Integrated Delivery Empowered by Computational Geometry

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Abstract

Achieving innovative architectural vision increasingly relies on, and is empowered by, computational geometry delivered through advanced design software such as Rhino, CATIA or Generative Components.

On this poster we describe a project that applied computational geometry techniques extensively to enable integrated project delivery and allow the design team to achieve its objective for efficiency and precision. We show how a geometric process is established and can be leveraged, not only throughout conceptual design and form finding, but further utilized for analysis, detailing, fabrication and construction. The Federation Tower example illustrates benefits achieved from early virtual prototype development, CNC-based fabrication, modular pre-assembly of components, and efficient installation in the field.
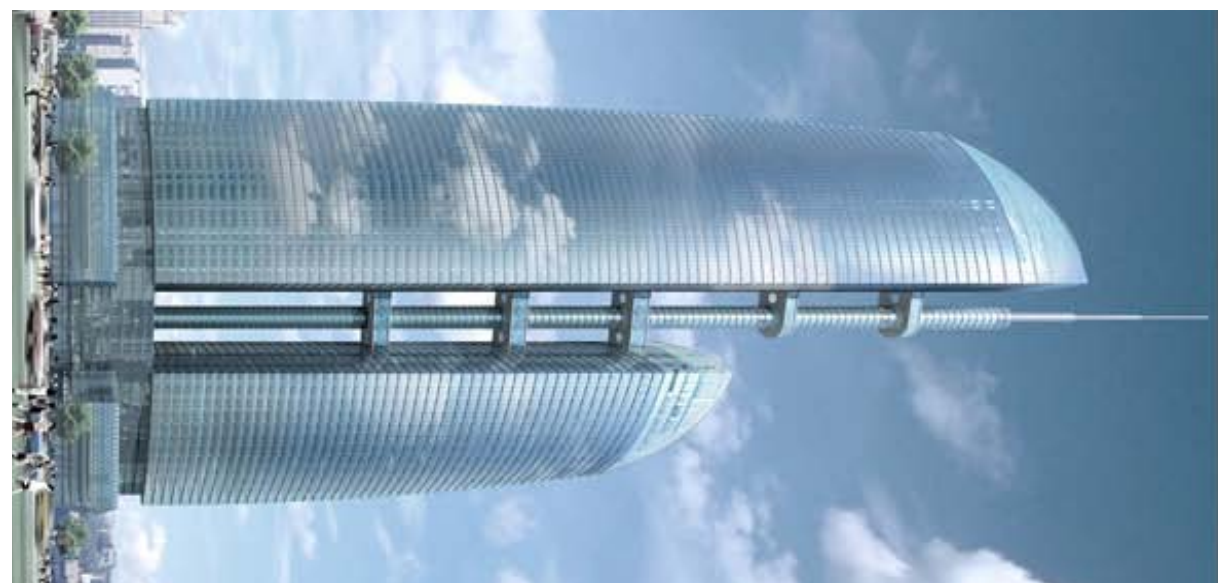
Moscow International Business Center

Moscow is undergoing an unprecedented construction boom. Just outside the historic center of the Russian capital, "Moscow-City" grows on a gigantic site that takes up 1 square kilometer.
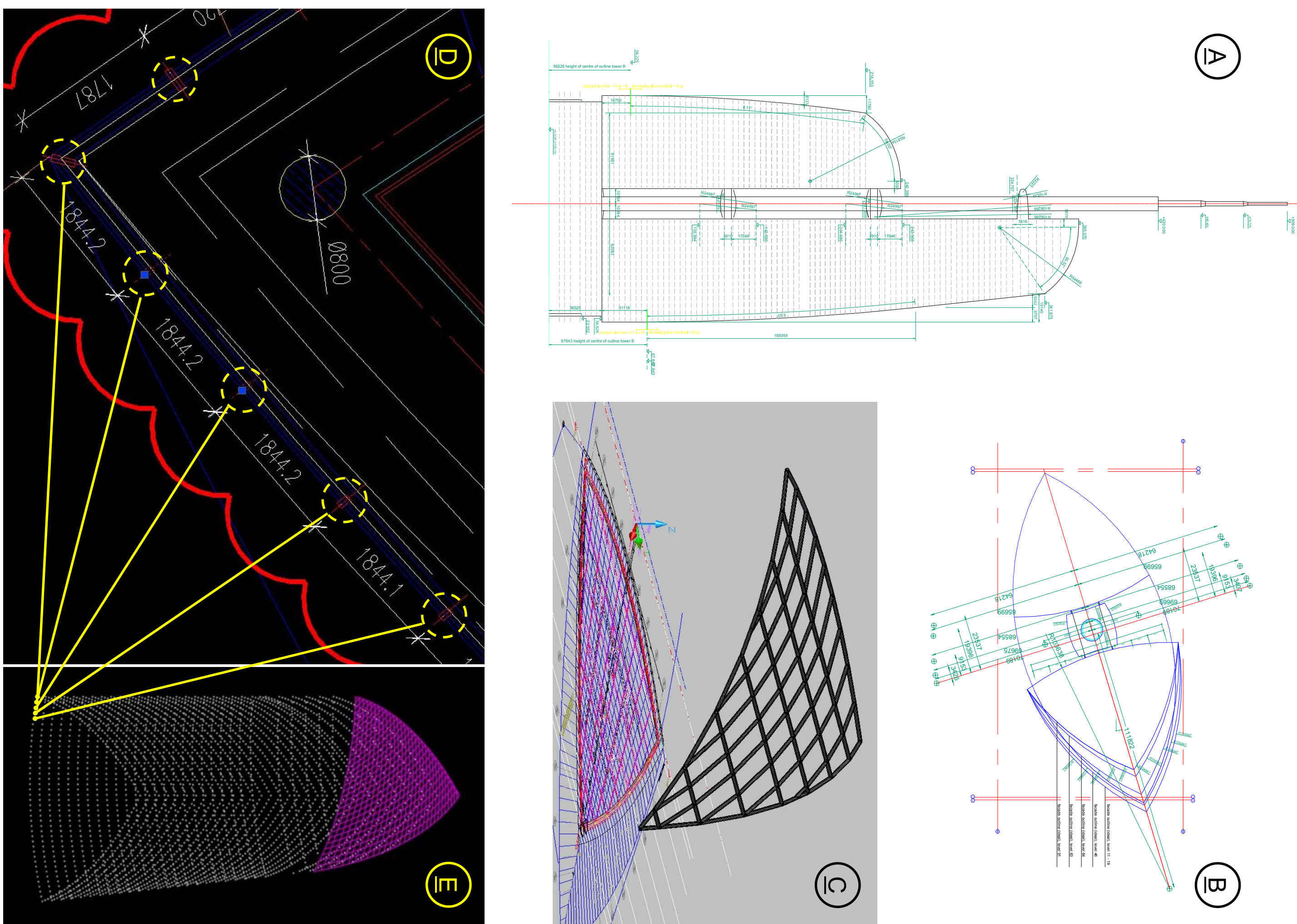
Federation Tower Roof Cap

At 365m, Tower A of Federation Tower will be Europe's tallest building when completed in 2009. Primary construction of the twin-towers started in early 2008. Both towers feature at their tops uniquely shaped, glazed roof structures.

