COST ESTIMATING AND MATERIAL TAKE-OFFS WITH PARAMETRIC TOOLS

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Cost estimation and material take-off is traditionally fairly straightforward when buildings are relatively repetitive, mostly made up of orthogonal forms, and include parts that could be easily measured and counted. As the future building stock moves towards more complexity in both overall form and building systems, traditional cost estimation techniques become much more difficult to use. Traditional cost estimation and material take-off generally begins with a set of architectural drawings and specifications. An estimator would go through the drawing sets and begin to calculate the quantity and sizes of materials, cross referencing additional information with the specifications. At this point all the estimation has been conducted by hand, with a person having been physically looking over each drawing sheet. Information is then entered into spreadsheets, organized and split up based on vendor trades. A vendor would receive the quantity, sizes and specifics of each material and provide a price. In many cases this practice works well, information is directly transferred from physical drawings to vendors for pricing. However, as building designs becomes more complex, retrieving information from 2D drawings becomes less practical.

Pulling data from 3D models becomes almost mandatory when dealing with double curved shapes and intricate components. Only so much information can be translated to 2D drawings before digital models become a necessity on complicated projects. The availability and willingness of receiving 3D models from architects and fabricators has become more widespread as a result. In turn, parametric modeling programs are becoming more popular as both design tools for these complex forms as well as a means to interpret and pull data out of them. Parametric tools such as Grasshopper, a popular visual programming interface for Rhinoceros 3D, can be used to construct parametric models or take existing models and parameterize particular parts.

PARAMETRIC CAPABILITIES

Integrating Grasshopper with cost estimating and material take-off efforts makes efficient use of the data-centric side of parametric programs. While Grasshopper has powerful tools used for form creation, manipulation, and rationalization, it also stores information about each operation being conducted and can easily produce quantities, sizes and relevant geometric information. This information can be visually displayed on drawings or diagrams for clarification, or just as easily exported as raw data into spreadsheets. Specific routines can be created within Grasshopper to find very detailed pieces of information, including panel size and cut dimensions for pattern cut lites, number of typical to atypical units, and number of unique panels.

