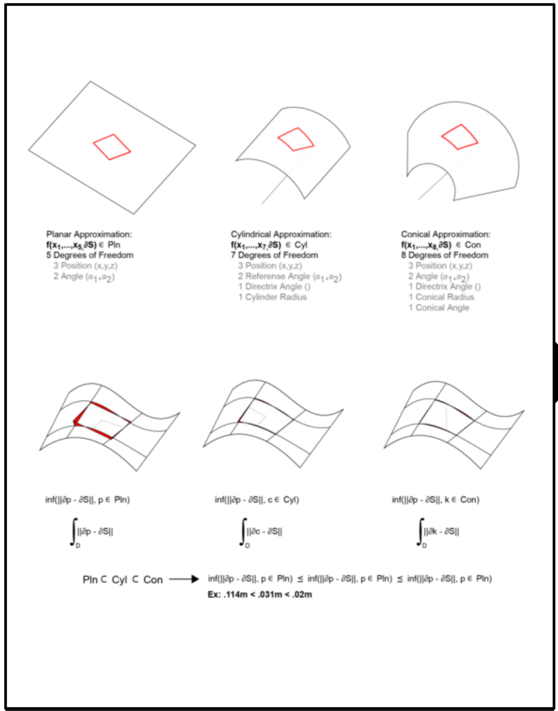
Cylindrical Glass Full Scale Prototype

Cylindrical Glass Optimization

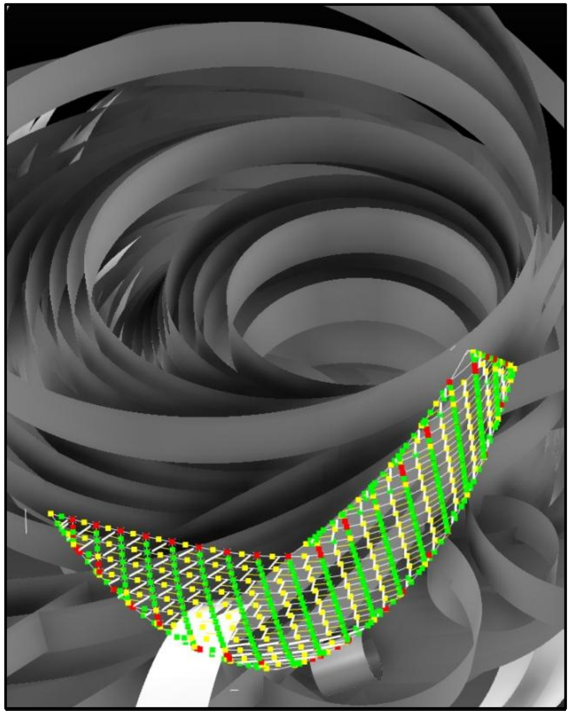
Mathematical optimizations found thousands of best-fit cylinders for the glass panels on the facade. These cylinders could be formed using an industrial process, creating the illusion of freeform surface in glass.