The footprints of the triangular with arc-shaped sides. Each tower's vertical envelope tapers as it increases in height. The roof cap, or "Tower Crown," is the intersection of a cylindrical surface with the slanted vertical part of the building envelope. The cap for Tower A is envisioned to be made of glass and steel, as transparent and elegant as possible.
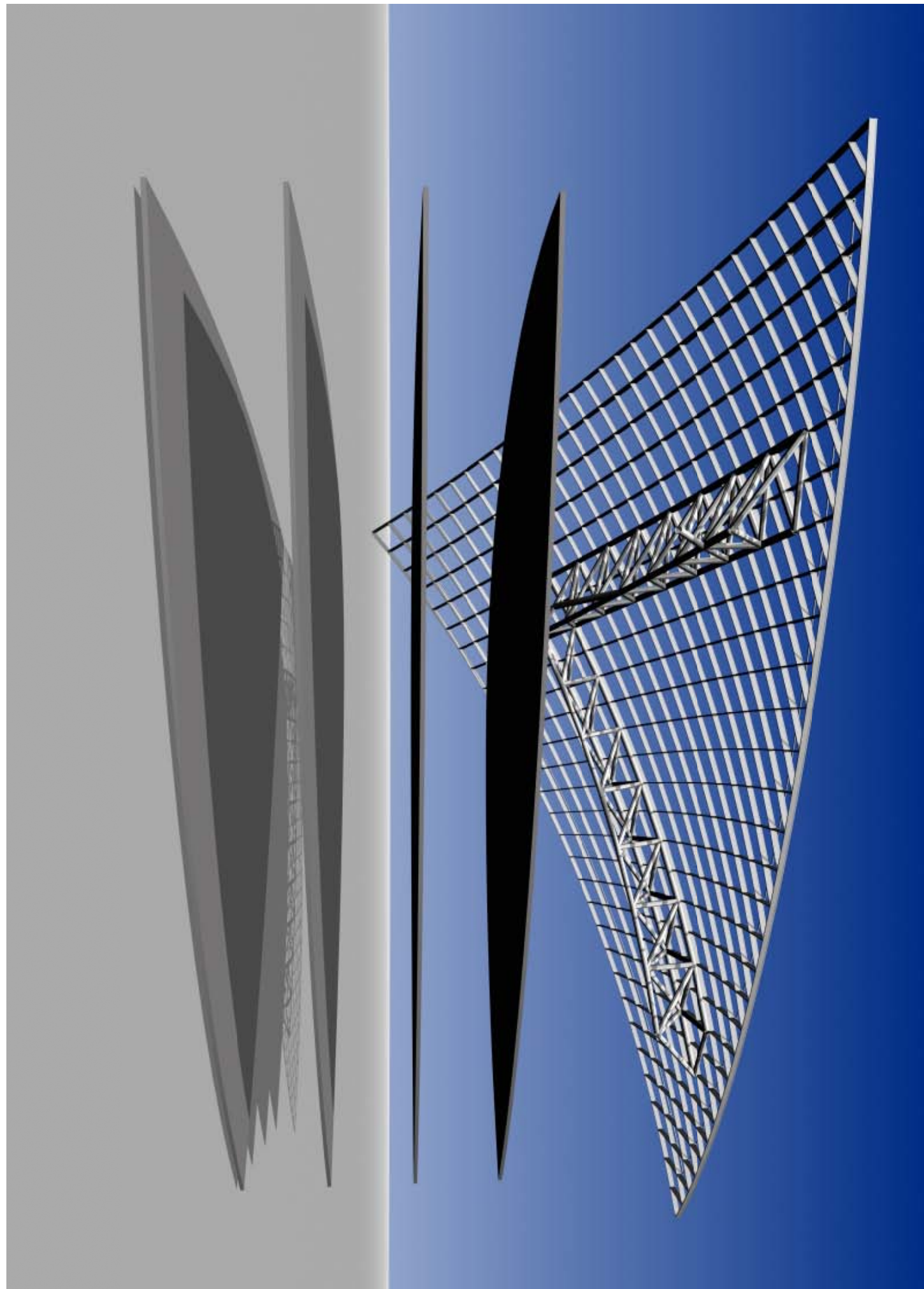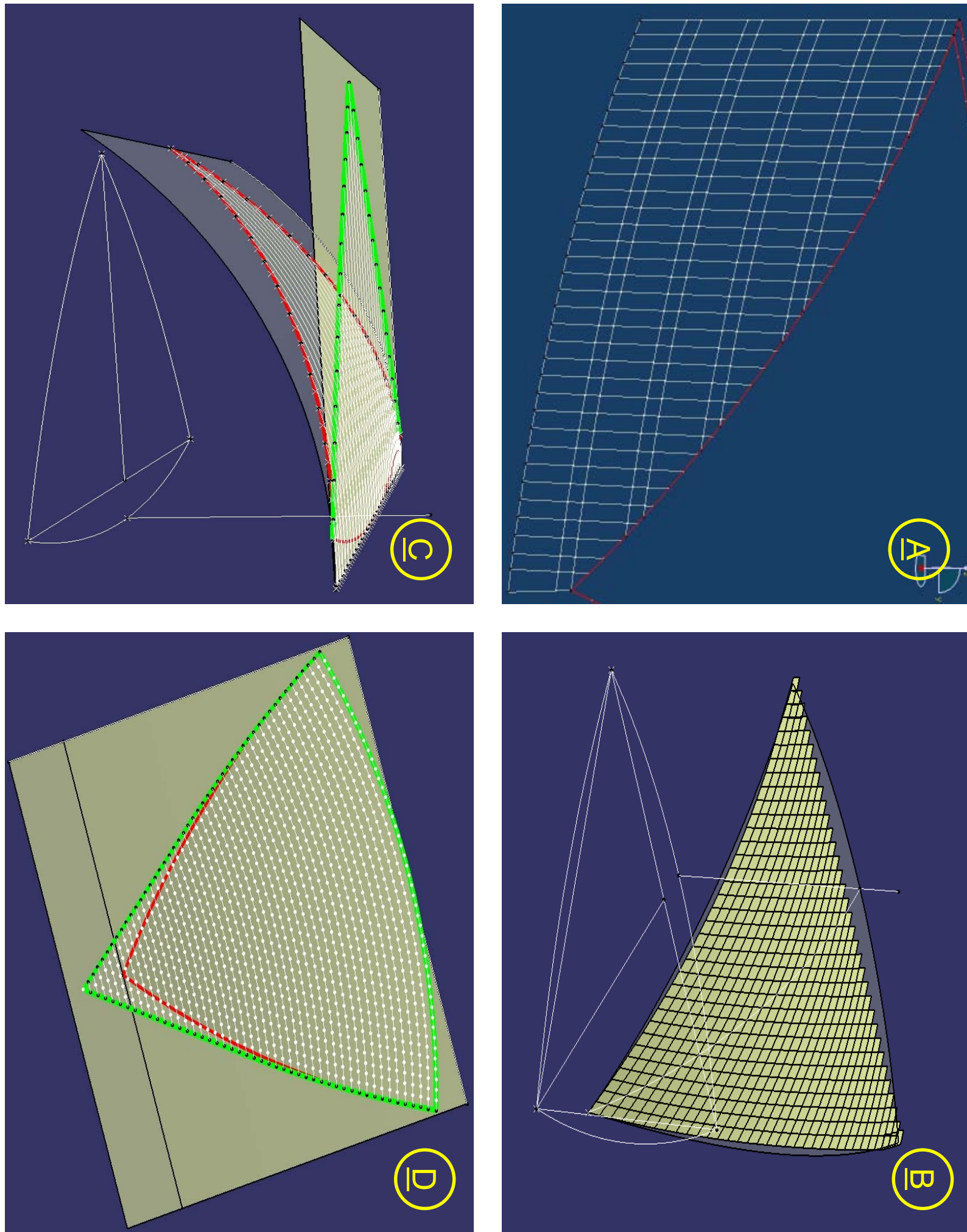
Initial Design