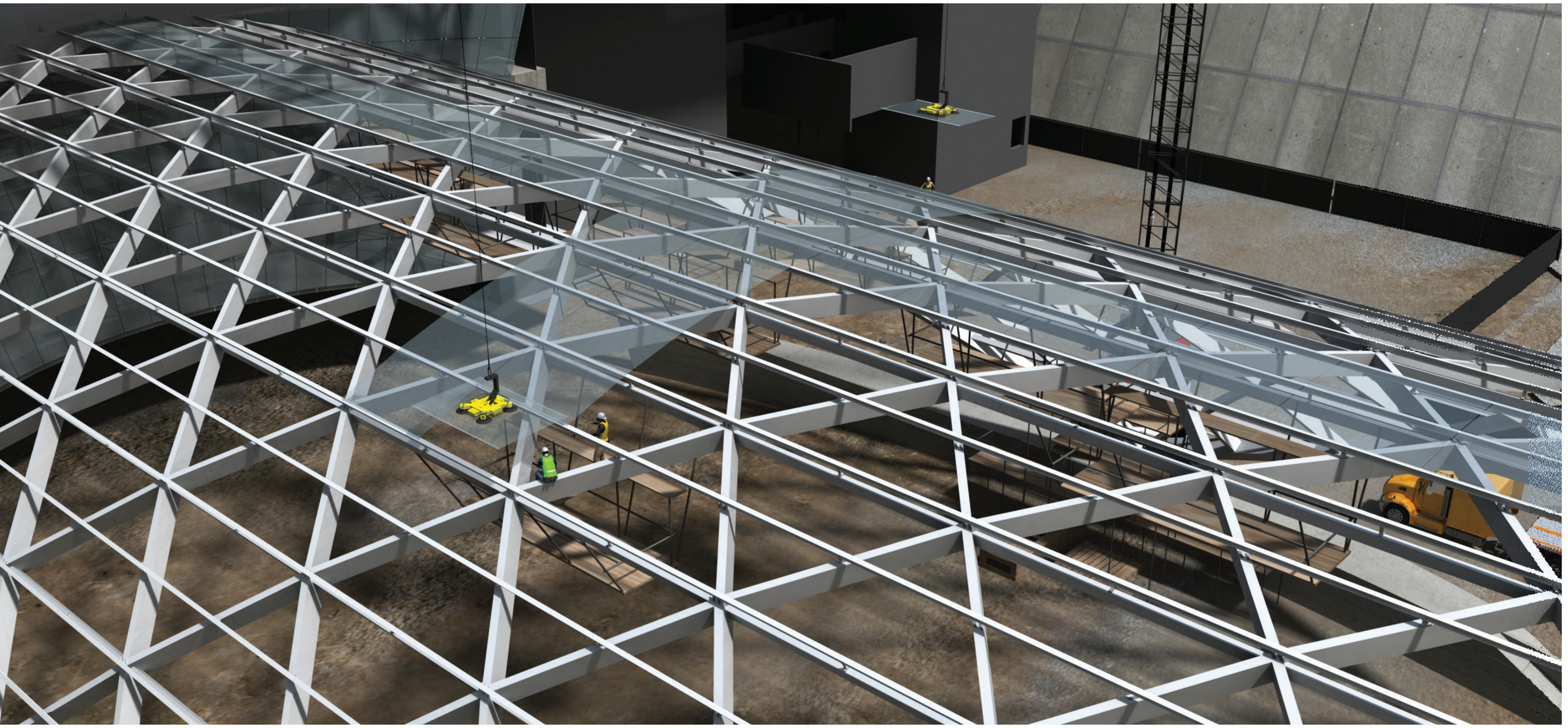


FIGURE 1
Grid-shell steel canopy covering a rail station.

FIGURE 2
Grasshopper routine controlling the steel structure and extracting component quantities, lengths and weight.

FIGURE 3
Grid-shell steel structure in Grasshopper with color coded unique connection nodes.

Furthermore, if continuous estimation is to be conducted with a developing design, the initial investment of building a parametric information model can drastically reduce time and resources required for estimation at design checkpoints along the way. As changes are made to the project, numbers and take-offs are retroactively updated, reflecting price and quantity changes at the same speed as design.