Global Constraint Definition

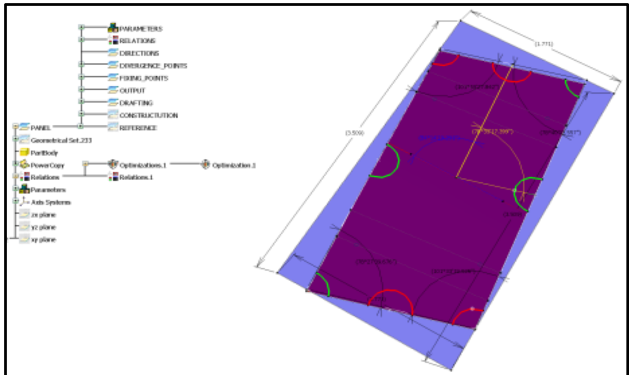


Numeric and Geometric Optimzation

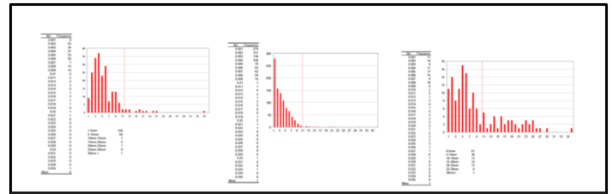


Cylinder, Bi-cylinder,
Deformed Cylinder Fitting

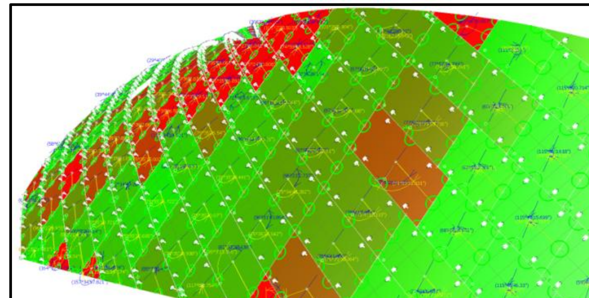
Glass Optimization Process



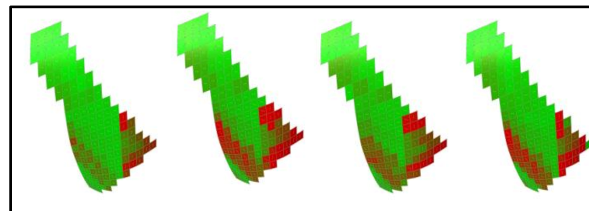
Parametric Component



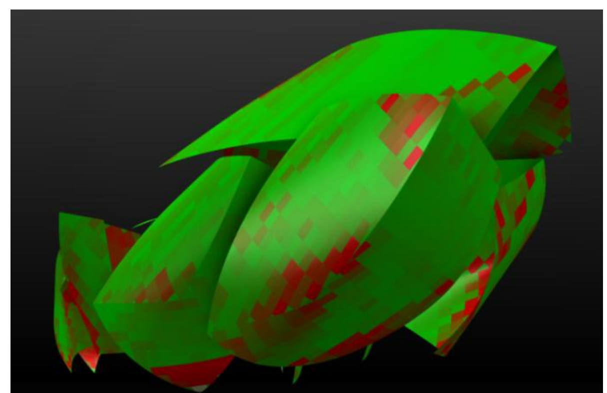
Frequency Optimization



Surface-Level Optimization



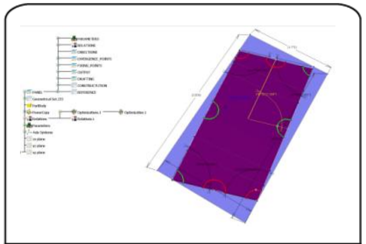
Local Surface Deformation



Global Project Optimization

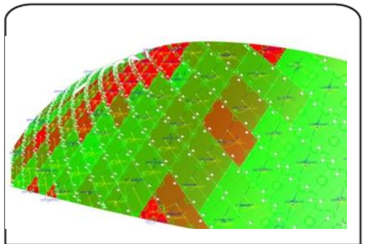
Parametric Optimization Workflow

With a model server, several computers could simultaneously optimize portions of the project glass, accelerating analysis dramatically.



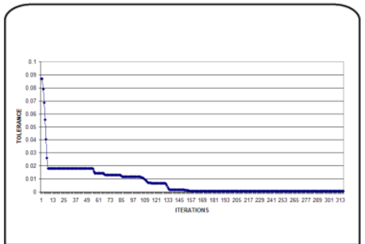
Parametric Definition

Geometric, material, and installation constraints embedded in the prototype



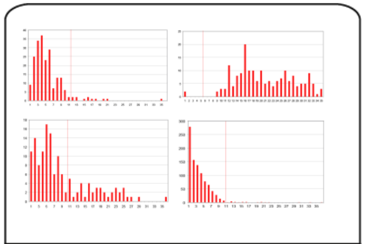
Adaptive Instantiation

Each unit is unique and adapted exactly to its own location



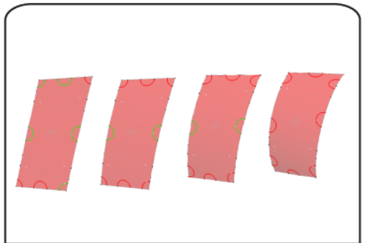
Convergent Optimization

Optimizations run to converge toward any nonlinear design conditions



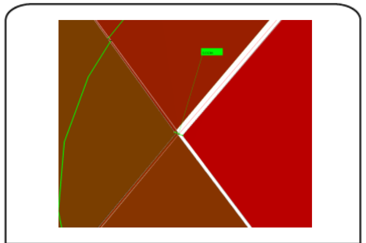
Frequency Analysis

Statistical frequencies indicate which types of modules are most common



Family Decomposition

From frequency analysis, families are chosen and each module detects the closest family