The original design was developed entirely in 2-D. The images below show the basic geometric assumptions for the form of the two towers (A + B). The paneling gridlines for the Tower B roof cap run parallel to the main directions of curvature (C). To allow development of an alternate schema for Tower A a mullion points were compiled from 2-D plans into a single 3-D model (D + E). This approach allows smooth continuation of vertical mullion lines into the roof surface.
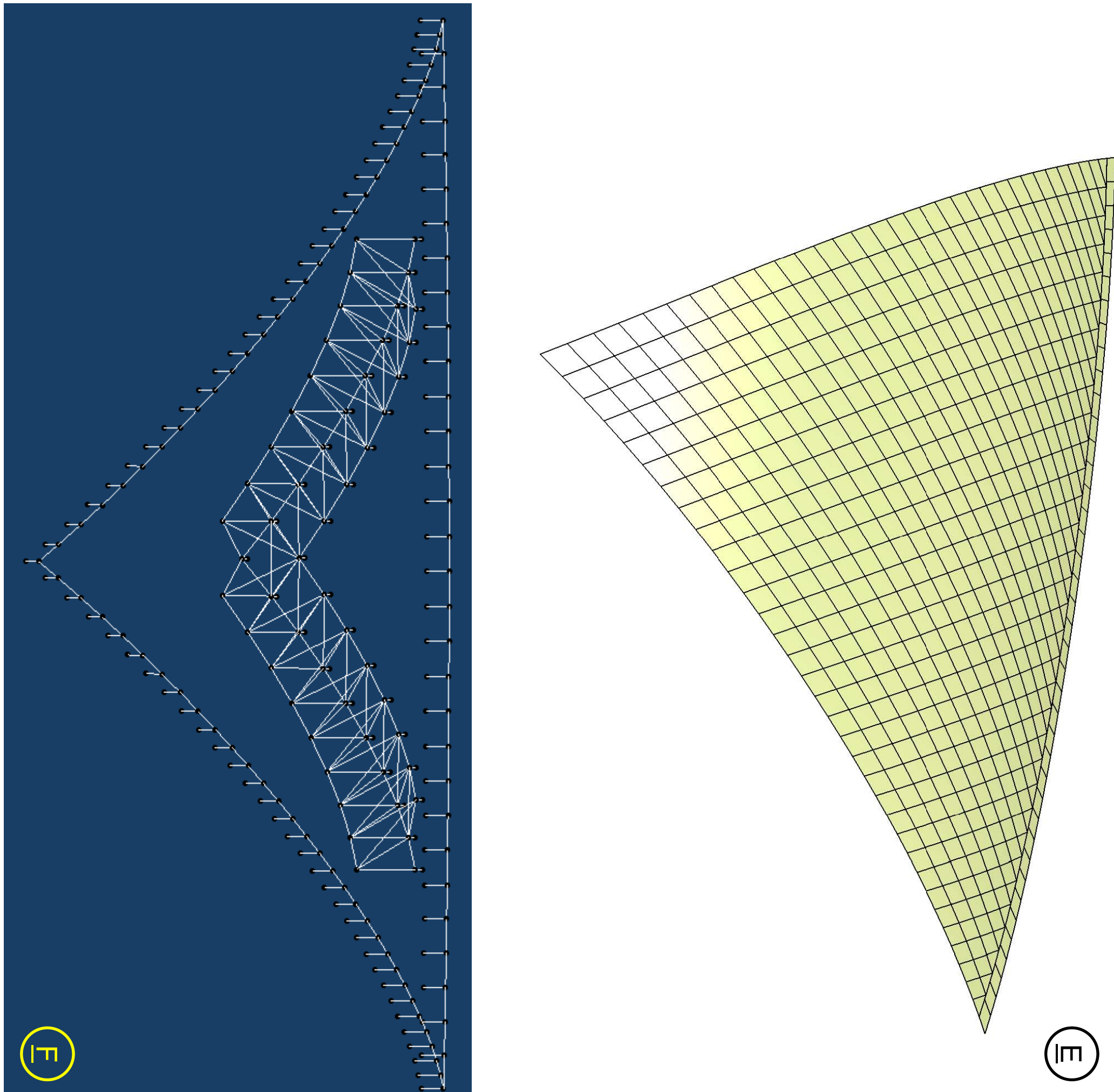

Geometric Design Development

The paneling of the roof surface was expected to yield to, maintain and continue all three curved side-lines, as well as integrate with the placement of the outer façade mullions. The goal was to produce an aesthetically pleasing design that was also efficient in a way that can be tied to performance metrics such as weight, cost, complexity, and environmental performance.