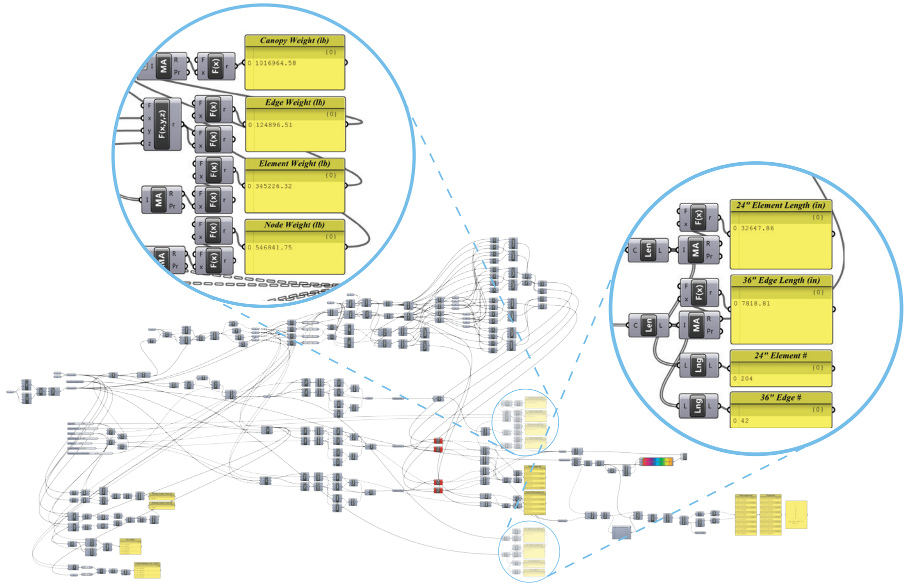
APPLICATIONS

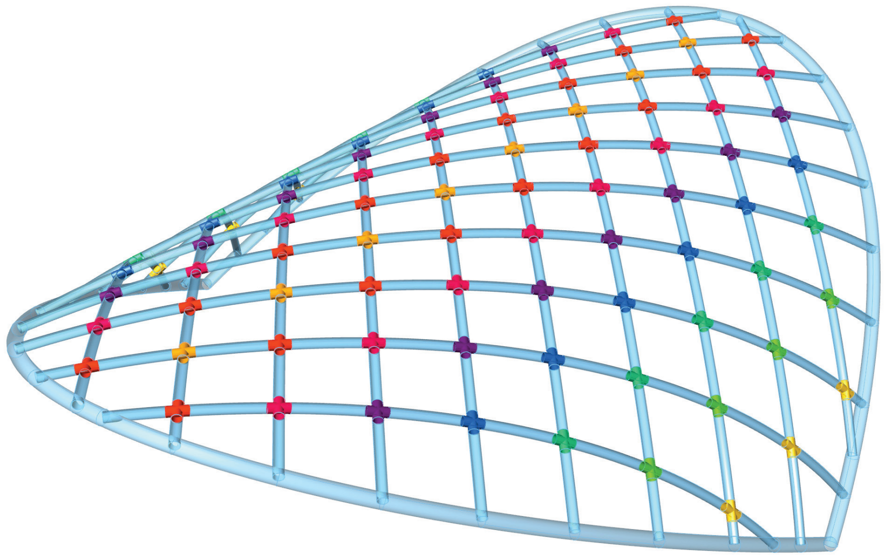
Two Grasshopper applications are used in the following case study projects. The first, a set of two open-air canopies for an airport's metro rail station utilized Grasshopper to take initial geometry and build up a fully functional parametric model for design optimization, as well as cost estimation, take-off and structural calculations. The second created a workflow in Grasshopper that could be re-set to new geometries from the architect's BIM model, delivered at each new design milestone.

CANOPY CASE STUDY

This project consisted of two skylight canopies covering a rail station and pedestrian passage through a hotel at an airport. Both canopies were designed as large steel grid-shell structures with glass skylights covering them. A package of preliminary drawings, a BIM model, and control surfaces and curves in Rhinoceros 3D were provided by the architect and consulting engineer.

After a more efficient re-design of the structure was proposed, a parametric model using initial surfaces and curves was constructed in Grasshopper. The model utilized a new structural