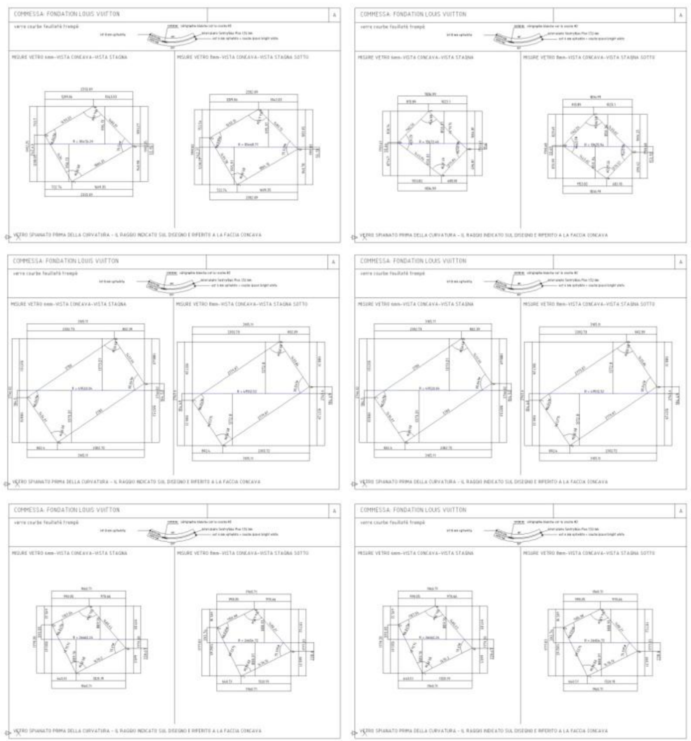


Tolerance Verification

Since results are no longer exact, tolerances are verified globally

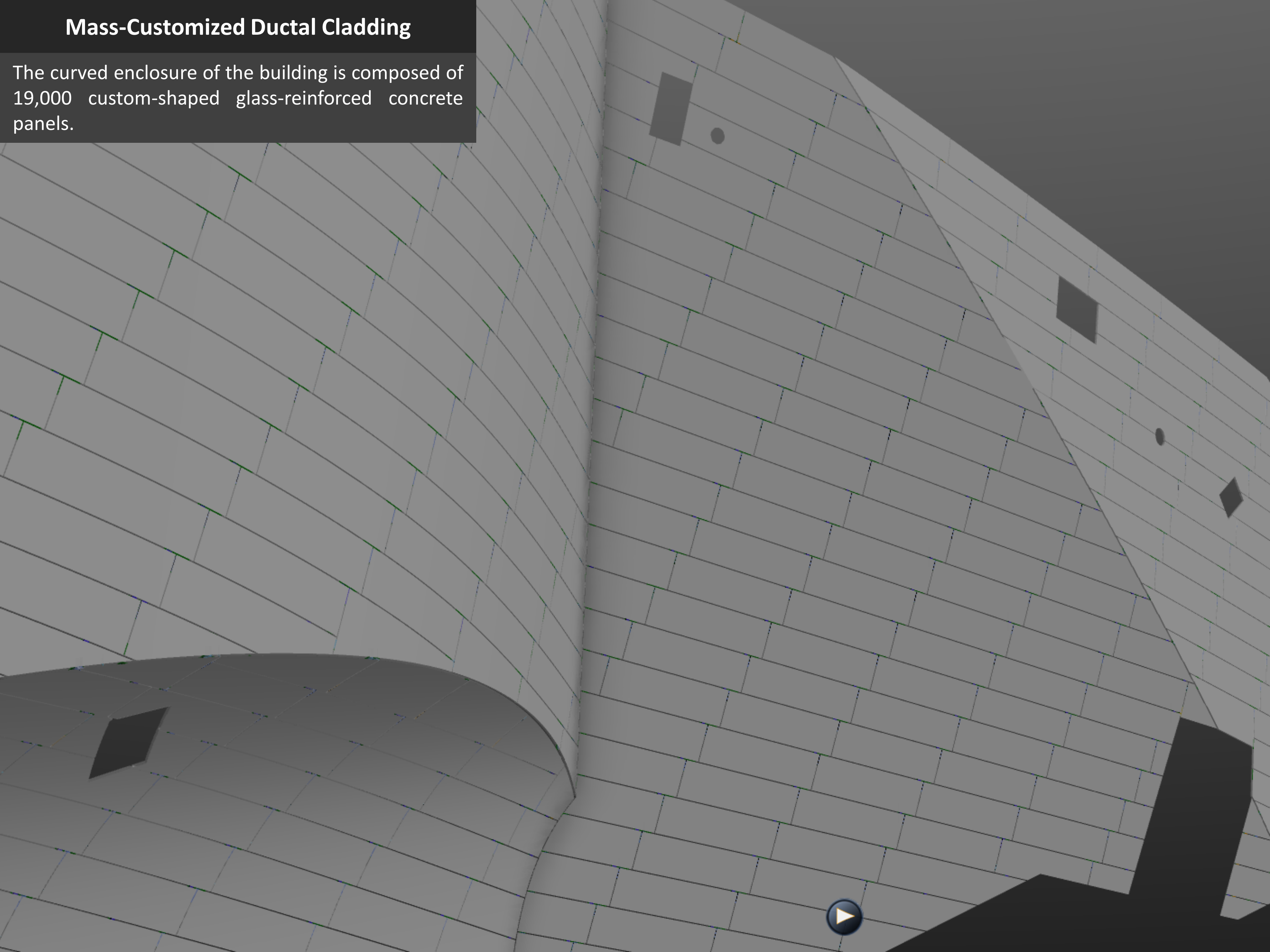
CNC Bending of 3500 Curved Glass Panels

The bending of the panels was executed by a large, CNC cylindrical glass bending machine, with shop drawings and validation drawings from the BIM.

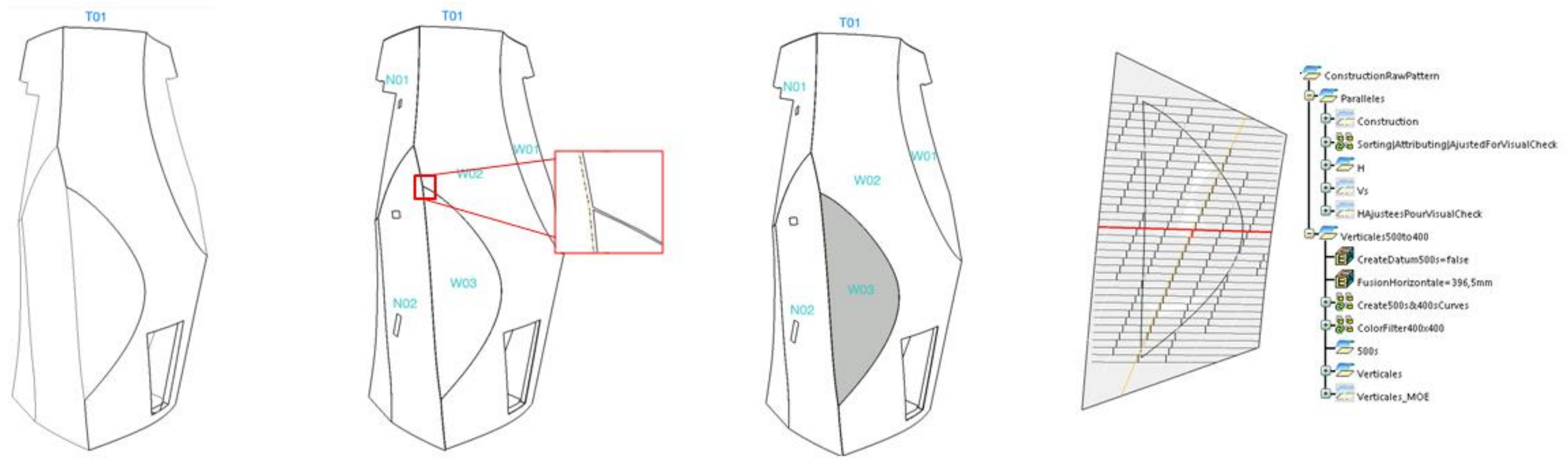


Mass-Customized Ductal Cladding

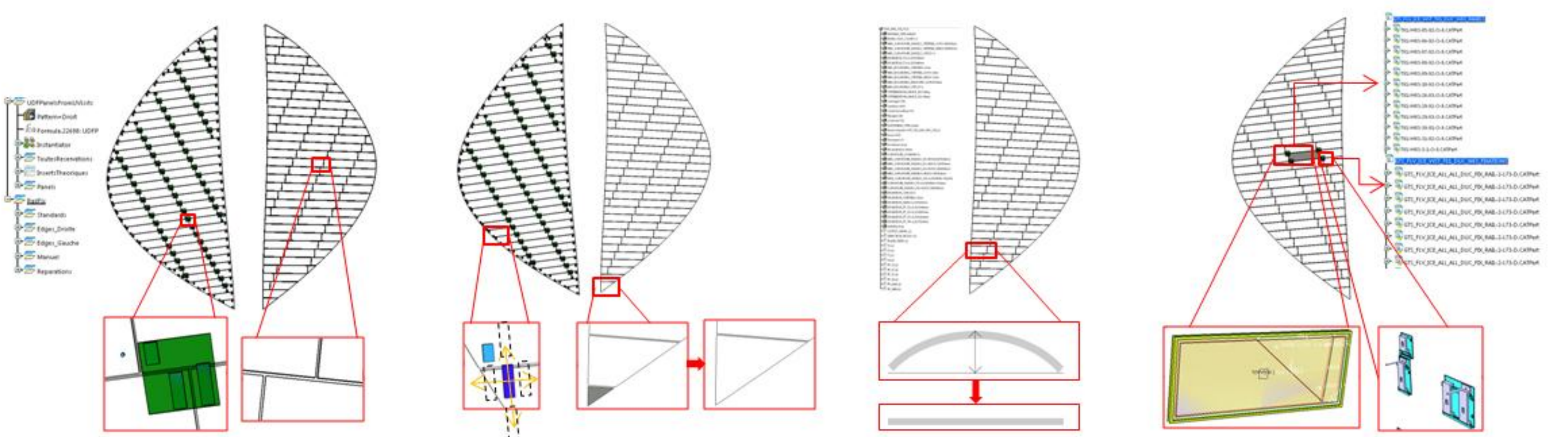
The curved enclosure of the building is composed of 19,000 custom-shaped glass-reinforced concrete panels.