All work related to the development of the roof cap geometry was carried out in CATIA / DP. Because of the algorithmic work approach all operations were scripted using VBA. Image (A) below shows the correct roof edge and where vertical mullion lines force grid points of the roof grid. Image (B) shows a paneling schema that produces identical panels, but it does not yield to the edge geometry required. Finally, various algorithms were studied that unroll the edge vertexes into a plane, produce a grid utilizing master and slave curves in plan, and map the points back into the curved surface (C + D).
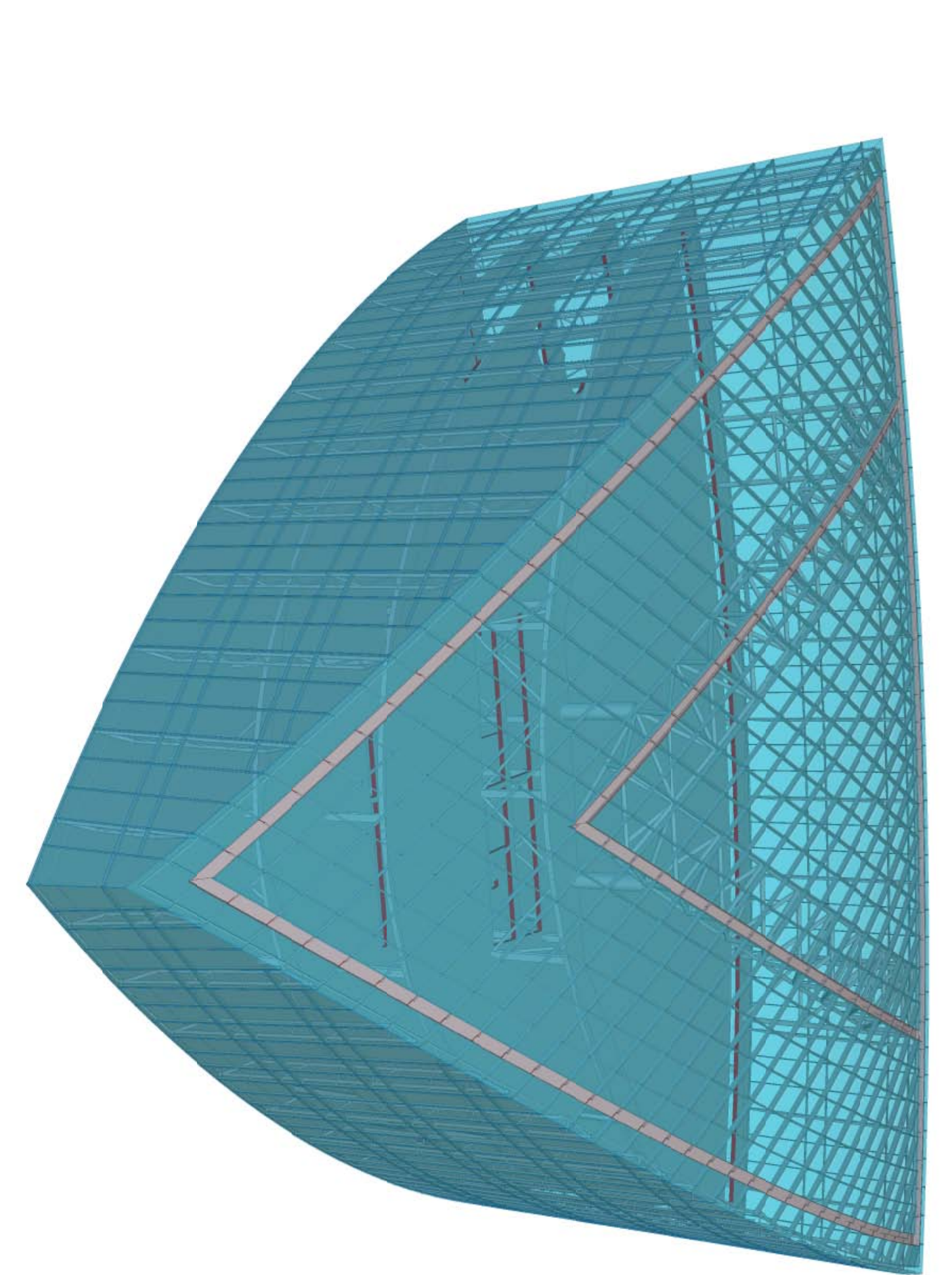

The final geometry was slightly adjusted on the back edge, to allow for 40 million lines on the back face vs. 34 on the two sides (E). With the grid in place, assemblies such as rails and trusses could be generated normal to the roof surface and at precise grid points (F).

Integrated Design

Although all glass panels and all members of the support structure are geometrically unique, their forms follow similar development rules. Designing any "typical" detail in 3-D allowed the generation of parametric components that were then replicated throughout the whole model. We developed a process that allowed us to work with two models simultaneously. We used a CATIA model as a geometry hub and carried out the physical modeling using VBA script in the detailing software Tekla. This approach allowed us to automatically generate content in Tekla.
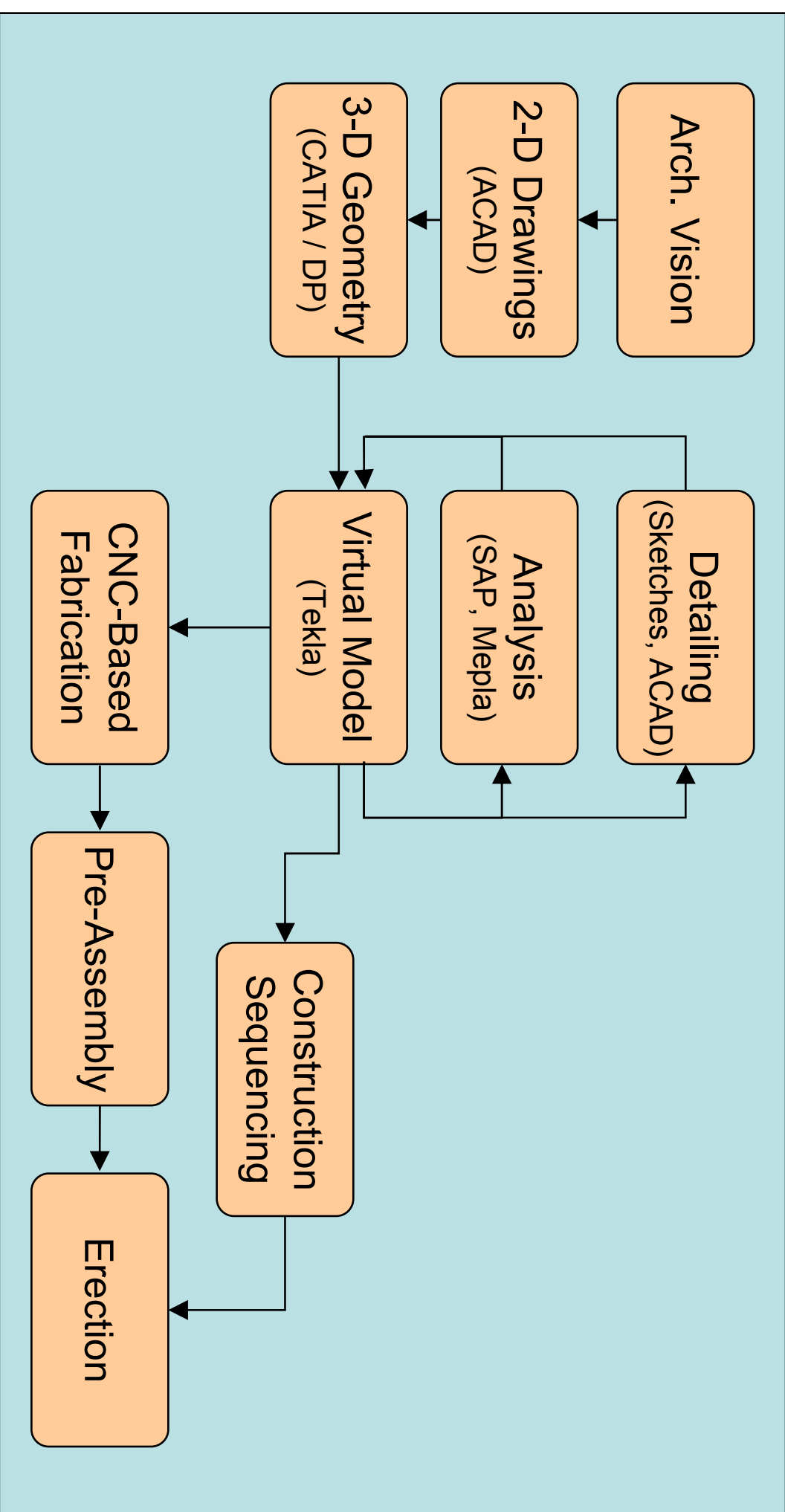
The images below illustrate the two model methodology explained above. The CATIA and Tekla models are both used simultaneously by scripts when content is generated. Vertical bow trusses that are oriented normal to the surface of the sloping façade are shown in their geometric development phase in CATIA (A), and in the physical model (B). Similarly, rain gutters that were integrated with the roof grid are shown in their geometric development (C), where a tube extruded along a 3-D spline is intersected with the grid to produce control points for the plate material that makes the physical gutter (D).

