APPLIED PARAMETRICS FOR FAÇADE DESIGNS AND MATERIALS

FIGURE 1: When completed (construction started in June 2018), the seven-story 633 Folsom office tower in San Francisco will feature sculptural sunshades finely tuned, parametrically defined for energy and daylight performance.

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Robert Perry, AIA, is a Senior Associate and Design Director in the San Francisco Gensler office. He is a leading expert in the use of parametric modeling to deliver innovative design concepts for large-scale mixed-use and office building projects both in the U.S. and internationally.

LEARNING OBJECTIVES

After reading this article, you should be able to:

+ **DISCUSS several benefits of parametric modeling.**
+ **SUMMARIZE the attributes of fiber-reinforced polymer (FRP) composites and terra cotta.**
+ **LIST testing procedures used to reach the final choice of materials for two projects.**
+ **EVALUATE the building code and historic preservation requirements faced by the design team in each of the case study projects.**

Parametric modeling has proven an invaluable toolset that enables architects to test complex design concepts and organize large quantities of data into manageable work streams. This process facilitates rapid idea testing and identification of efficiencies within a concept while also meeting client demands and schedule expectations. It also automates a portion of the traditional design process, which frees up the designer's time and energy. And it's cost effective: the Grasshopper software that sits on the Rhinoceros 3D platform is open-source and free.

Parametric iteration makes it possible to achieve unique solutions that require digital surface modeling and then apply them to interesting building materials that might previously have been considered unviable—turning ideas into reality. The examples presented in this course describe how parametric modeling supported conventional fabrication of fiber-reinforced polymer (FRP) and terra cotta to realize the desired parametrically defined concepts.

The ability of these materials to be sculpted by machine or hand establishes a natural relationship to computationally formed digital surfaces. A feedback loop can then be defined based on fabrication methods and limitations to inform the digital surface and preparation for fabrication. FRP, for example, is better suited for curved and complex surfaces than for flat surfaces. This curvature creates inherent structural characteristics that then establish further efficiencies with the use of FRP, such as hollow-core, shelled parts.

The following case studies describe a high-level process of design and fabrication methods as seen through the lens of cost, design intent, and technical feasibility. In the case of 633 Folsom, the design testing aided the search for the best materials; for 100 Stockton, where the façade material (terra cotta) was locked in, parametric modeling supported the exploration of designs.

Parametric modeling can be an effective tool in developing design concepts that employ composite and natural building materials.


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Physical mock-up of custom-shaped sunshades for 633 Folsom in San Francisco.

633 FOLSOM, SAN FRANCISCO

Located on the southeast corner of Hawthorne and Folsom Streets in San Francisco, 633 Folsom is the site of a seven-story office tower originally built in 1966. Tenant turnover created an opportunity for the owner to reimagine the property by adding five new levels and completely overhauling the MEP systems and building envelope. When completed (construction started in June 2018), 633 Folsom will provide nearly 270,000 sf of office space and 5,000 sf of ground-floor retail in a 12-story building.

The intent was to create a façade that would enhance the workplace experience—especially the wellness component—and contribute to the character of the South of Market (SoMa) neighborhood. Reconfiguring the ground floor will enable new retail storefronts to engage Folsom Street. Above street level, floor-to-ceiling glass will address tenant demand for daylighting and provide a connection to the outdoors. Sculptural sunshades tuned for energy and daylight performance will provide for lower exterior reflectivity while maintaining high light transmittance to the interior workplace. The completed building will bring together targeted solar shading and connectivity to views with opaque façade material and texture.

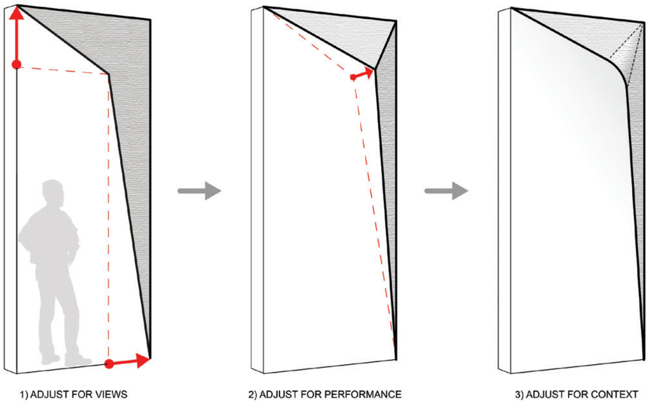


FIGURE 2. Custom-shaped sunshades

High-rise façade design for noncommercial office building districts prompted an exploration of materiality, textures, and performance that would lead to a contextual solution for a new office building. The design team's aversion to all-glass buildings in the specific neighborhood led them to develop a performance-based, parametrically defined façade that uses FRP to realize complex sunshade geometries (Figure 1). The concept addressed the perceived negatives of commercially available opaque panel enclosures—blocked view, reduced daylight, heightened glare—to create a unique solution of custom-shaped sunshades

