

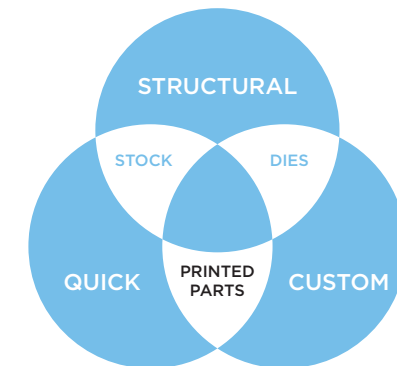
3D PRINTED PARTS FOR ENGINEERING AND OPERATIONS APPLICATIONS

NATHAN LUCERO

PRINTED PARTS AND THE FABRICATION GAP

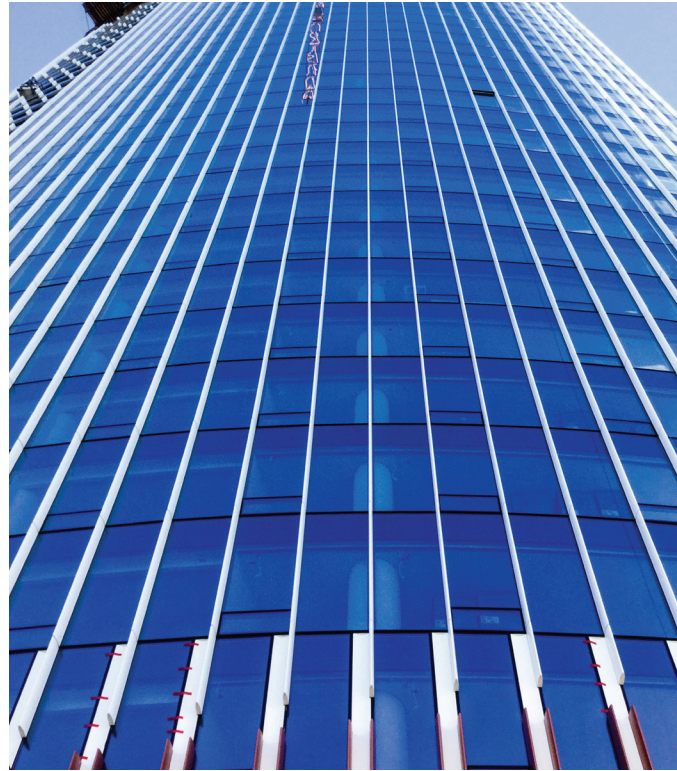
Facade engineering is a balance of using standard stock shapes when possible and introducing highly customized shapes to meet a project's unique aesthetic and performance requirements. To mock-up such designs early in a project often relies on similar stock shapes that are readily available in lieu of the custom fabricated shape that is cost prohibitive in low quantities. Enter, 3D printed parts.

3D printed parts provide a highly customizable alternative for early visual, table-top mock-ups in a relatively short amount of time but without the minimum run limitations or costs of custom extruded or cast parts. Printed parts can also be designed into tools that are custom to a project or function. A printed part can make a difficult task easier, and thus faster. Printed parts are incredibly accurate and dimensionally stable so they can be used to gauge or measure dimensions.



PROTOTYPES

Printed parts are ideal when reviewing the handling or function of a design and the material finish is irrelevant. Sometimes we create designs that are hard to communicate using standard details. The next best way to communicate the parts is with 3D renderings, but renderings do not allow the parts to be handled. Fabricating parts from actual materials can be expensive and require a long lead time. Printed parts allow new parts to be communicated and handled at a low cost and in a short amount of time.



TESTING FIT

Caps are good parts to test using printed prototypes because caps have to mate perfectly with extrusions that are usually unique to a project. Using a 3D printer, caps can be printed and tested in a short amount of time. Once the printed mock-ups work well, the final parts can start the first round of fabrication with a greater confidence of being functional. This saves time, money, and resources. Other system components recently tested via 3D printed prototypes include anchors, glass captures, bullnoses, and panels,

PACIFIC GATE VERTICAL FIN CAP

This cap used a continuous perimeter wall. The wall was created using an offset of inside vertical fin profile. The cap was then secured to the fin with a screw going through the straight wall on the backside. Different wall offset distances and shapes were tested. Using the exact profile of the inside of the fin created a wall that was far too tight. One offset was too large and pushed the edge of the cap face out of flush with the fin profile. Several variations of the vertical fin cap were printed and tested before a functional design was achieved. The color orange was used to put emphasis on which part was being tested (Fig. 2).