Integrated Delivery

Once detailing, fabrication, and erection enter the equation, complexity reaches a new level. Although we used CATIA to deal with the challenge of minimizing offsets of planar glass panels, structural and façade details were first developed in 2-D and then tested in the 3-D Tekla model – manually in selected locations first, and automatically across the whole model later. The images below show three approaches of aligning glass panels: bent (A), lowered at top and bottom vertexes (B), and lowered only at bottom vertexes (C). Initial concept details were modeled in CATIA (D + E), which proved to be much less efficient then using detailing techniques available in Tekla (e.g. cuts, blends, placing of true 3-D objects).
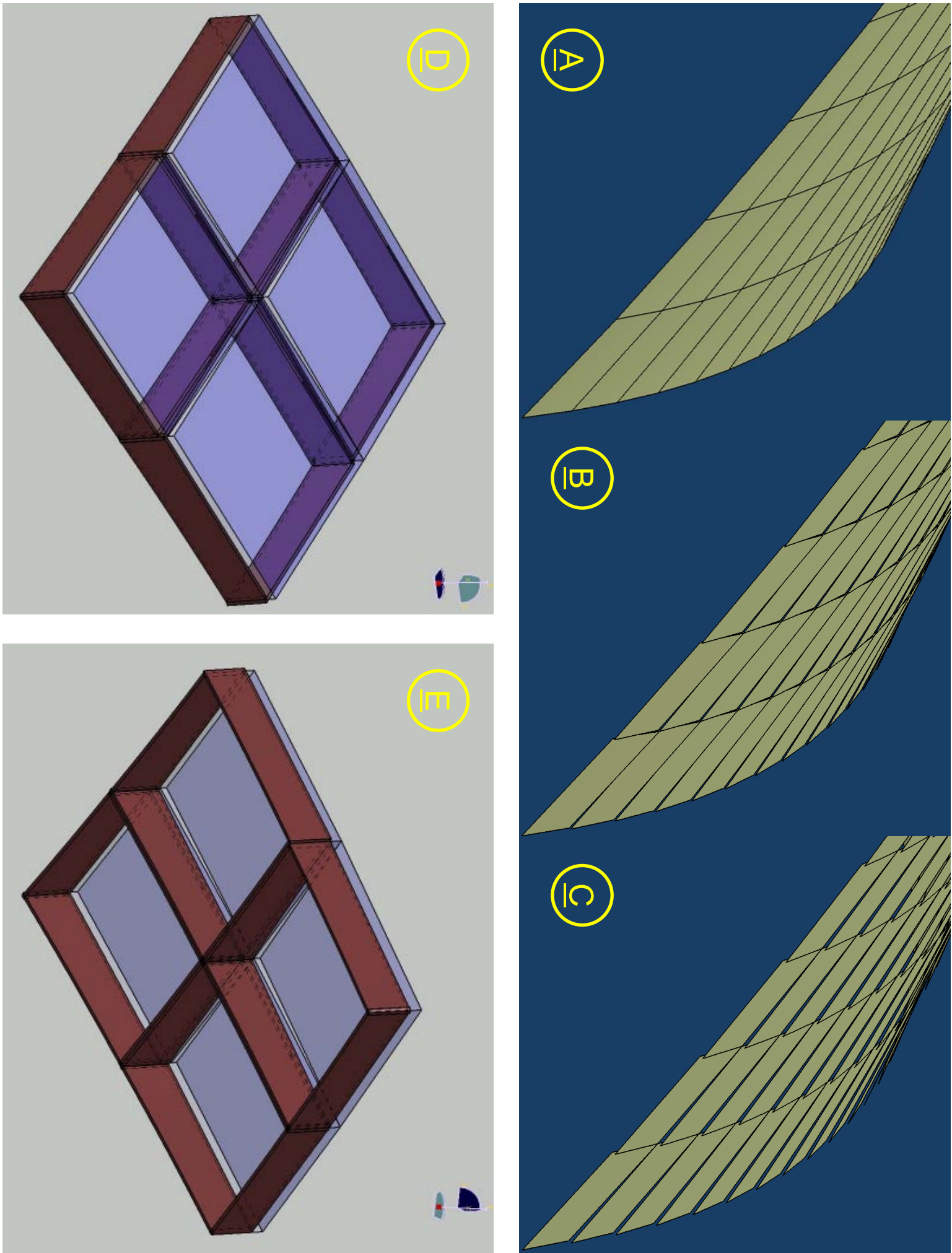
One of the options to install planar glass panels on our cylindrical lattice is to use wedge-shaped aluminum members glued onto the glass surface. As mentioned above, we developed options in 2-D (A + B) and tested them locally in the 3-D model (C + D).