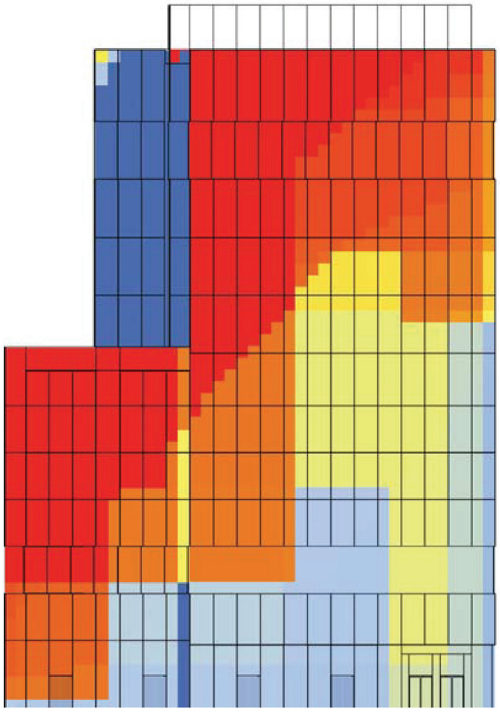


FIGURE 3. **Elevation showing incident solar radiation mapping.**

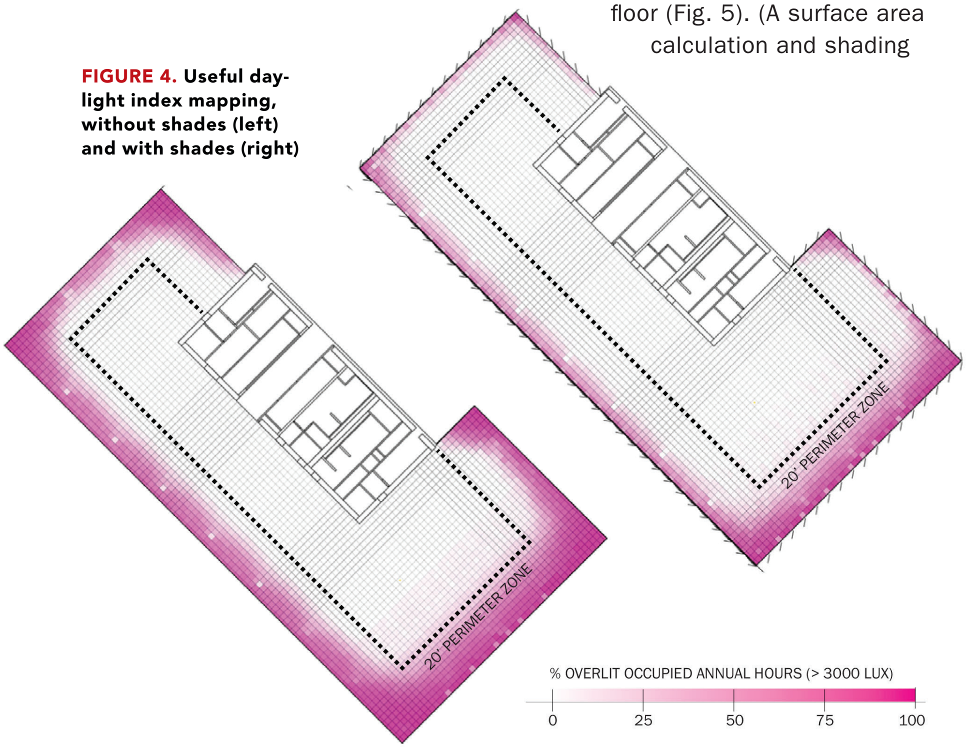
(Figure 2).

Parametric modeling and environmental analysis tools, such as the Ladybug plug-in for Grasshopper, were used to study and define the depth and dimensions of the sunshades. Through incident solar radiation tests on each façade, the design team identified irregular exposure patterning (largely due to building orientation and shading of existing and future zoned building heights) which suggested that less shading depth was needed at the lower levels, while deeper shading was needed toward the top (Fig. 3). Additional daylight analysis and overshadowing diagrams further tuned the sunshade depth and shape (Fig. 4 & 5).