OCEANWIDE PLAZA EXTRUSION CAPS

In these caps, the use of studs was explored instead of a continuous offset wall. The size and location of the studs were tested using printed parts. Oceanwide Plaza also has mitered caps that require a little more time to design and test. The project team designed and tested different caps to see if they could be used on opposite ends of straight or mitered extrusions (Figs. 3 + 4). Using the same cap on opposite sides of the same extrusion reduced the number of unique molds.

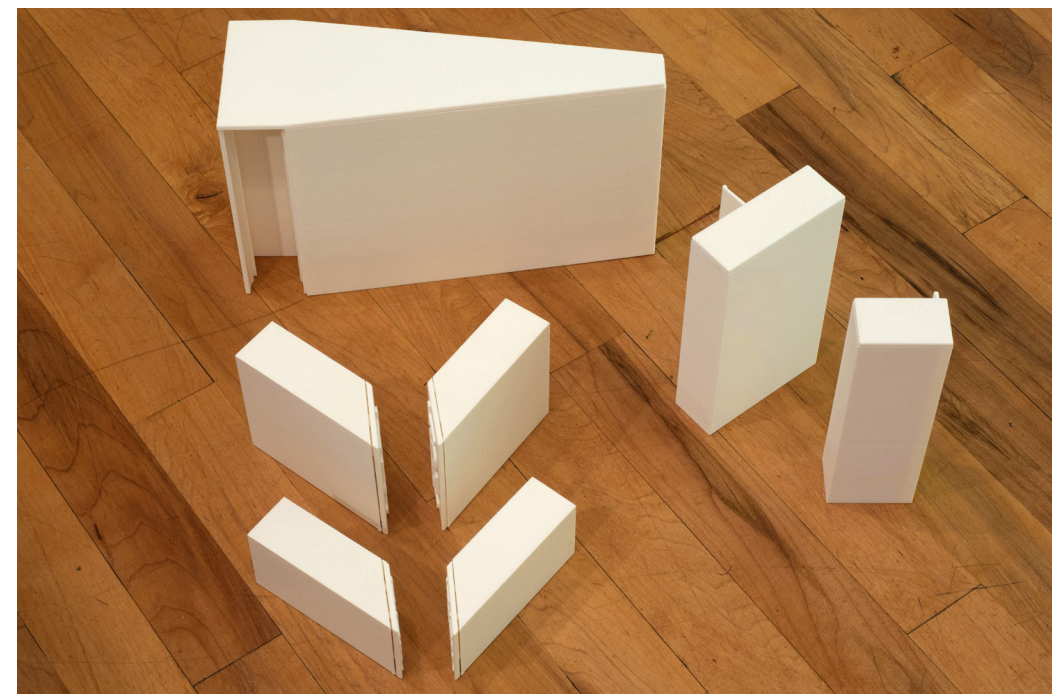
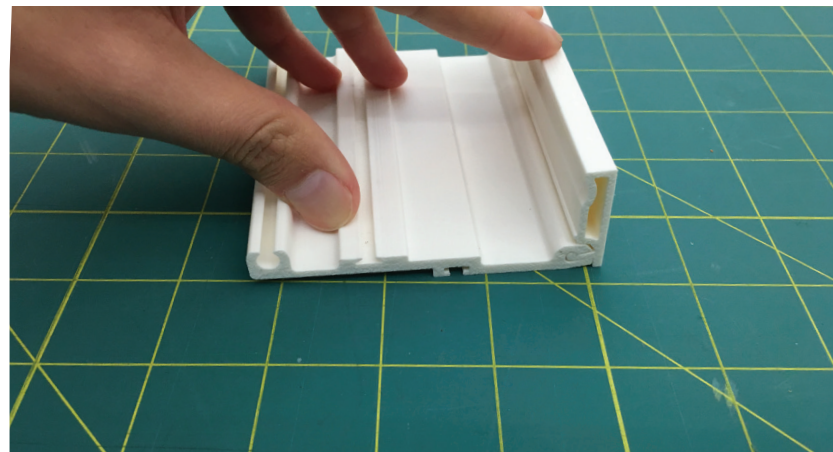
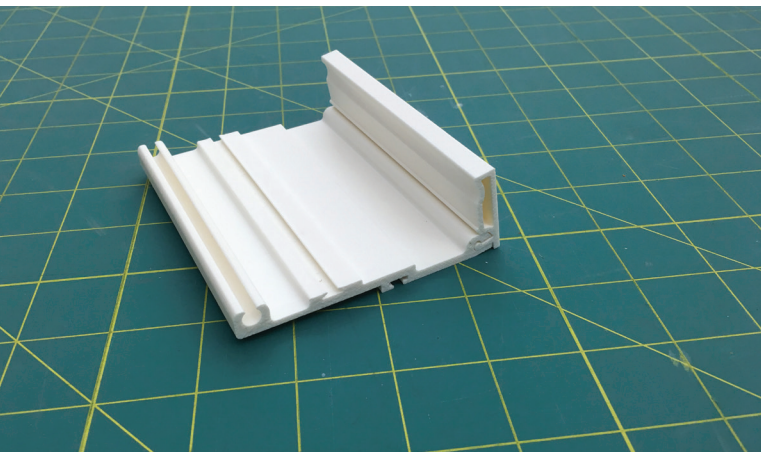
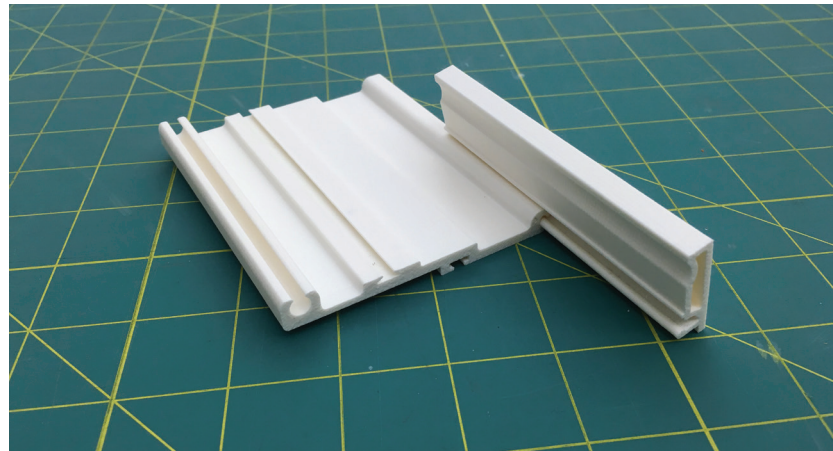