Analysis models were created from either the CATIA or the Tekla model using translation routines developed in-house. The images below show a Mepla model for structural analysis of glass panes (A) and a SAP model for analysis and design of the structural steel (B).
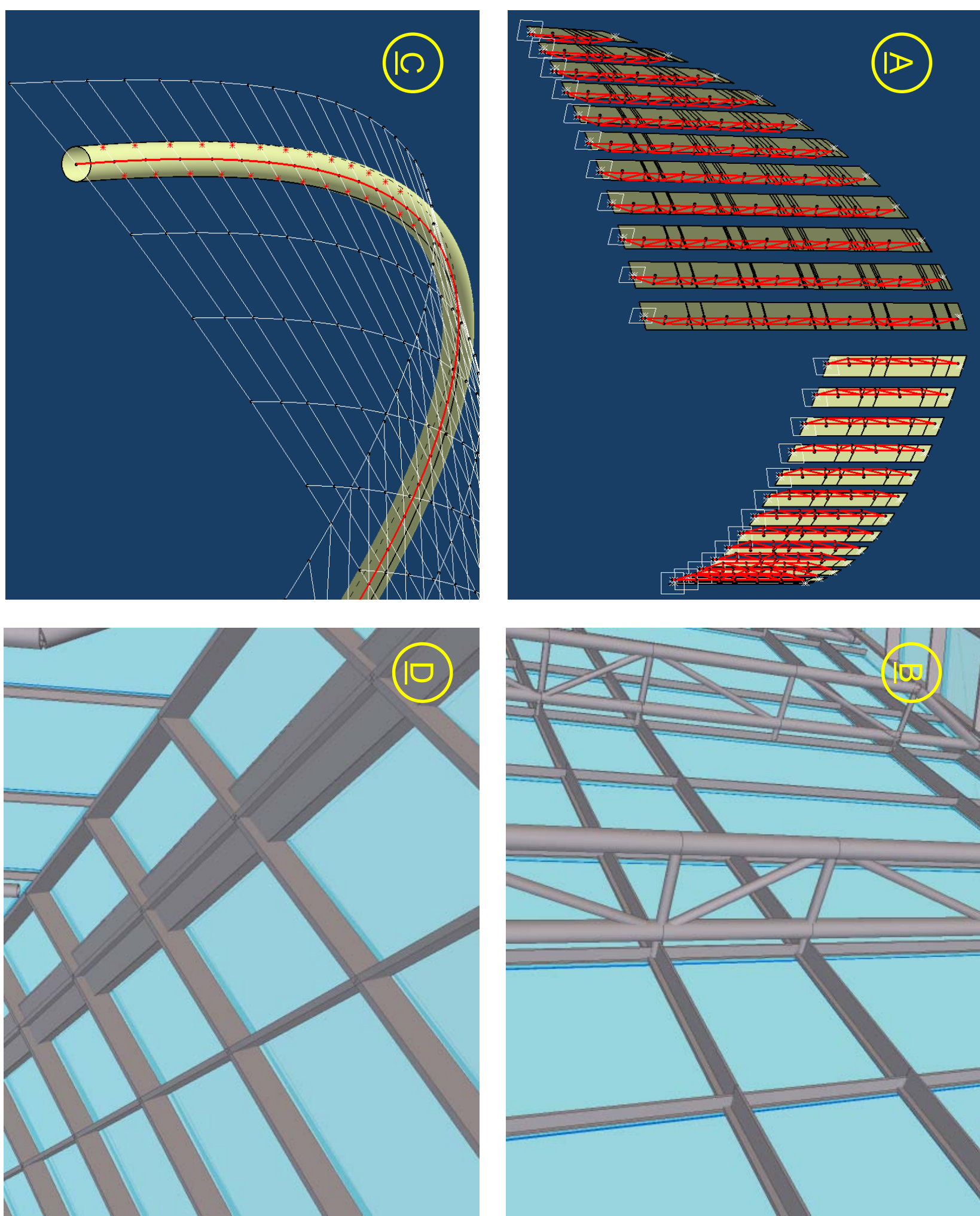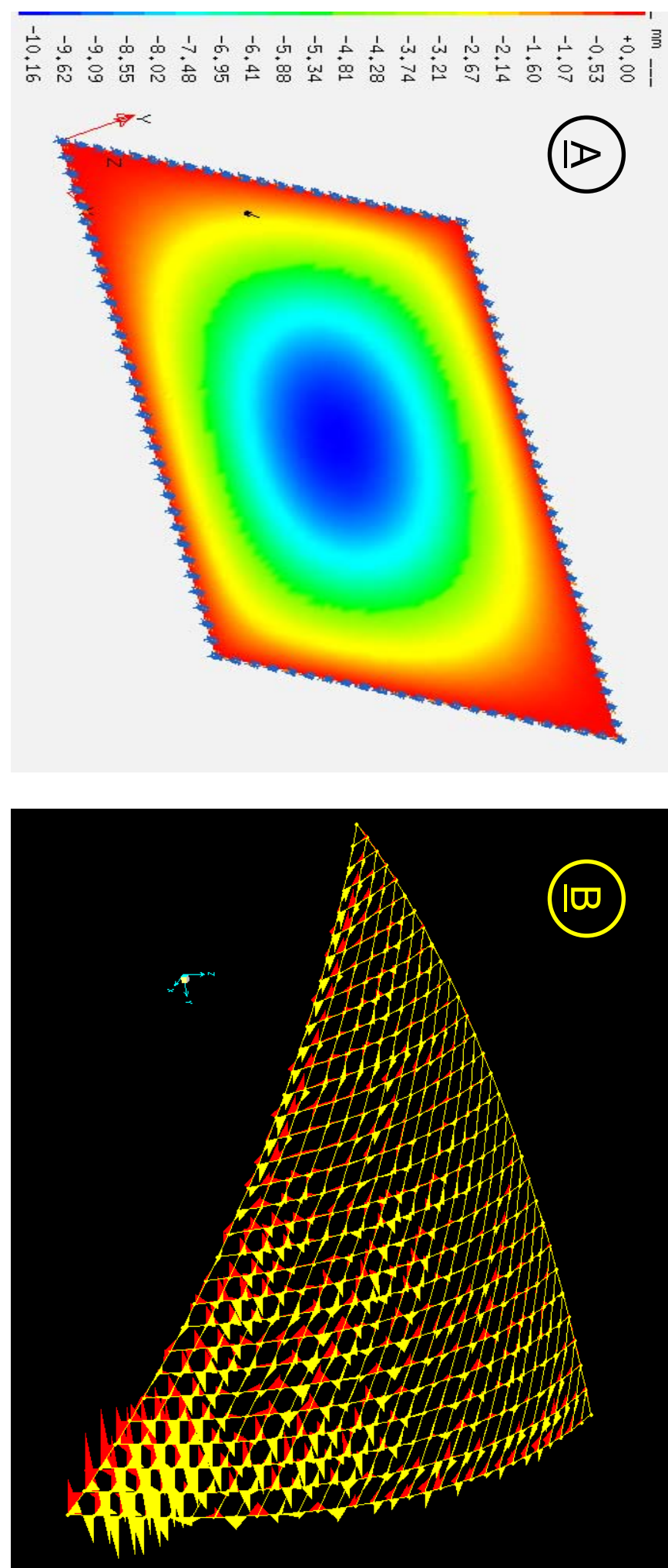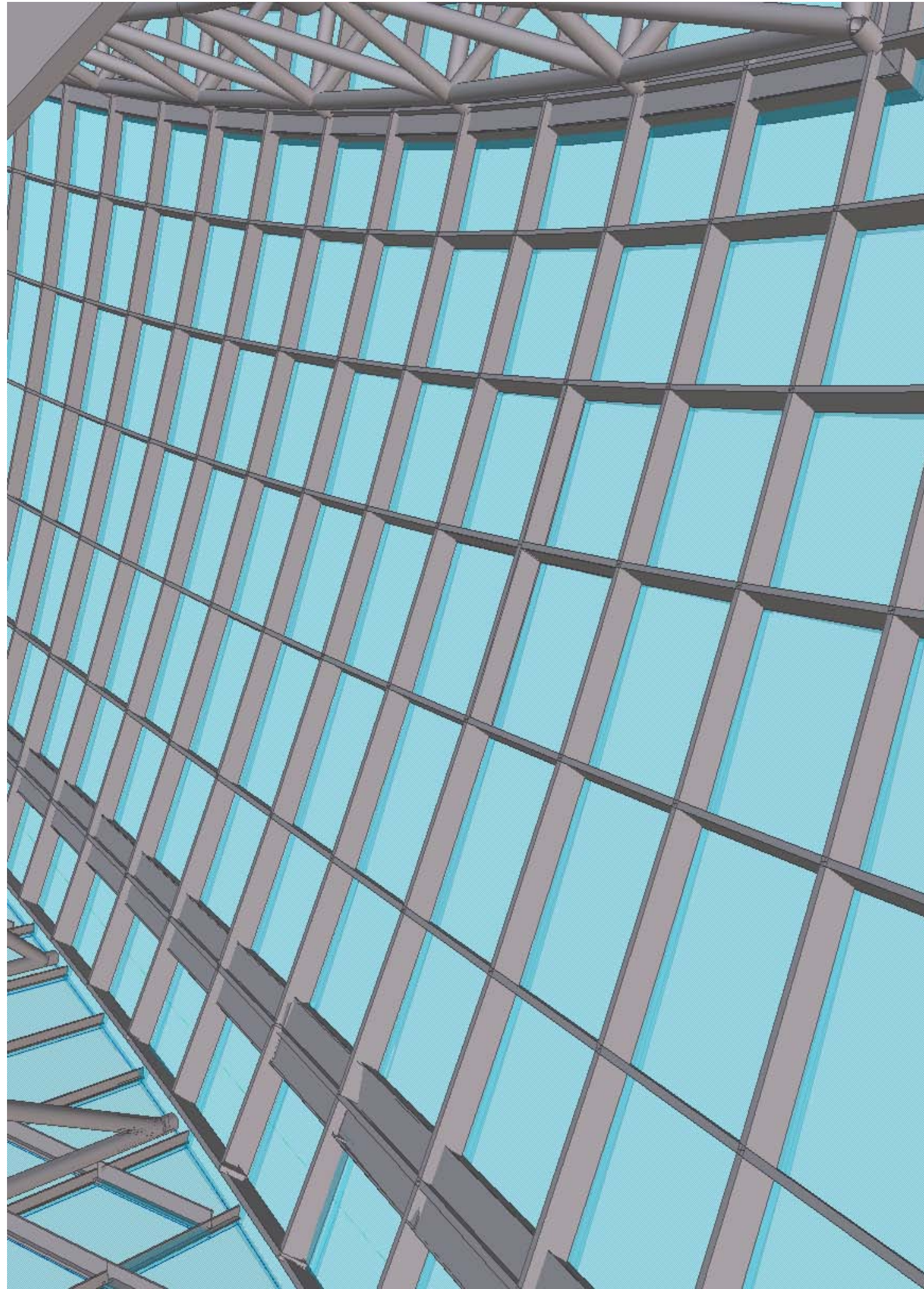
About the Authors