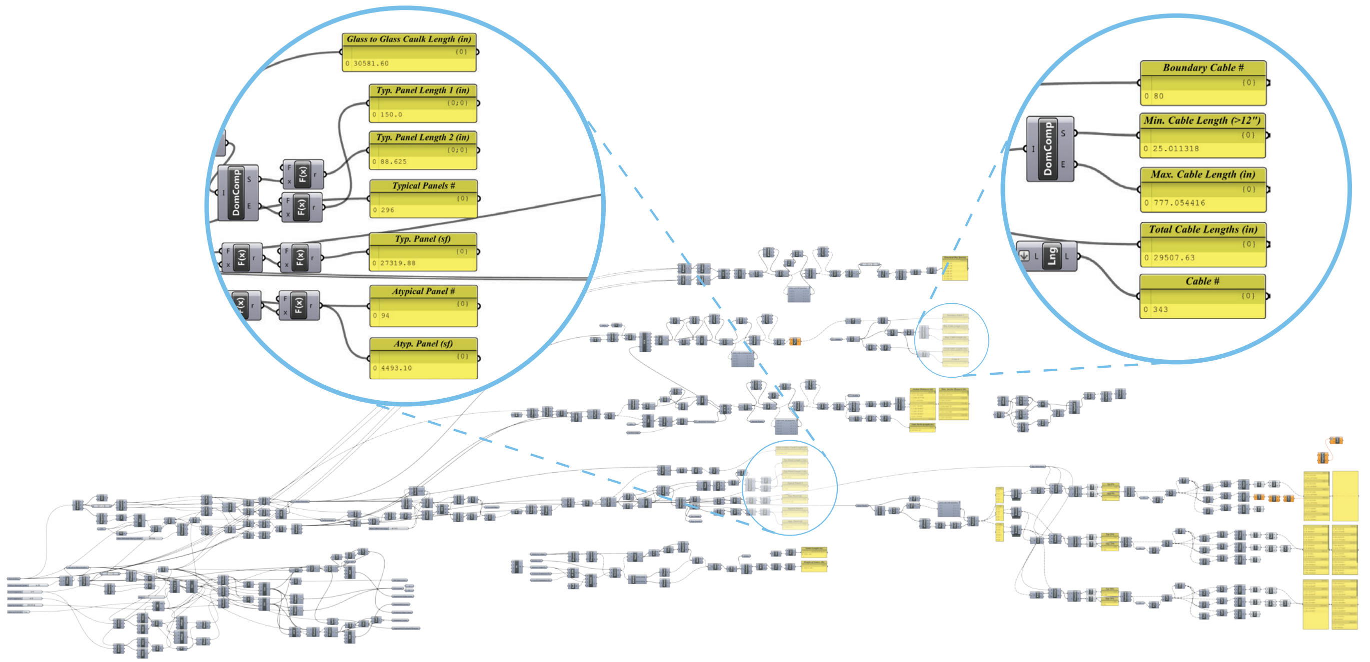




grid that would require less structural members and connections, reducing the amount of field welding required. In addition to introducing flexibility in the design of the structure, the parametric model was able to account for the number of unique connecting nodes and weld lengths, along with the quantity of steel tubes, overall weight and surface area of the structure. The immediate calculation of total connections and weld lengths provided the means of finding an optimal steel configuration for strength and material usage.

As the steel structure was being configured, each design was exported to a structural analysis program to be tested, allowing proper steel sizes for each member to be calculated. The member sizing information was then easily entered into Grasshopper, and the subsequent weight of the entire structure calculated.

A glass cassette skylight system was to be affixed to the steel structure with aluminum rails connecting to each other. Due to the single dimension of curvature in the canopy, the glass panels could be flat and aligned along rows, with the joint acting as the change of angle. Cables attached just beneath the glass, spanned across the grid-shell steel structure, aligning with the glass divisions. As the system was designed, a minimum and maximum panel size based on deflection, loads and other considerations was outlined. Aligned with the structural grid, the glass panel grid coincided with the sizing outline. The glass panels were broken up and separated between the typical flat uncut lites, and the atypical pattern cut perimeter panels. The number of lites and total square footage was continuously calculated as any changes to the glass grid were made. The smallest and largest lites of glass were also calculated to ensure extreme glass panels would not be structurally unsound or too small for production. The linear length of silicone and caulking for the glass joints and connection to the perimeter beam



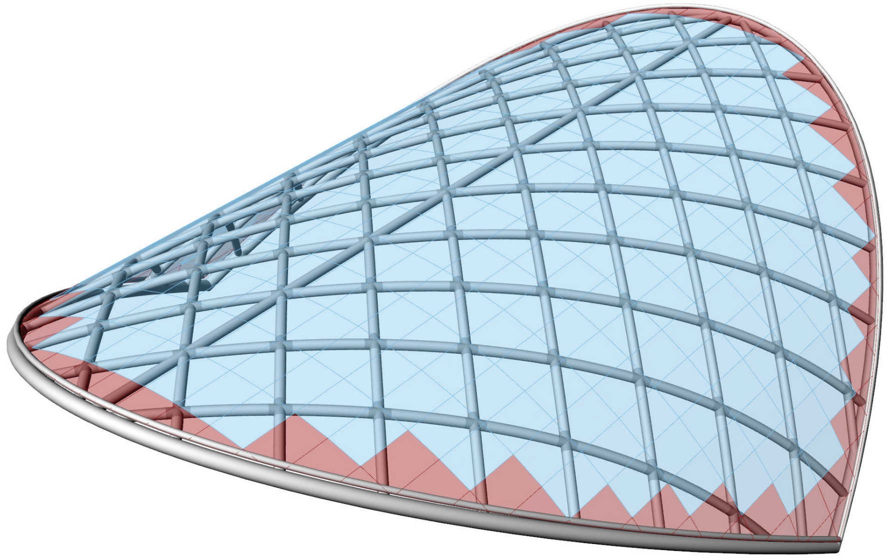


FIGURE 4
Grasshopper routine panelizing the canopy glass, extracting typical dimensions, number of lites, cable minimum and maximum lengths, and cable quantities.