Concrete Façade Rationalization



1. Extraction des surfaces de référence
2. Découpes (Maitre/esclave)
3. Séparation des Surfaces
4. Construction du Pattern

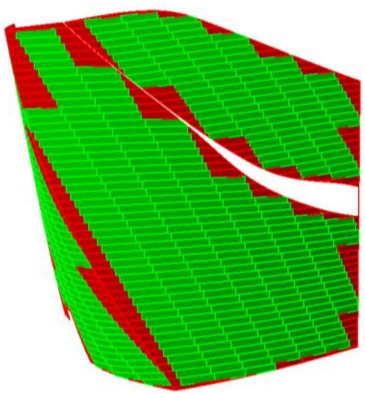


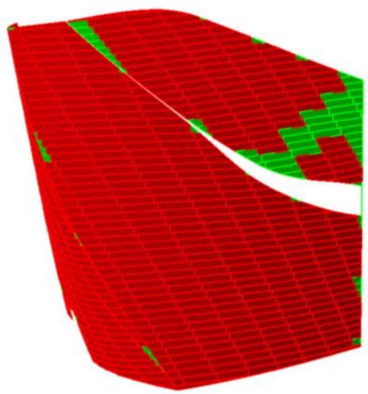
5. Création panneaux & fixations
6. Fusion/Découpe des panneaux et déplacement des fixations
7. Optimisation plat courbe
8. Séparations des panneaux & fixations + Délivrables de fabrication

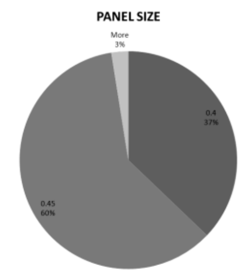
Ductal Optimization Process

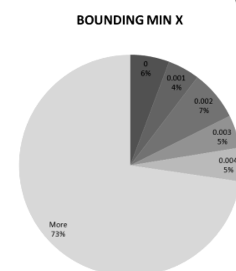
The custom BIM information embedded in each of the panels was statistically analyzed to reduce mold variation.

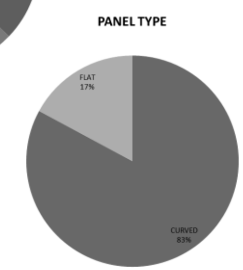
	Part Name	Feature Name	PANEL_NAME	PANEL_AREA	BOUNDING_MIN_X	BOUNDING_AREA	BOUNDING_VOLUME	ANGLE_1	ANGLE_2	PANEL_FLAT_COUNT
GT_MetaData	PartName	FeatureName	PARM.PANEL_NAME	PARM.PANEL_AREA	PARM.BOUNDING_MIN_X	PARM.BOUNDING_AREA	PARM.BOUNDING_VOLUME	PARM.ANGLE_1	PARM.ANGLE_2	PARM.PANEL_FLAT_COUNT
				m2	m	m2	m3	DegMinSe	DegMinSec	
1	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0001	0.268	0.0126	0.586	3.00E-03	0	0	0
2	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0002	0.248	0.004	0.504	9.80E-04	0	0	0
3	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0003	0.35	0.0086	0.73	3.00E-03	0	0	0
4	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0004	0.213	0.0056	0.439	1.00E-03	0	0	0
5	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0005	0.293	0.0047	0.598	1.00E-03	0	0	0
6	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0006	0.374	0.0066	0.771	2.00E-03	0	0	0
7	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0007	0.45	0.007	0.925	0.003	0	0	0
8	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0008	0.373	0.0055	0.764	0.002	0	0	0
9	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0009	0.429	0.0069	0.882	0.003	0	0	0
10	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0010	0.429	0.0069	0.882	0.003	0	0	0
11	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0011	0.429	0.0074	0.883	0.003	0	0	0
12	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0012	0.427	0.0089	0.887	0.004	0	0	0
13	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0013	0.429	0.0081	0.886	0.003	0	0	0
14	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0014	0.429	0.0066	0.881	0.003	0	0	0
15	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0015	0.448	0.0095	0.93	0.004	0	0	0
16	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0016	0.448	0.0073	0.922	0.003	0	0	0
17	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0017	0.044	0.0004	0.088	1.87E-05	0	0	1
18	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0018	0.45	0.0153	0.955	0.007	0	0	0
19	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0019	0.084	0.001	0.17	8.04E-05	0	0	1
20	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0020	0.45	0.0164	0.959	0.007	0	0	0
21	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0021	0.129	0.0018	0.259	2.34E-04	0	0	1
22	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0022	0.45	0.0173	0.962	0.008	0	0	0
23	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0023	0.175	0.0031	0.356	5.49E-04	0	0	0
24	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0024	0.45	0.0178	0.964	0.008	0	0	0
25	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0025	0.223	0.0049	0.455	1.00E-03	0	0	0
26	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0026	0.45	0.0178	0.964	0.008	0	0	0
27	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0027	0.27	0.0071	0.557	0.002	0	0	0
28	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0028	0.45	0.0178	0.964	0.008	0	0	0
29	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0029	0.317	0.0096	0.66	3.00E-03	0	0	0
30	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0030	0.45	0.0176	0.963	0.008	0	0	0
31	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0031	0.365	0.0123	0.768	0.005	0	0	0
32	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0032	0.45	0.0169	0.96	0.008	0	0	0
33	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0033	0.431	0.0163	0.919	7.00E-03	0	0	0
34	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0034	0.431	0.0146	0.913	0.006	0	0	0
35	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0035	0.084	0.001	0.168	8.21E-05	0	0	1
36	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0036	0.45	0.0122	0.944	0.005	0	0	0
37	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0037	0.138	0.0018	0.279	2.48E-04	0	0	1
38	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0038	0.45	0.0117	0.942	0.005	0	0	0
39	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0039	0.193	0.0028	0.391	5.37E-04	0	0	0
40	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0040	0.45	0.0122	0.944	0.006	0	0	0
41	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0041	0.072	0.0287	0.208	2.00E-03	0	0	0
42	EST-ICB_CHP	BOUNDING_BOX	E01.EST-ICB_CHP_0042	0.41	0.0415	0.97	0.017	0	0	0