The use of these analytics allowed for a precision of study in half-inch increments of shade depth. Final shade depth distribution was set at a minimum of 14 inches at the lowest floor and a maximum of 26½ inches at the highest, going up by about two inches at each floor (Fig. 5). (A surface area calculation and shading analysis revealed that a 26-inch custom-shaped sunshade had equivalent cumulative performance values of a flat, horizontal and vertical 32-inch sunshade). The analysis enhanced the external expression of the building by creating a gradient of sunshade depths vertically along the height of the building. Based on the solar orientation of each façade and the changing shade depth, the team determined that 16 unique sunshades would be required to adequately shade the building enclosure.

Having completed the analytical design to define the geometries of the sunshades, the designers set out to find a material that would lead to a buildable solution. In addition to building the complex sunshade shape itself, we had to consider impacts that potential sunshade materials would have on the performance of the unitized curtain wall. Collaborating with wind engineers, façade consultants, and fabricators, we evaluated stainless steel, glass-fiber reinforced concrete, solid surface Corian, slumped glass, and fiber-reinforced polymer. The evaluation considered wind-induced vibration response, imposed weight, flexure related to building movement, surface finish, code compliance, and cost. Each of these materials could physically achieve the desired shape, but weight, vibration, and cost became points of focus. Excess load on the unitized curtain wall required costly structural upgrades to the system, visible and

FIGURE 4. **Useful daylight index mapping, without shades (left) and with shades (right)**