FIGURE 5
Typical and atypical glass lites on the steel structure.

FIGURE 6
Grasshopper routine extracting glass square footage, aluminum extrusions and sealant lengths, and lite measurements.

FIGURE 7
Glass types grouped based on their location throughout the model.

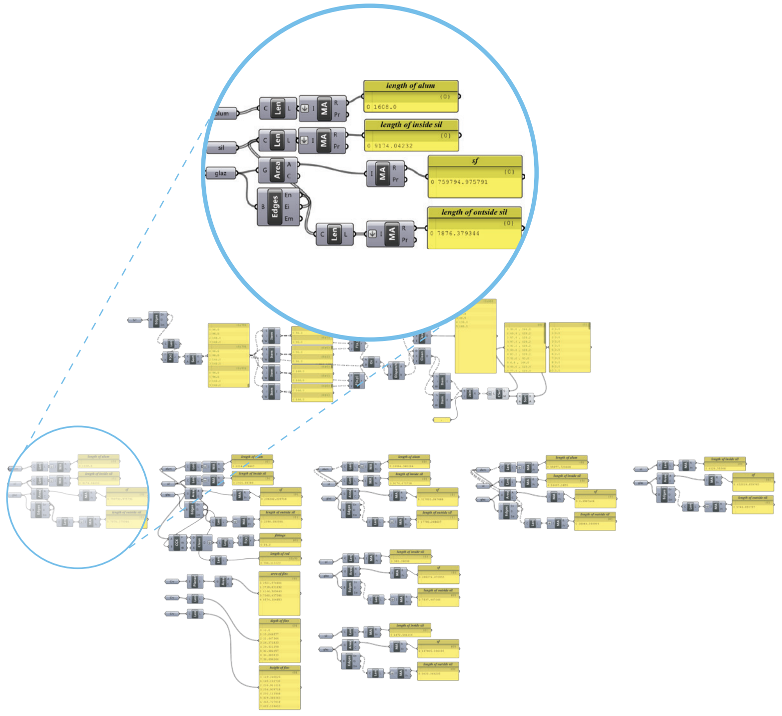
was also continuously calculated. In addition to the glass panel information being accounted for, the aluminum substructure was also being cataloged. The linear length of silicone for the glass joints and connection to the perimeter beam was also continuously calculated.

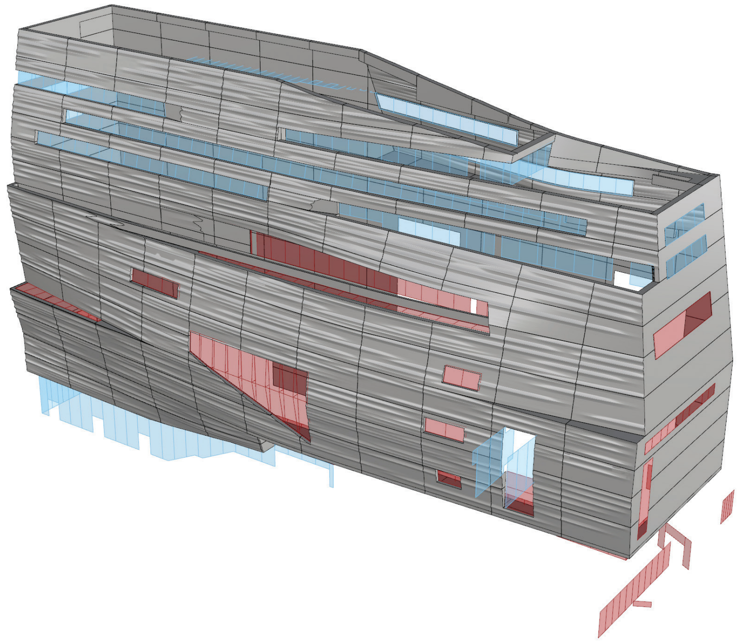
These values were then exported to spreadsheets to be prepared for vendors. The finished surface area for the steel structure was tabulated and sent to a painting vendor. The length of steel for each member size, minimum and maximum piece length, number of nodes, and length of welds was extracted and sent off to the steel fabricator. The total square footage and number of typical and atypical pattern cut lites was prepared and sent to glass vendors. The total lengths of cables, including maximum and minimum dimensions, was extracted for the cable vendor.