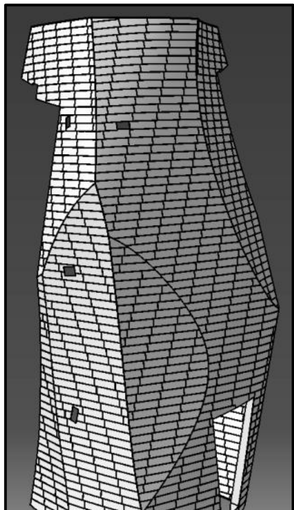




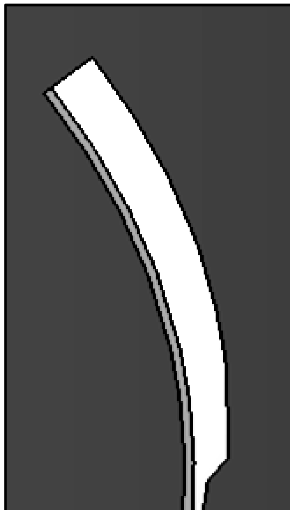


CNC Cutting of 19,000 Ductal Molds

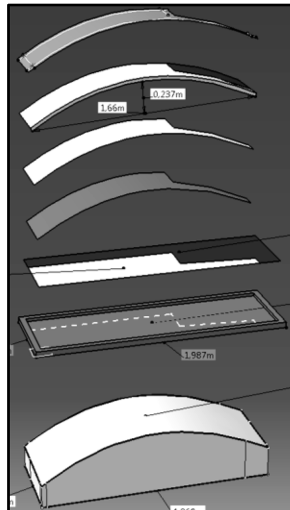
Each mold shape was either cut with hot wire (for ruled and developable surfaces) or routed (for non-ruled surfaces).



Assembled Panels



Single Panel



Casting Assembly

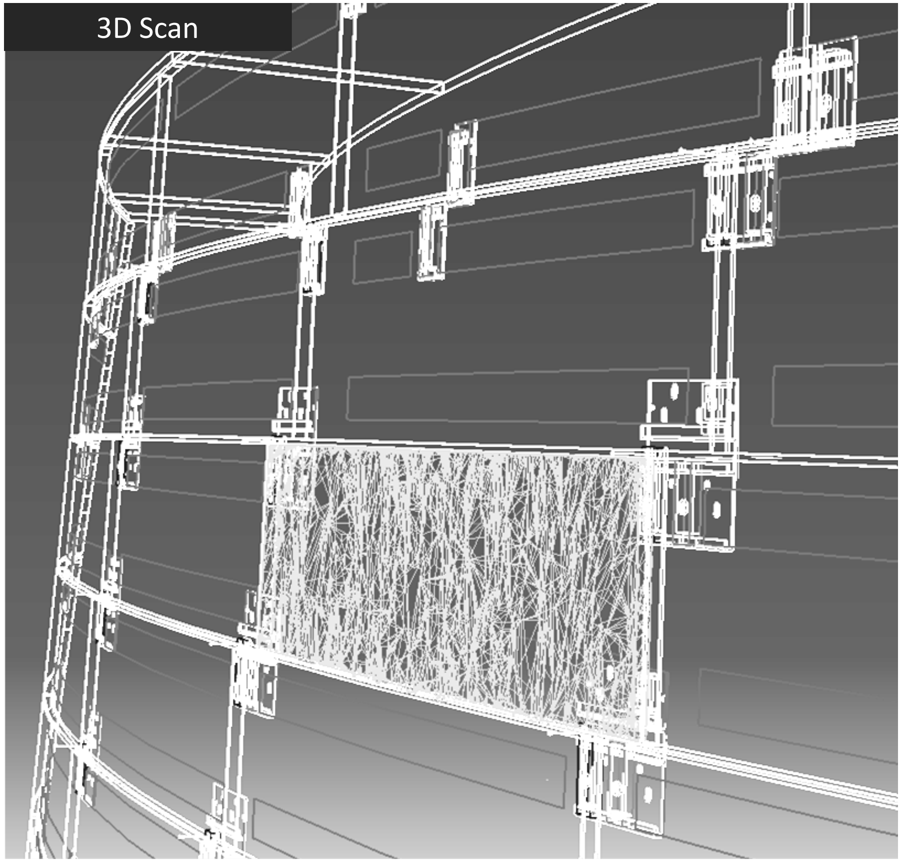
Routed Foam – for non-ruled surface panels

Hot Wire Cutter – for ruled surface panels

Robotic Design Confirmation

Each panel is robotically scanned and automatically positioned in the model, to confirm correct design and fixation ahead of shipping installation.

