From Design to Fabrication: Precast Concrete with form•Z

BY MARK THURNAUER

Recent advancements in computer software and technology have had a profound effect on the design and construction of architecture. The architect at forefront of the integration of computer technology throughout design and production is Frank Ghery, whose architecture firm has utilized software from the aeronautical profession. With the capability to translate 3D computer models into production drawings and data for fabrication, it would seem that there are no limitations in the development of architectural forms. But, buildings are still governed by good detailing practices such as: material limitations, weather resistance, construction tolerances, and feasible construction sequencing. The Varsity Village Athletic Center at the University of Cincinnati is a tremendous example of sharing 3D computer model data between designers, fabricators, and contractors.

The form of the Athletic Center generated as a response to where architect Bernard Tschumi chose to situate the building on the site. Wedged between the existing basketball arena to the east, the football stadium to the west, and bound by the new Rec Center at the north, the selected site is both dynamic and confining. Pedestrian circulation crosses the site in both the north/south and east/west directions. The footprint of the new structure overlaps two existing sub-grade floors containing a mechanical room and a football locker room that remained operable throughout construction (Figure 1). The building also spans over an existing loading dock for the basketball arena that accommodates video broadcasting trucks which require barrier-free maneuverability. To resolve these site challenges, a structural system was devised that allowed for large column free spans.

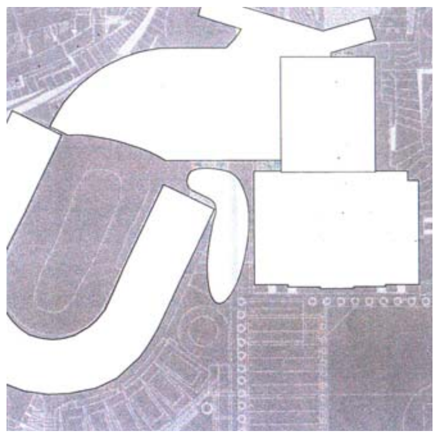

Figure 1: **Figure ground sketch by Bernard Tschumi Architects**

Arup Engineers developed a structural system referred to as the diagrid exo-skeleton which allows the building to span above the existing sub-grade levels with only one column penetration through the existing building. This structural system is comprised of an exterior frame that acts as a large triangulated truss following the curvature of the plan. The rigidity of the truss minimizes the number of required support points at grade (Figure 2). The Diagrid was initially envisioned to be fabricated out of structural precast concrete. This posed many detailing complications such as: differential thermal expansion of the external to internal structure, waterproofing, and connection between the precast panels. To resolve these problems, the structure was switched to a steel frame enclosed within the building envelope. Numerous exterior cladding options were considered but architectural precast concrete was selected for cost and aesthetics.

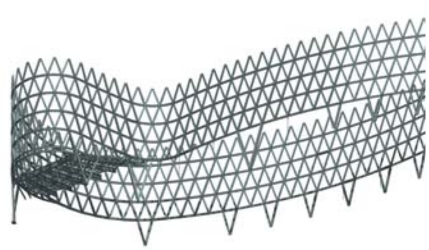

Figure 2: **Axonometric of Steel Diagrid Exo-skeleton.**

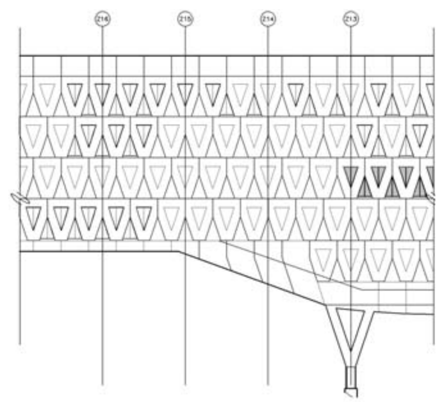

Figure 3: **Unwrapped elevation of precast concrete cladding.**

The diagrid was conceptualized as an unwrapped skin (Figure 3). As such, the diagonal members of the envelope were straight segments. After wrapping the linear elevation around the curvilinear plan form, the diagonal members were actually helical geometry. Yet, the steel members behind the skin remained straight members. During schematic design, 2D sections were drawn through the building envelope to determine the relationship between the steel structure and the precast cladding. The thickness of the precast cladding, quantity of insulation, fireproofing coverage on the steel, and the steel construction tolerances all needed to be accounted for in the design (Figure 4). The position of the steel in relationship to the precast was variable and therefore 2D drawings inadequately conveyed the relationship between all of the building components. The geometric complexity of wrapping the diagrid elevation around the curvilinear plan form could not be understood without 3D modeling. Working with the precast concrete fabricator during design helped to resolve constructability issues. Helical or warped surfaces would be expensive to form and difficult to strip from the formwork. The windows in the exterior envelope needed to be flat to meet the project budget.