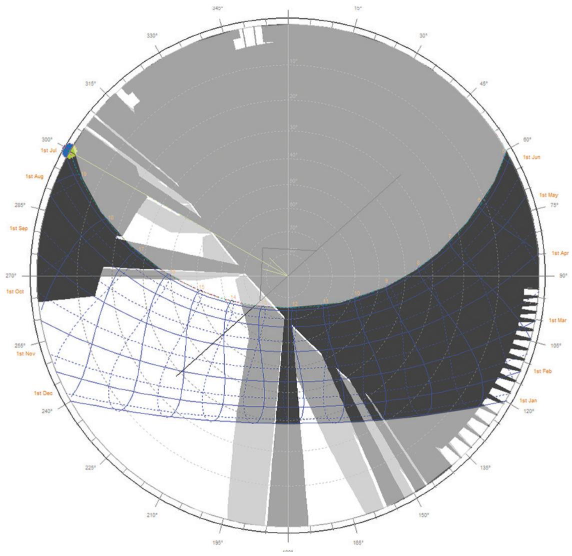


FIGURE 5. **Stereographic projection of façade and annual sun paths**

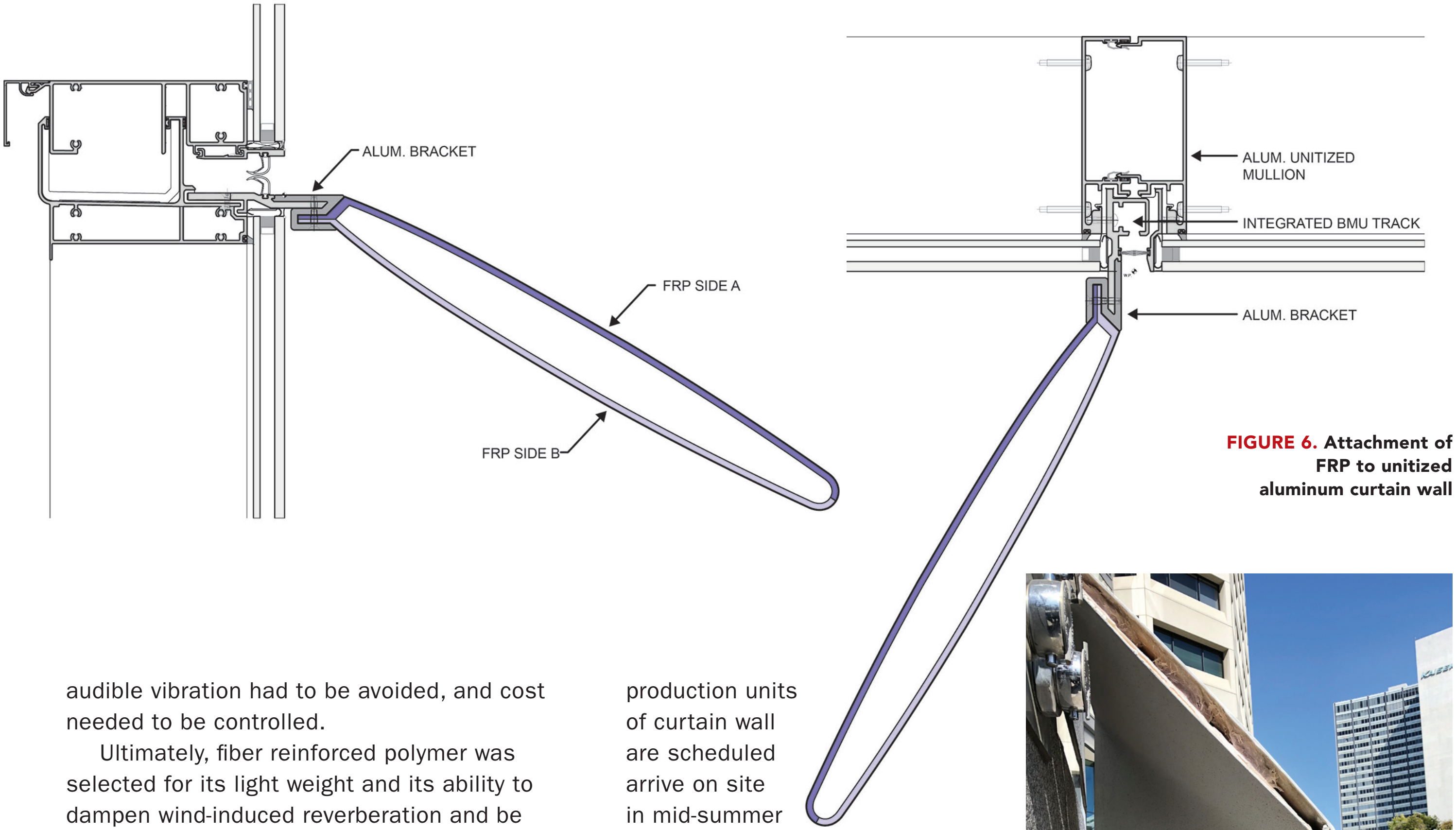


FIGURE 6. Attachment of FRP to unitized aluminum curtain wall

audible vibration had to be avoided, and cost needed to be controlled.

Ultimately, fiber reinforced polymer was selected for its light weight and its ability to dampen wind-induced reverberation and be shaped into complex surfaces.

Next came the task of how to integrate the FRP sunshades into an aluminum and glass curtain wall assembly. The design team worked to define a unique aluminum extrusion that could receive the FRP on one end and attach to the unitized mullion on the other end (Fig. 6). (The vertical aluminum mullion profile also has a custom-designed track to guide the window-washing platform for the building.)

Finite element analysis (FEA) further proved the sunshade could be built as a two-part "clamshell," minus a core. A cross-sectional curved profile was added to the sunshade at this point in the process. The FEA deflection test concluded that a maximum cross-sectional dimension of three inches would create a structurally sound, self-supporting FRP component (Fig. 7).

The use of FRP on a high-rise façade also prompted building code considerations. The sunshade geometry created a re-entrant corner between the FRP and the glass, which introduced the possibility of heat buildup at this juncture. The design team collaborated with the local jurisdiction and an accredited test lab to define a test protocol and perform a flame spread test. The sunshade geometry proved to be a non-issue and the specified aggregate composition in the FRP passed the flame spread requirements (Fig. 8).

With construction in full swing, the first production units of curtain wall are scheduled arrive on site in mid-summer 2019. The FRP sunshades will arrive separately and then be fixed to the individual curtain wall units on each floor prior to final positioning on the slab edge. Installation of the FRP sunshades will be closely observed for quality control by both the architect and general contractor.

FIGURE 7. Partial, full-scale mockup showing hollow core cross-section

100 STOCKTON, SAN FRANCISCO

The former Macy's Men's Store, a seven-story building at 100 Stockton Street, San Francisco, is just steps from Union Square. The 1970s-era building originally served a wholly internalized shopping experience and to this day lacks a relationship with the street life of the neighborhood, which in recent times has become much more pedestrian oriented. The design team saw this vital community asset as a prime candidate for a makeover that would inspire further revitalization of Union Square and attract world-class tenants.

Construction has begun on a repositioning plan to activate the façade across all levels, restore a relationship with the street and pedestrians, and make it compatible with the aesthetic vernacular of the historic district. The current opaque exterior wall, clad entirely with travertine over concrete, will be replaced by a

FIGURE 8. **Flame spread test.** **FIGURE 9.** **New façade organization and design expression.**

glass and terra cotta enclosure system. The use of a historic material within current design methods became the concept that inspired a digitally defined terra cotta façade.