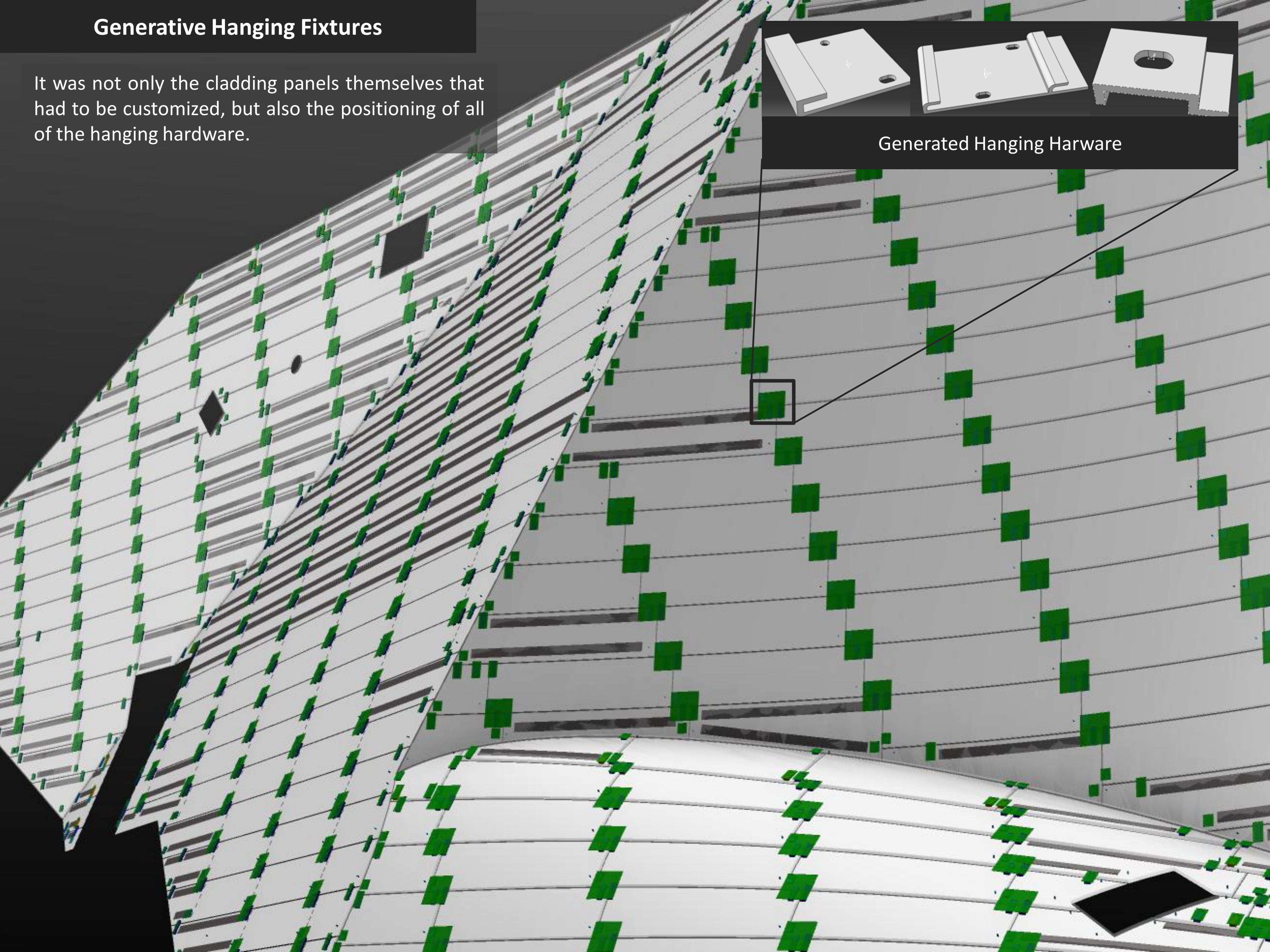
3D Scan



Robotic Scanner

Generative Hanging Fixtures

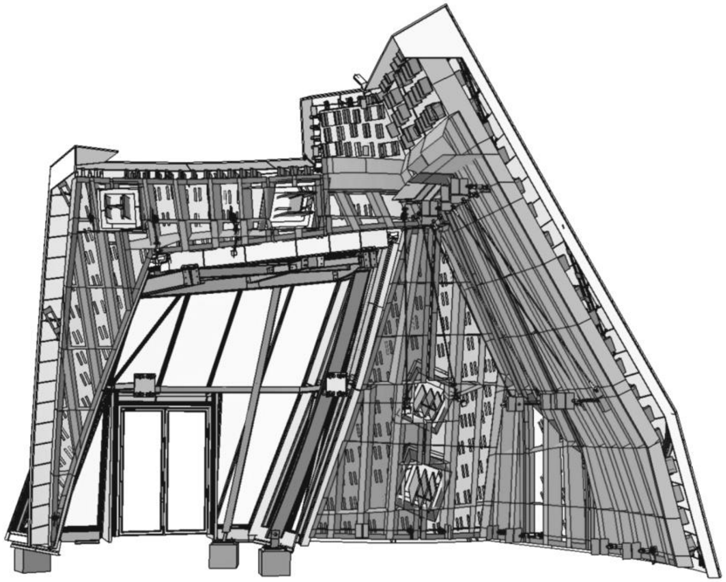
It was not only the cladding panels themselves that had to be customized, but also the positioning of all of the hanging hardware.

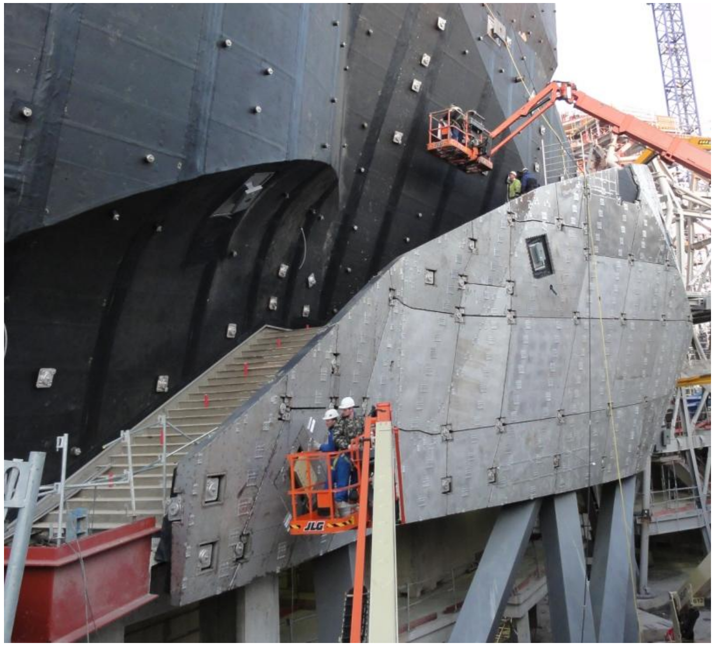


Generated Hanging Harware

Ductal Fixation Nodes, Under Construction

Ductal Installation and BIM Support





High-Fidelity Analysis

The team built custom tools, with industrial-strength databases in the background, to complete the structural, wind, and other analysis of the building.