To resolve the casting problems of the helical geometry, a modeling method was developed that generated flat surfaces at the window openings while creating the perception that the diagonal members are helical (Figure 5). The method was envisioned as if projecting the image of a triangle on a cylindrical surface; the image of the triangle warps around the surface, creating the appearance of helical edges. When the projected image passes through the cylinder, the cut out would have planar sides. The first attempt at this method resulted in a shape that did not have positive draft. The cutting shape was revised from an extrusion of the triangle to a shape that went from the triangle and extended to a point on axis with the radius of the face of the building skin.

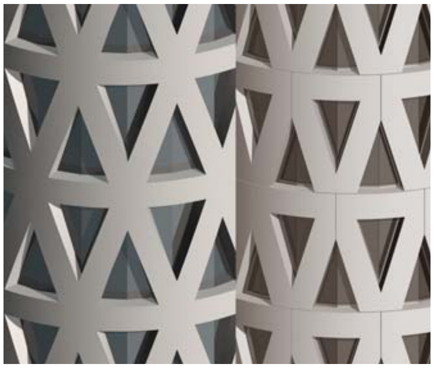

Figure 5: **Image of true helical geometry on left and actual modeled solution on right.**

During Design Development, High Concrete was hired to fabricate a full-scale mockup of one panel. This offered an opportunity to test the fabrication method. The initial intent was to make the formwork directly from the computer model by implementing the use of a five-axis milling machine. The method successfully reproduced the geometry, but the formwork lacked durability and was destroyed when stripping the piece from the form (Figure 6). Before being awarded with the project, High Concrete had anticipated finding a coating that

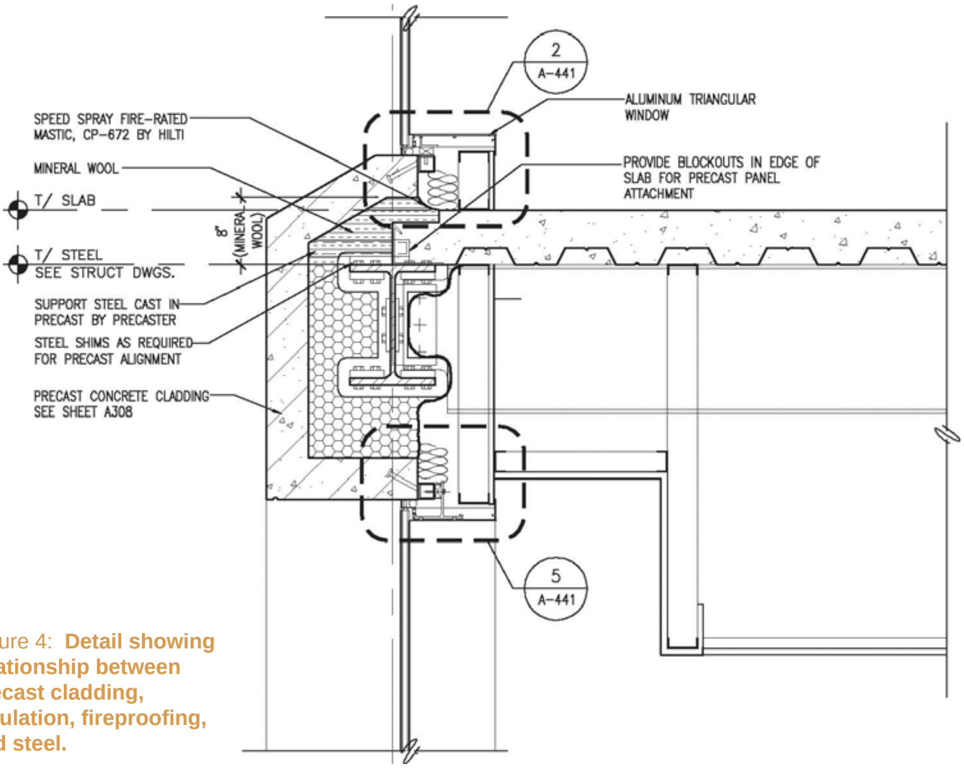

Figure 4: **Detail showing relationship between precast cladding, insulation, fireproofing, and steel.**

would allow multiple castings from one form. The milled formwork was also too labor intensive to set up. High Concrete decided that the final formwork would be all steel construction for durability and speed of assembly. Helser Industries was hired to design and fabricate the formwork (Figure 7). The 3D model was exported from **form•Z** and imported into Autodesk Inventor to generate the geometry for fabricating the formwork.