The design solution, based on the patterns and other commonplaces of surrounding terra cotta buildings, involved a large-scale façade articulation that organized the building elevation into three vertical segments (Fig. 9). The bottom segment defines individual storefronts; the middle creates a balcony experience; the upper levels contain additional retail and commercial uses.

Evolving from a traditional running bond pattern and taking advantage of terra cotta's ability to be shaped, the storefront piers become a gradient of bricks that morph from human-scale to building-scale proportions. To enhance the visual texture, each terra cotta brick face is folded along a diagonal axis, which results in the formation of two nonplanar surfaces within each brick face (Fig. 10).

Here again, parametric modeling was employed to generate and manage these terra cotta shapes. Grasshopper was used to define and test the gradient scale while providing real-time data on material quantity, unique mold counts, and total bricks. The parametric process allowed for early, well-informed collaboration with terra cotta suppliers to further refine the design and move it toward an efficient, buildable solution. Early mockups of the terra cotta brick were defined digitally and hand crafted using traditional techniques (Fig. 11). From studies of the mockup and further collaboration with the terra cotta experts, the team determined that ram pressing would be the most cost- and time-effective method for producing the larger terra cotta parts while maintaining the smaller

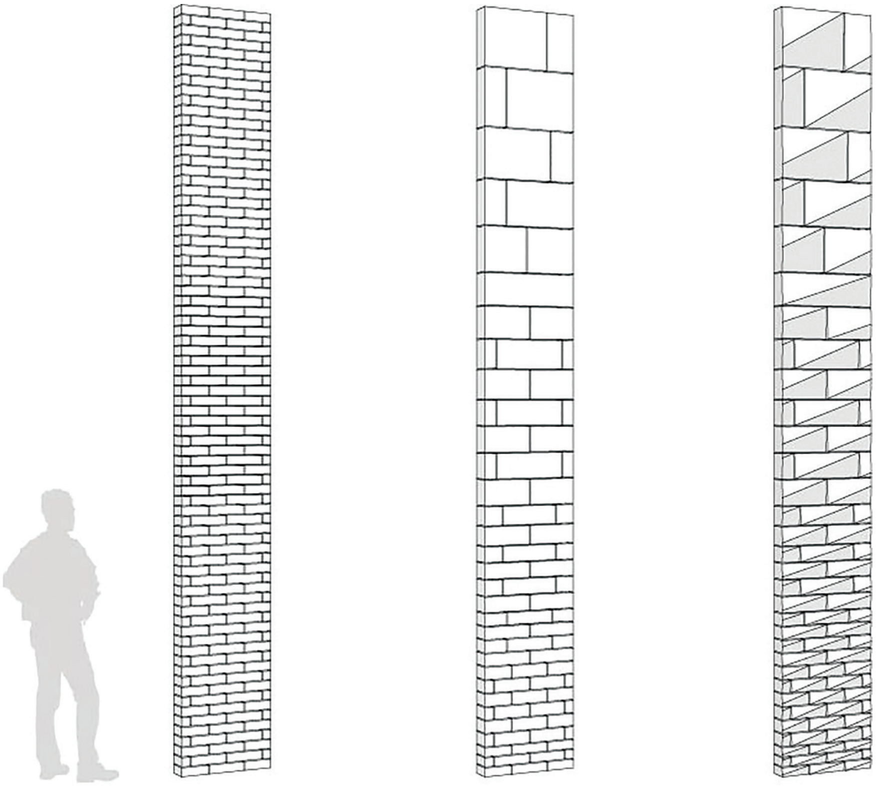


FIGURE 10. Terra cotta pattern logic

FIGURE 11. Handcrafted terra cotta prototypes

intended pattern (Fig. 12).

The middle façade segment was designed to draw the pedestrian's eye up the building. City zoning required this building to maintain retail uses for a minimum of five levels. To differentiate the upper floors from neighboring buildings, specifically at level three, the design introduced a continuous balcony and eye-catching mullion pattern (Fig. 13).

Advanced scripting using Python and Grasshopper enabled the design development and contractor communication for the upper façade segment. Inspired by surrounding buildings and their structurally expressed façades, the upper façade uses a grid pattern to settle into its neighboring context. In response to the large angled architectural composition, the grid is further articulated by an undulating profile that disrupts an otherwise visually static façade grid.