Dr. Vilkner, director of automation at Thornton Tomasetti, is responsible for firm-wide research and strategic development related to integrated structural design and building information modeling. His versatile expertise includes work-flow integration through automation and custom interoperability, advanced collaboration techniques, and complex data structures. He has in-depth technical knowledge, including data mining, problem modeling and knowledge exchange, through the APIs of Revit, Tekla, Digital Project, AutoCAD ADT, Rhino, MS Project, Primavera, etc. Dr. Vilkner holds a Dipl.-Ing. diploma from University of Rostock, Germany, and M. Phil. and Ph.D. degrees from Columbia University, New York.

Dr. Wilfried Laufs is vice president at Thornton Tomasetti with responsibility for specialty structures within the firm's building skin practice. He focuses on the use of new materials, structural glass elements, and challenging structures with complex geometries and architectural building elements. His expertise includes the application and development of software programs to assist in structural form-finding and detailing that are integral to the design esthetic and visual identity of spaces. Dr. Laufs believes an integrated design approach comes from the unity of architecture and structural engineering. He holds Dipl.-Ing. and Dr.-Ing. degrees from the University of RWTH Aachen, Germany and has worked in Stuttgart, Lon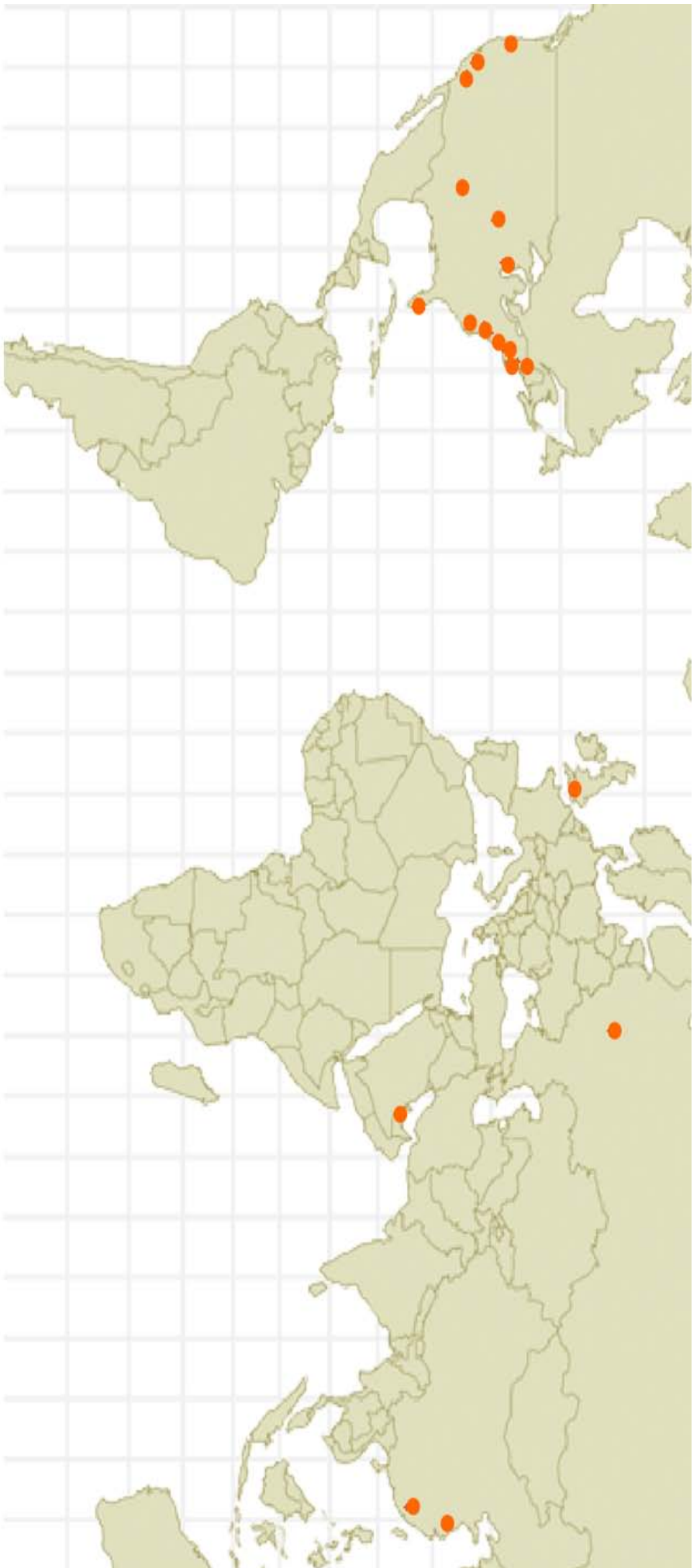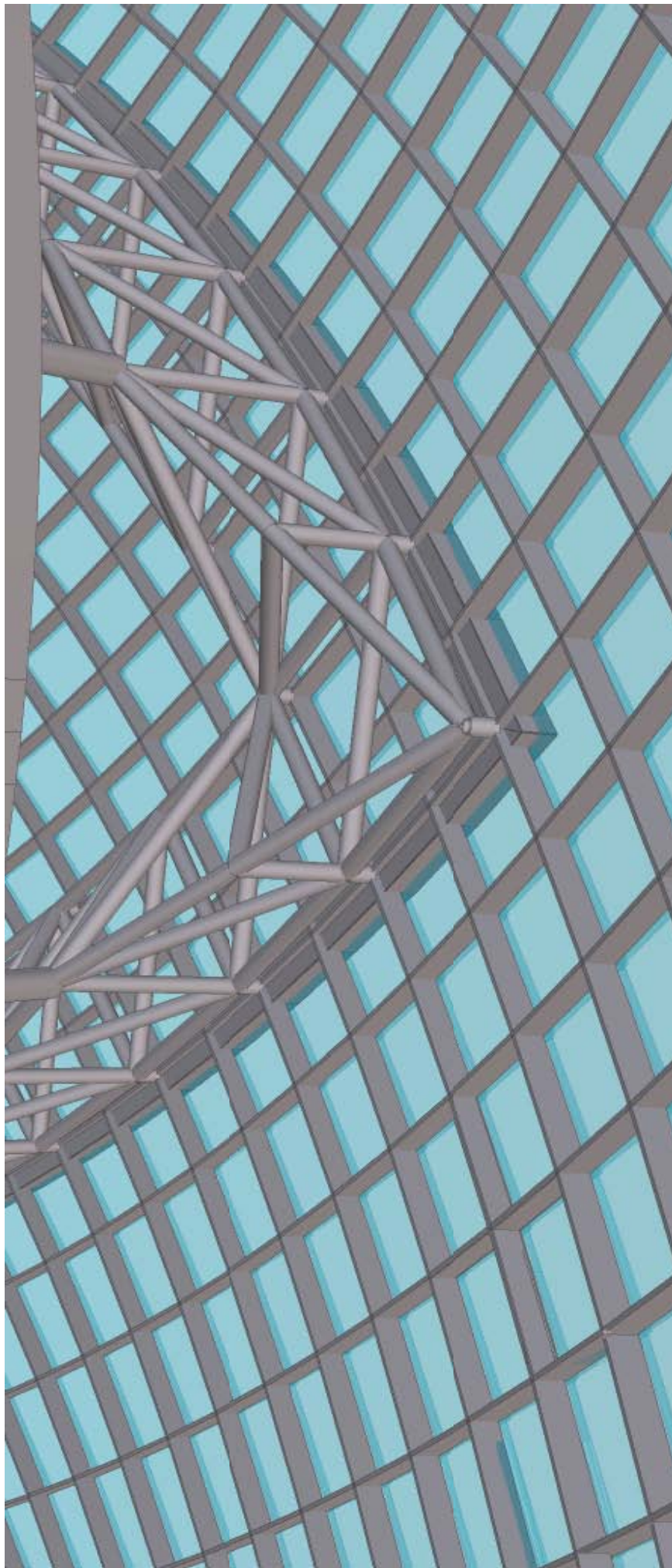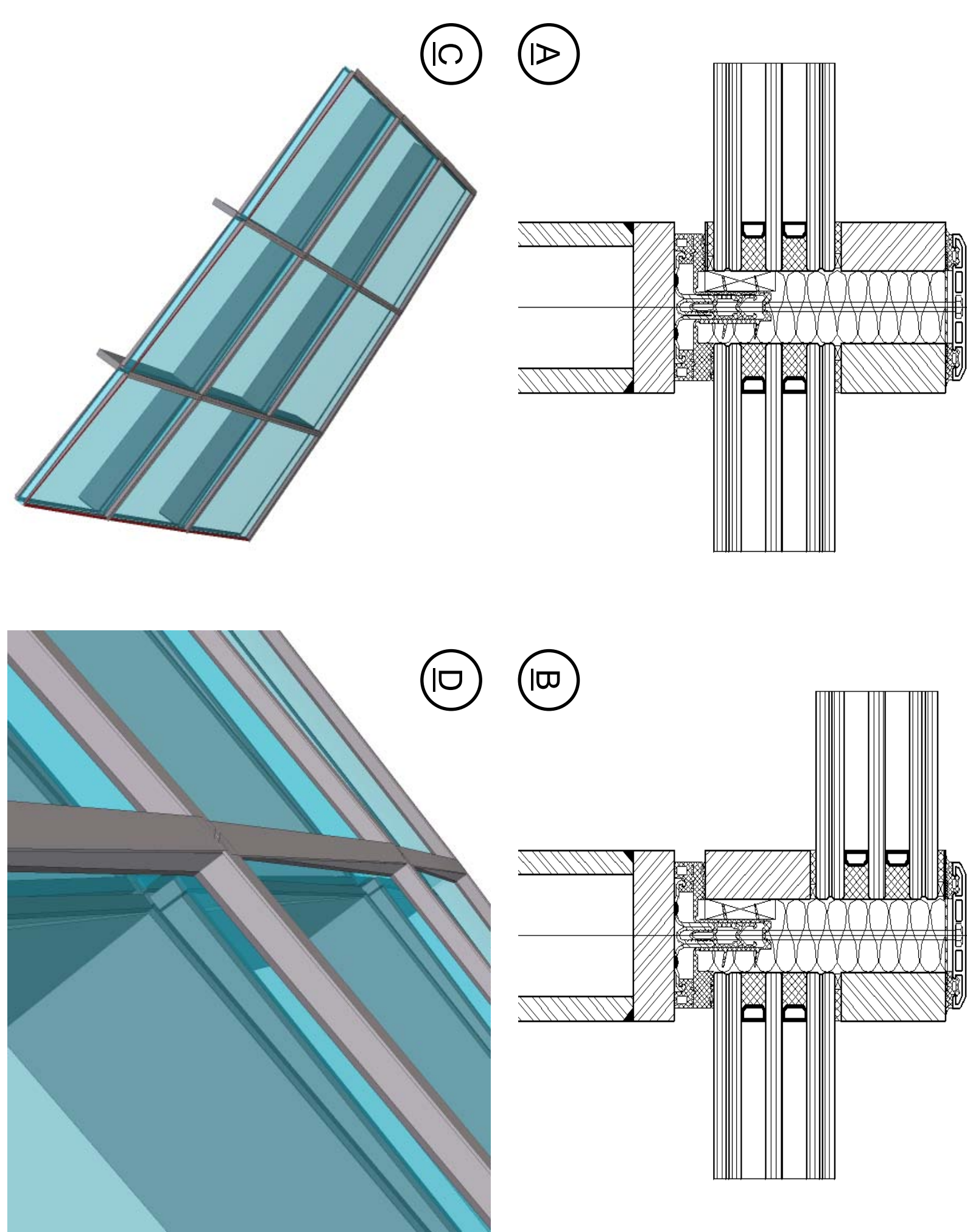don, Bangkok, New York and on projects on four continents.