Comprehensive Analysis Model

The project used the full range of pre-construction simulations, with custom-programmed interchanges among the various tools.

Light Analysis

Analysis of lighting quality and impact, reflexion quality on different types of materials.

Crowd Flows Simulations

Simulation of different flow scenarios : people individual trajectories in the building, crowd flows - in order to estimate number and position of emergency exits, or optimize the space for a particular scenography, etc.

Landscape Modeling

Precise modelling of landscape near FLV - in prevision of any changes in the landscape.

Fire Analysis

4D modeling of buiding behavior during a fire, of crowd dispersal.

Security Scenarios

Optimization of number and position of security cameras (pieces of art protection).

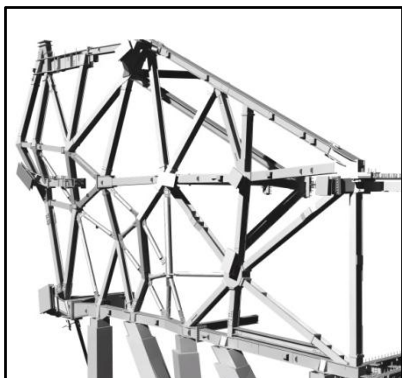
Ageing Analysis

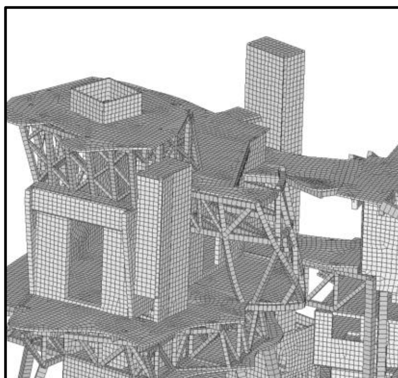
Simulation of different states of the building in 5 / 10 / 100 years :

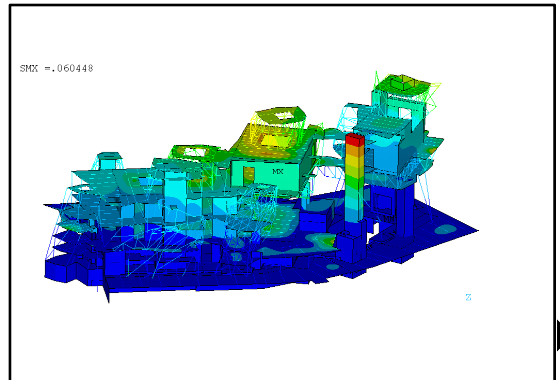
- Underligning the elements to be replaced, the equipments to repair.
- Simulation of potential issues or scenarios : overflowing...
- Simulation of ageing of materials (dust, color changing..)

Structural Optimization and Simulation

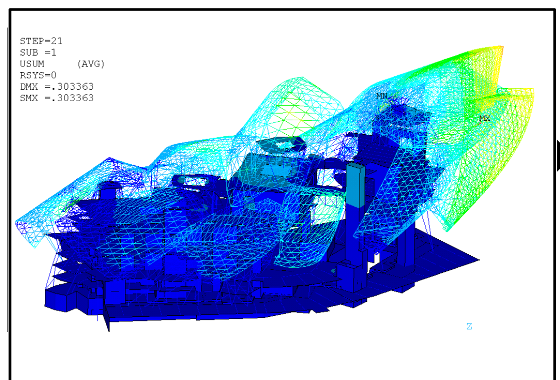
Each design iteration required advanced structural analysis and custom scripts. The vast size of structural results required that they be stored in a BIM-connected SQL database.