The canopies represented a unique opportunity to merge a parametric re-design model with cost estimation and take-off exercises. As the design changed, the information regarding lengths, sizes, quantities, surface area and total square footage would automatically re-calculate and export with ease to spreadsheets, rather than be painstakingly counted by hand.

SAN FRANCISCO MUSEUM OF MODERN ART EXPANSION

This museum expansion project consisted of two systems: an opaque fiberglass reinforced polymer (FRP) panel that covered the majority of the building, including both a flat and rippled surface treatment, and a unitized glass system. The project was being designed under a design-assist contract with the architect, meaning the design would undergo many changes and would need periodic updates to cost estimates and material take-offs to keep up.





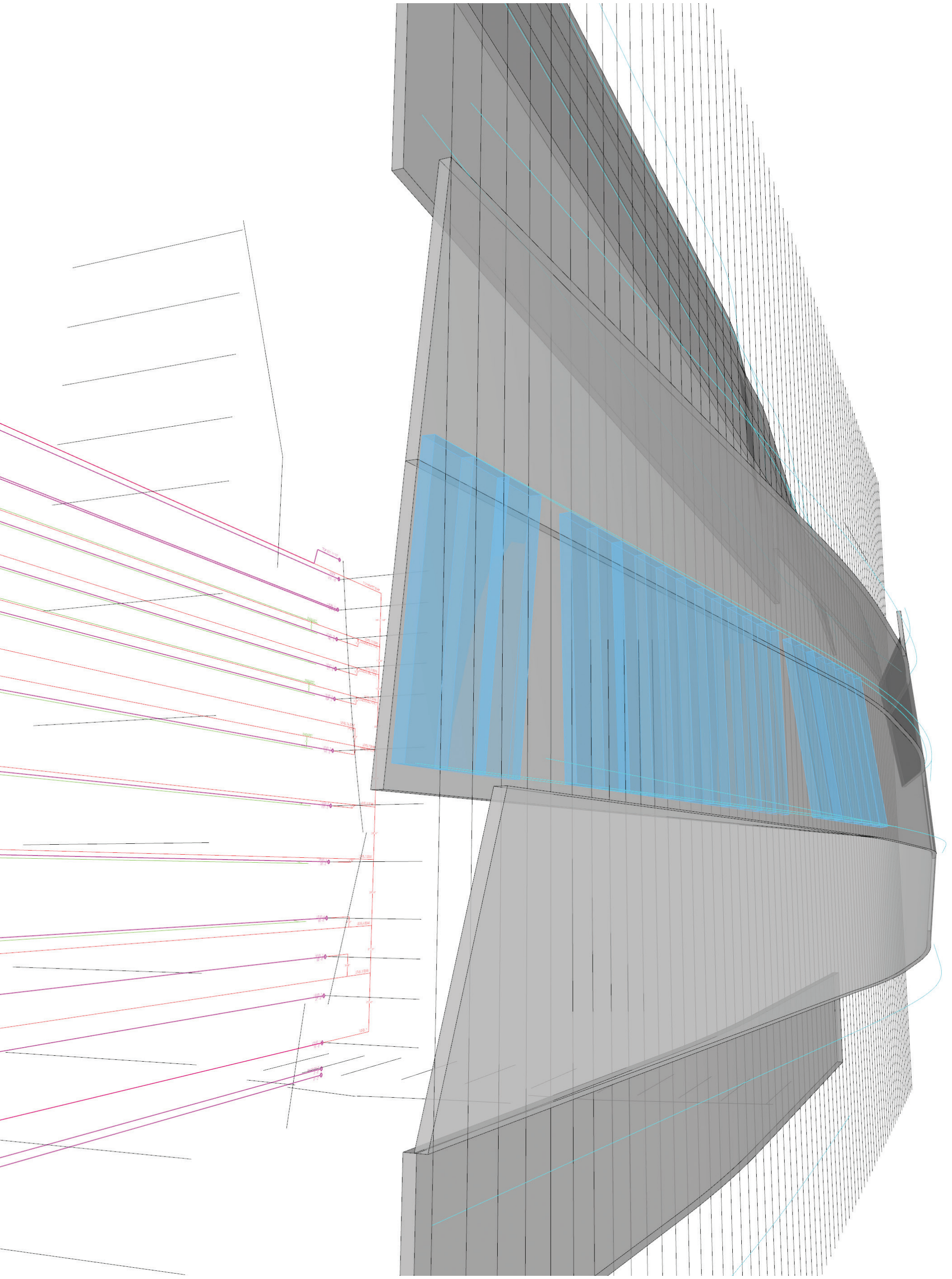


FIGURE 8
Unitized FRP panels aligning to planar control surfaces.

The architect provided standard architectural drawings and an in-development BIM model to start with. The information given was based off the beginning of design development and would knowingly change multiple times throughout the design lifespan of the project. In this case, rather than building up a fully functioning parametric model, and before there was no major re-design required, a parametric work-flow which could incorporate geometry from a BIM model for cost estimation and take-off was favored.

The BIM model was imported into Rhinoceros 3D and all the glass and exterior surfaces were separated from the rest of the model to be linked into Grasshopper. The glass was divided and regrouped based on their location and types (1, 2, 3a, 3b, 3c, 4, etc.). The opaque surfaces were brought into Grasshopper for rationalization and to be panelized. After the glass was grouped, the total square footage of glass, typical and atypical pattern cut panels, and aluminum extrusion and sealant lengths were calculated. A particular routine was developed to find duplicate glass panel sizes and to group them together for a clearer estimation count. Complete area for glass coverage per each glass type was a key validation metric between the Studios design-assist team and the architect, as the Studios worked through many modeling iterations. All the relevant glass quantities, sizes, and cuts were then exported to spreadsheets directly from Grasshopper for pricing.

The initial rationalization of the opaque surfaces was based on a system that would be cold-warped into position. Various panel widths were analyzed in Grasshopper to determine the spectrum of warpage that would result from the panelization. Once an acceptable amount of warpage was determined, the total quantity, square footage and lengths of aluminum extrusion frames and sealants for that panel width were pulled out of the model for pricing.