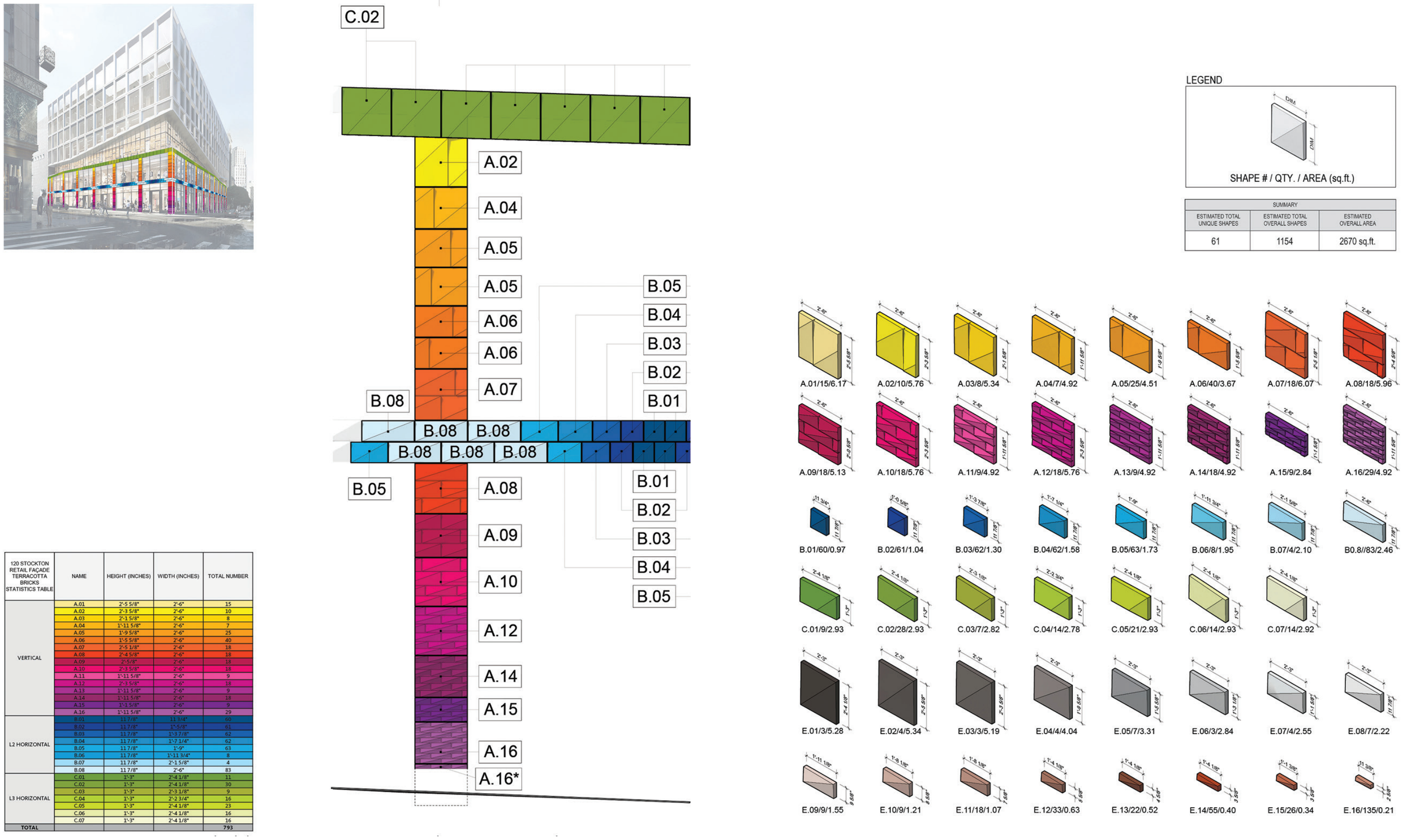
To control, monitor, and document the unique façade grid components, a workflow from Grasshopper to Revit was established. The changing grid was made efficient through algorithms in Grasshopper that limited the number of different grid dimensions. The process allowed for simple algorithmic inputs to control complex outputs of façade grid dimensions and the resulting terra cotta shapes (Fig. 14). While the final documentation was created in Revit, the façade model geometry was generated in Grasshopper and translated to Revit through an Excel spreadsheet that contained the numerical geometric data. The façade grid pattern and scale also reflect the unitized method of façade construction as a modern technique.

Through the use of a robust parametric process, the design team was able to provide an in-depth, accurate depiction of the complex design intent at an early stage. The use of parametric modeling during the Design Development stage allowed for meaningful collaboration with contractors, which in turn created a feedback loop that informed the digital process of the design for the bidding phase of the project.