Often, precast concrete is utilized for its economy of repetition. The elevation of the Athletic Center appears as if it is comprised of a few repeating shapes. The geometry however is much more complex (Figure 8 and 9). The plan has seven different radii, each requiring a separate shape. The transition between each radii requires two unique shapes to stitch the transition. Within each radius, there are numerous panel variations such as: parapet panels, infill panels, bottom panels, and panels covering the base V-shaped columns. In total, the envelope is made of over 450 pieces of precast concrete, consisting of over 140 unique shapes, every piece 3D modeled. The steel formwork achieved efficiency by being fabricated as a large kit of interchangeable parts creating all the possible variations.

Even though the geometry of the formwork was generated directly from the model, traditional 2D shop drawings

Figure 6: **Photo of form made from five-axis milling machine.**

Photo provided courtesy of High Concrete.

Figure 7: **Photo of steel form fabricated** by **Helser Industries.**

Photo provided courtesy of High Concrete.

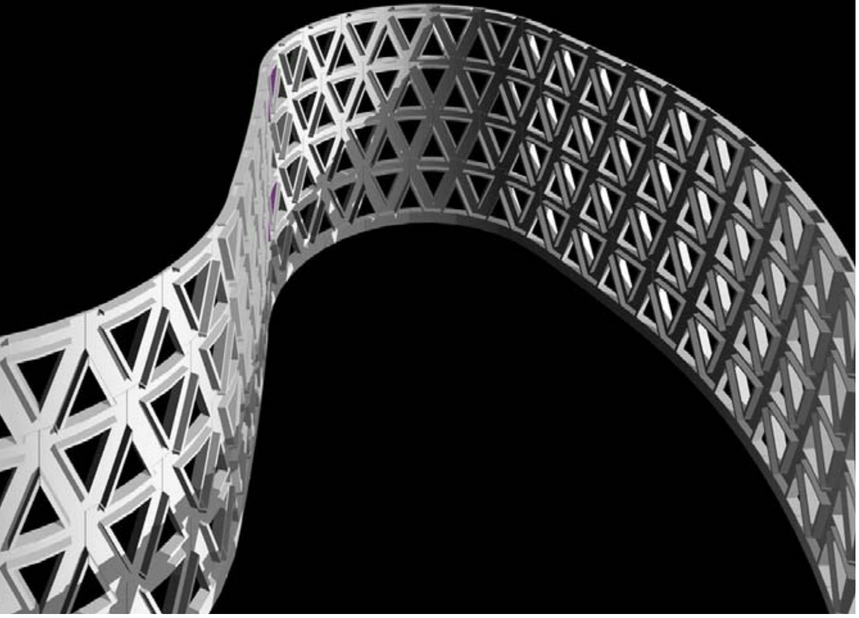

Figure 8: **Perspective of precast concrete computer model.**

Figure 9: **Perspective of the precast computer model illustrating the compound helical geometry.**

were still a contractual requirement of the project. High Concrete hired Glaserworks to produce the 2D shop drawings from the **form•Z** model. 2D elevations and sections were created in **form•Z** for all the pieces and exported to AutoCAD. The model geometry was also queried to provide 3D coordinates of the panels in preparation of erection drawings. Since the formwork was generated directly from the 3D model, the 2D shop drawings primarily served to check that the formwork was properly assembled and to indicate the spacing of steel reinforcement and connections.

The 3D model of the precast cladding was also utilized to check for proper tolerances between the steel structure and the precast cladding. The steel fabricator was required to submit a 3D model as part of the shop drawing review. Detecting interferences between the steel and precast within **form•Z** was not an automated process. Given the size and complexity of both models, performing a Boolean operation between the two models would not have been possible. Numerous sections were cut through the model and closer attention was given to areas where steel and precast were observed to be closer than construction tolerance. This exercise paid off as two areas of interference were detected and the steel and precast were adjusted prior to delivery, saving both time and money.

The utilization of 3D computer modeling resulted in minimal fabrication errors and almost flawless erection (Figure 10 and 11). Out of all of the prime contracts on the project, the precast concrete contractor had the fewest number of conflicts, resulting in minimal change orders. Though the production of shop drawings and error checking was a tedious manual process of exporting information from the model, future software development promises to automate the process. The Precast Concrete Software Consortium, a group of precast concrete producers from North America, is currently working to develop 3D parametric modeling software similar to that used in the steel industry. It is reasonable to presume that design professionals and fabricators will work with different software, so the 3D computer model needs to be capable of transfer without loss of quality. There is still a reluctance to share digital information between designer and contractor due to liability concerns, but sharing of information may actually reduce potential problems. The complex forms of leading architecture today often cannot be conveyed through traditional methods and the free flow of 3D data throughout the life of a project is essential for the project's success.

Figure 10: **Construction photo of north side of building.**

Figure 11: **Construction photo of east side of building.**

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