BIM Model Subdivision

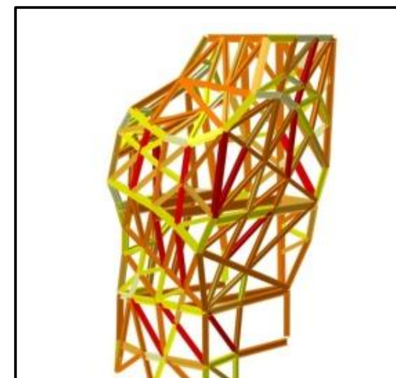

Analysis Mesh Generation



Analysis Mesh Generation

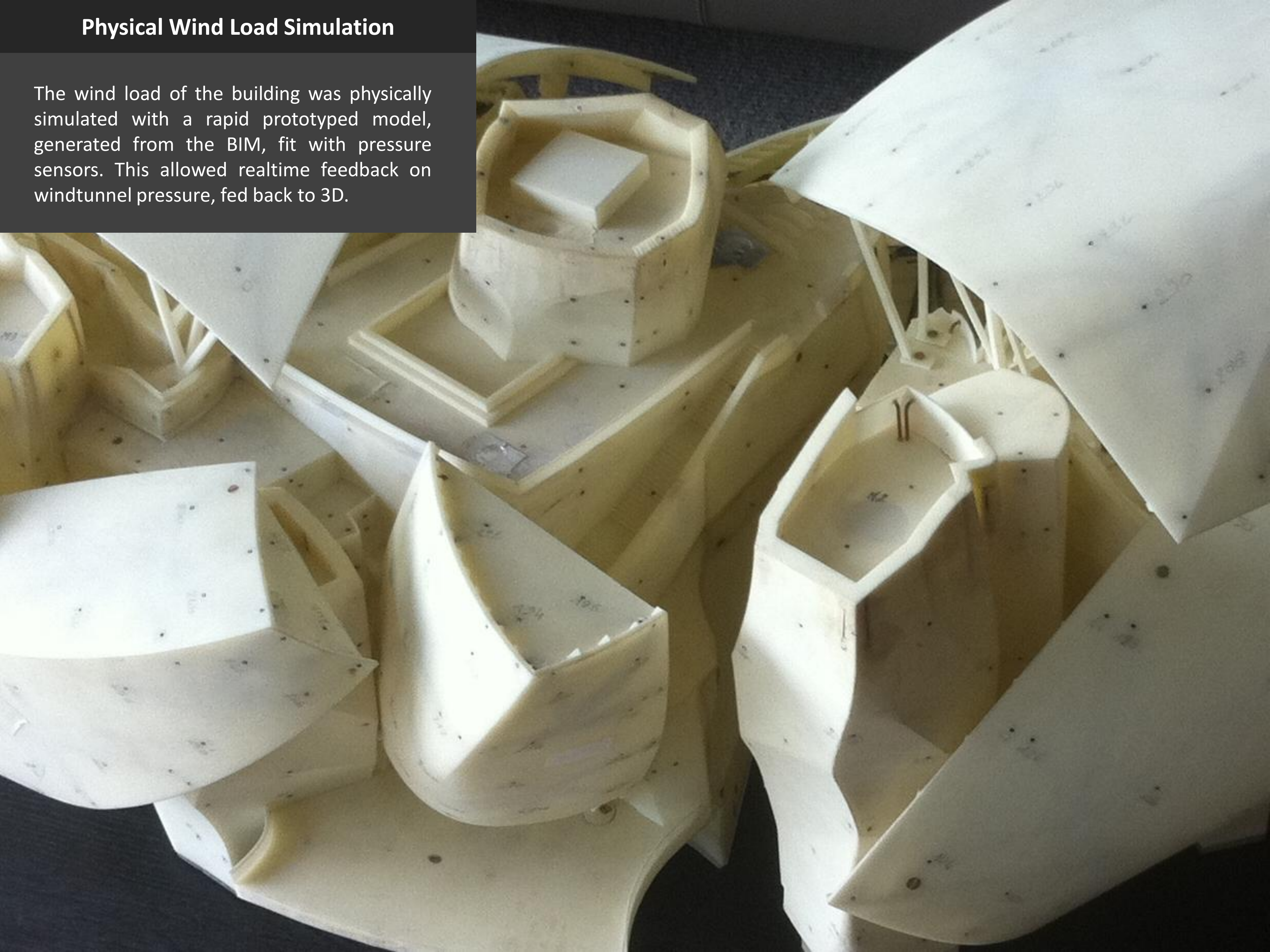


Analysis Mesh Generation


Analysis Results in BIM

Physical Wind Load Simulation

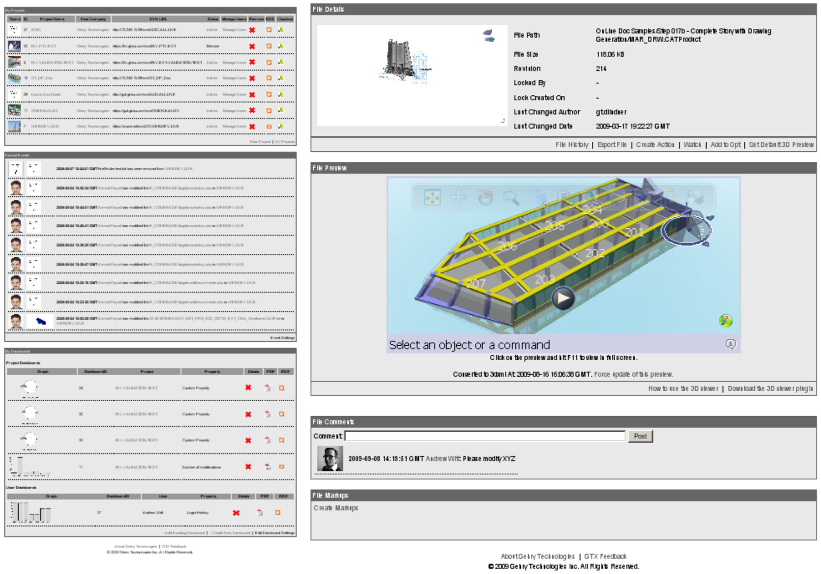
The wind load of the building was physically simulated with a rapid prototyped model, generated from the BIM, fit with pressure sensors. This allowed realtime feedback on windtunnel pressure, fed back to 3D.

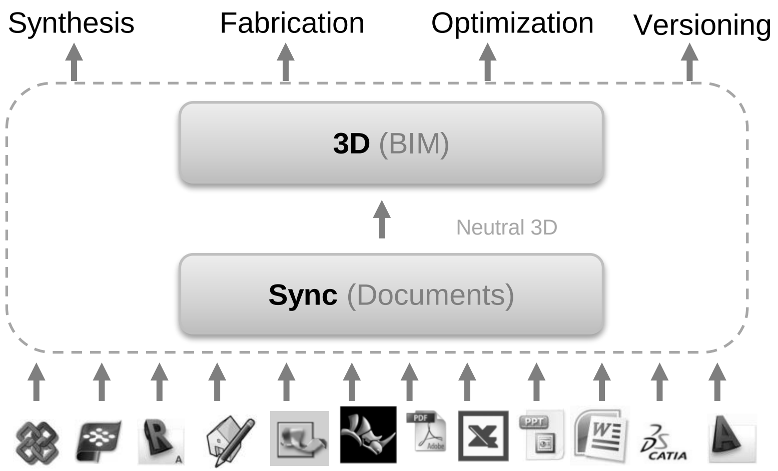


New Technology Development

The model server developed for the project was a new system in AEC, custom developed for FLV with version control, concurrent distribution, and tracking.

Cloud Model Server Architecture





Conclusion

The FLV project represents early steps toward a truly cloud or grid-centric approach to AEC collaboration. Beyond FLV, these processes provide a model set of services for other projects. The flexible use and development of tools for model collaboration break technology and organizational barriers and help accelerate design cycles. The project also resulted in new technology and novel applications of numerical methods to surface fitting in architecture. Ultimately, this project marks the beginning of a new phase of large-scale concurrent design, engineering, and optimization in AEC.