WHAT WE LEARNED ABOUT PARAMETRIC MODELING AND MATERIALS

Our work on these two projects gave the design team a richer understanding of how best to apply parametric modeling to help solve for complex design concepts and discover the optimal materials overcome specific design-related problems:

1. Parametric modeling tools can benefit the design process not only on complex design solutions but also on such basic concepts as massing or daylighting. When working through the design of the exterior cladding, parametric



120 STOCKTON RETAIL FAÇADE TERRACOTTA BRICKS STATISTICS TABLE	NAME	HEIGHT (INCHES)	WIDTH (INCHES)	TOTAL NUMBER
VERTICAL	A.01	2'-5 5/8"	2'-6"	15
	A.02	2'-3 5/8"	2'-6"	10
	A.03	2'-1 5/8"	2'-6"	8
	A.04	1'-11 5/8"	2'-6"	7
	A.05	1'-9 5/8"	2'-6"	25
	A.06	1'-5 5/8"	2'-6"	40
	A.07	2'-5 1/8"	2'-6"	18
	A.08	2'-4 5/8"	2'-6"	18
	A.09	2'-5/8"	2'-6"	18
	A.10	2'-3 5/8"	2'-6"	18
	A.11	1'-11 5/8"	2'-6"	9
	A.12	2'-3 5/8"	2'-6"	18
	A.13	1'-11 5/8"	2'-6"	9
	A.14	1'-11 5/8"	2'-6"	18
	A.15	1'-1 5/8"	2'-6"	9
	A.16	1'-11 5/8"	2'-6"	29
L2 HORIZONTAL	B.01	11 7/8"	11 3/4"	60
	B.02	11 7/8"	1"-5/8"	61
	B.03	11 7/8"	1'-3 7/8"	62
	B.04	11 7/8"	1'-7 1/4"	62
	B.05	11 7/8"	1'-9"	63
	B.06	11 7/8"	1'-11 3/4"	8
	B.07	11 7/8"	2'-1 5/8"	4
	B.08	11 7/8"	2'-6"	83
L3 HORIZONTAL	C.01	1'-3"	2'-4 1/8"	11
	C.02	1'-3"	2'-4 1/8"	30
	C.03	1'-3"	2'-3 1/8"	9
	C.04	1'-3"	2'-2 3/4"	16
	C.05	1'-3"	2'-4 1/8"	23
	C.06	1'-3"	2'-4 1/8"	16
	C.07	1'-3"	2'-4 1/8"	16
TOTAL				793

LEGEND

SHAPE # / QTY. / AREA (sq.ft.)

SUMMARY		
ESTIMATED TOTAL UNIQUE SHAPES	ESTIMATED TOTAL OVERALL SHAPES	ESTIMATED OVERALL AREA
61	1154	2670 sq.ft.

FIGURE 12. Optimized terra cotta mold shapes

modeling can guide energy-efficient designs through computational analysis and help move a design from unbuilt to built.

2. Parametric modeling can be incorporated into the design process as a tool for architects to iterate various design options quickly. This provides designers the means for greater creative exploration and ensures the client receives a thorough and investigative design process.

3. The building site and context can provide inspiration for building aesthetic and performance as it relates to façade design. At 100 Stockton parametric modeling was used to generate a bespoke terra cotta façade pattern, a material chosen for its wide use in the neighboring historic buildings.

4. Starting a design process unbound by known solutions can lead to unique and authentic building design. Using parametric modeling, the architect's concepts can be developed through an iterative process that best translates the concept toward buildable systems.

5. A building material investigation should be done to find a suitable material with the characteristics best fit to achieve the design concept. Evaluation of materials should consider economic, aesthetic, and functional factors such as combustion resistance, UV stability, strength and elasticity, acoustics, code coverage, and life cycle assessment.