As the system was developed, means and methods were simplified to a more typical unitized system that did not require cold-warping. In order to trace the architect's surface with planar units, the FRP panels were utilized to make up the double-curved surface within the first 20" off of the face of the planar units. Where the curvature exceeded the bounds of the FRP, faceted transition units were utilized to re-align the next set of planar surfaces with the architect's control surface. Grasshopper was utilized to minimize the number of faceted transition units and the distance of the FRP off the face of the unitized system to minimize atypical details and minimize FRP material.

The glass system on the San Francisco Museum of Modern Art expansion project exemplified a design workflow in which Grasshopper could be used on existing geometry (exported from a BIM model) to gather material take-off and pricing information during each step of the design process. The optimization and design of the FRP panels followed a more traditional parametric approach – blending design intent with material, structural and constructability constraints to produce a cost effective panel system.

CONCLUSION

Parametric software is able to efficiently gather material take-off and pricing information from 3D models. In many cases, Grasshopper is used as the means of creating the very geometry and components that will later need to be measured and priced. It is in a position to extract the most accurate information from geometry that it created. Along these lines, Grasshopper's ability to continuously pull out information from models as designs change, or to create a workflow which re-incorporates designs as they evolve, makes it an extremely valuable tool.

Moving forward, parametric-infused cost estimation and material take-off can even begin to influence the design process. As pricing information is readily available during design, the cost impact from design alternatives such as weight, surface area, number of pieces and connections can be calculated to give feedback on the feasibility of that alternative. An optimization sequence can begin to investigate how to reduce cost on a project by pushing design options through Grasshopper with design constraints and cost evaluating each configuration.

Overall, parametric software enables cost estimation and material take-off to be completed quicker, more accurately, and on complex projects incorporating geometries that would otherwise be difficult to extract information from. The continuous measurements and efficiency at which information can be gathered from digital models ensures that time can be spent refining designs rather than manually looking over 2D drawings and re-counting elements at each design milestone.