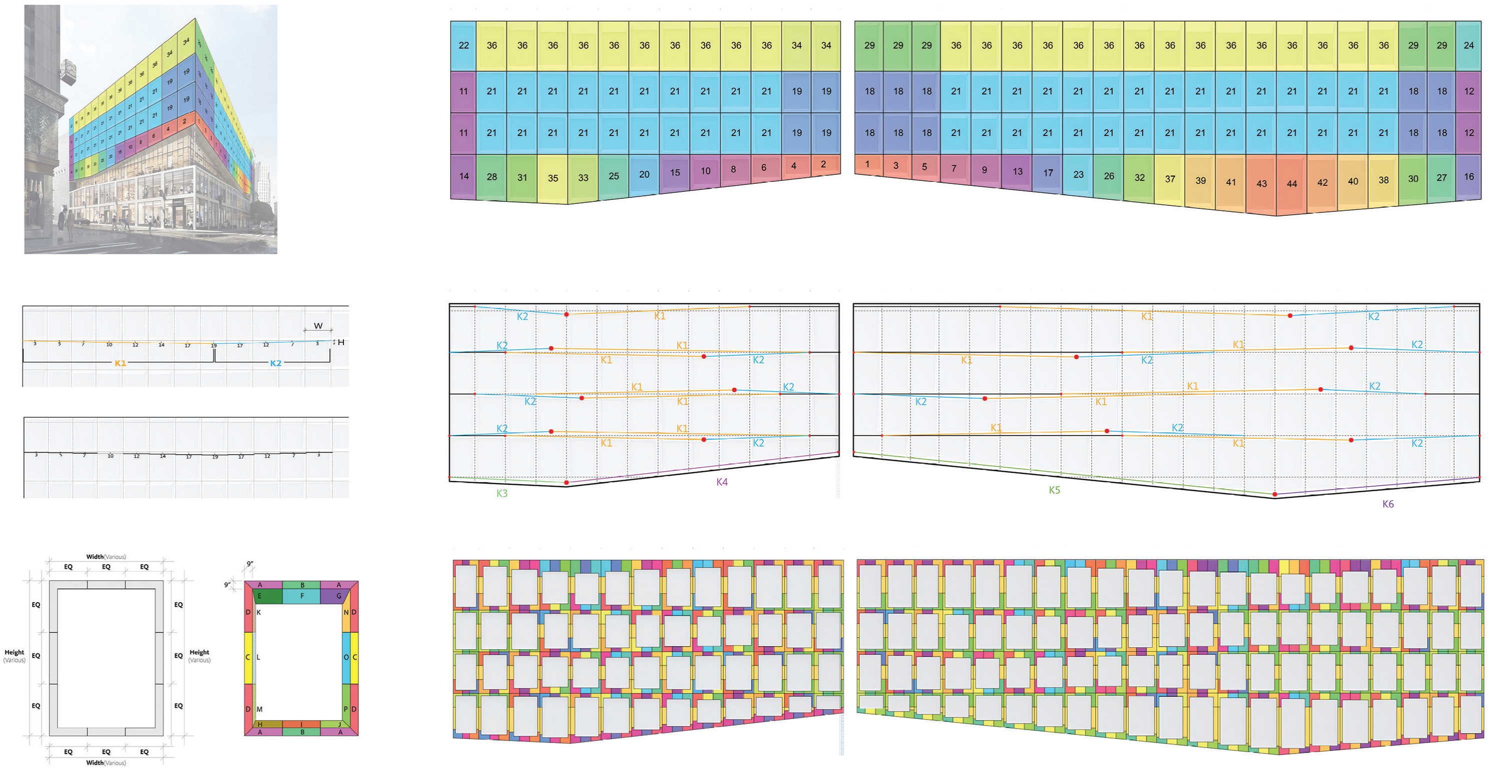
6. Cost factors for custom-fabricated façade elements must maintain a balance of not only unique mold quantities, but also assembly-line efficiency and project schedule to ensure parts arrive on time to the site. When considering custom fabrication for enclosure systems, the architect, general contractor, and subcontractors should work collaboratively to examine costs and schedules through a holistic project lens.

7. Materials testing, such as flame spread and structural deflection, needs to be considered when engineering custom façade components. Consultation with code consultants and local authorities having jurisdiction is best practice to ensure that public safety and welfare are protected. Additional cost and schedule implications of materials testing should be considered early

FIGURE 13. O'Farrell street elevation

in the planning phase to avoid having these extra steps create delays in the project schedule.

8. Parametric modeling empowers architects with useful design data that can enable early and advanced collaboration with contractors. Quick testing and documenting of design ideas for cost estimates and constructability reviews are necessary to move a concept efficiently toward feasibility. In the case of 100 Stockton, maintaining the historical context through the execution of the right material was vital to the success of the project. Parametric modeling was used to manage the complex terra cotta geometries, enabling the designers to proceed into each design phase with certainty about the complexity of their design intent. +



22	36	36	36	36	36	36	36	36	36	36	34	34
11	21	21	21	21	21	21	21	21	21	21	19	19
11	21	21	21	21	21	21	21	21	21	21	19	19
14	28	31	35	33	25	20	15	10	8	6	4	2

29	29	29	36	36	36	36	36	36	36	36	36	36	36	36	36	36	36	29	29	24
18	18	18	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	18	18	12
18	18	18	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	18	18	12
1	3	5	7	9	13	17	23	26	32	37	39	41	43	44	42	40	38	30	27	16

FIGURE 14. Unique façade components visually organized.