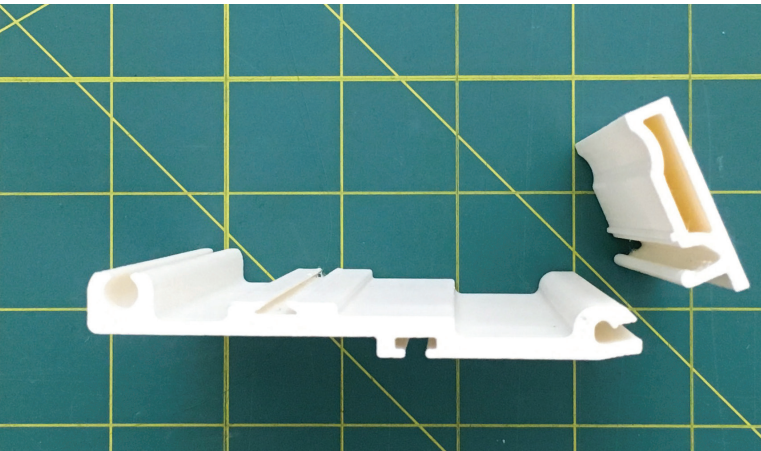


FIGURE 1
Pacific Gate curtainwall featuring vertical fins.

FIGURE 2
Full scale 3D printed Pacific Gate vertical fin (gray) and mating cap prototypes (orange).

FIGURE 3 + 4
Full scale 3D printed Oceanwide Plaza extrusions and mating cap prototypes.



GLASS CAPTURE FIT TEST

The design intent of this a glass capture is to use as little room as possible without using a standard snap or fastened capture. This design allows the capture to be slid in from the side. A wedge gasket between the capture and the glass sets the capture into its correct place while applying pressure between glass and

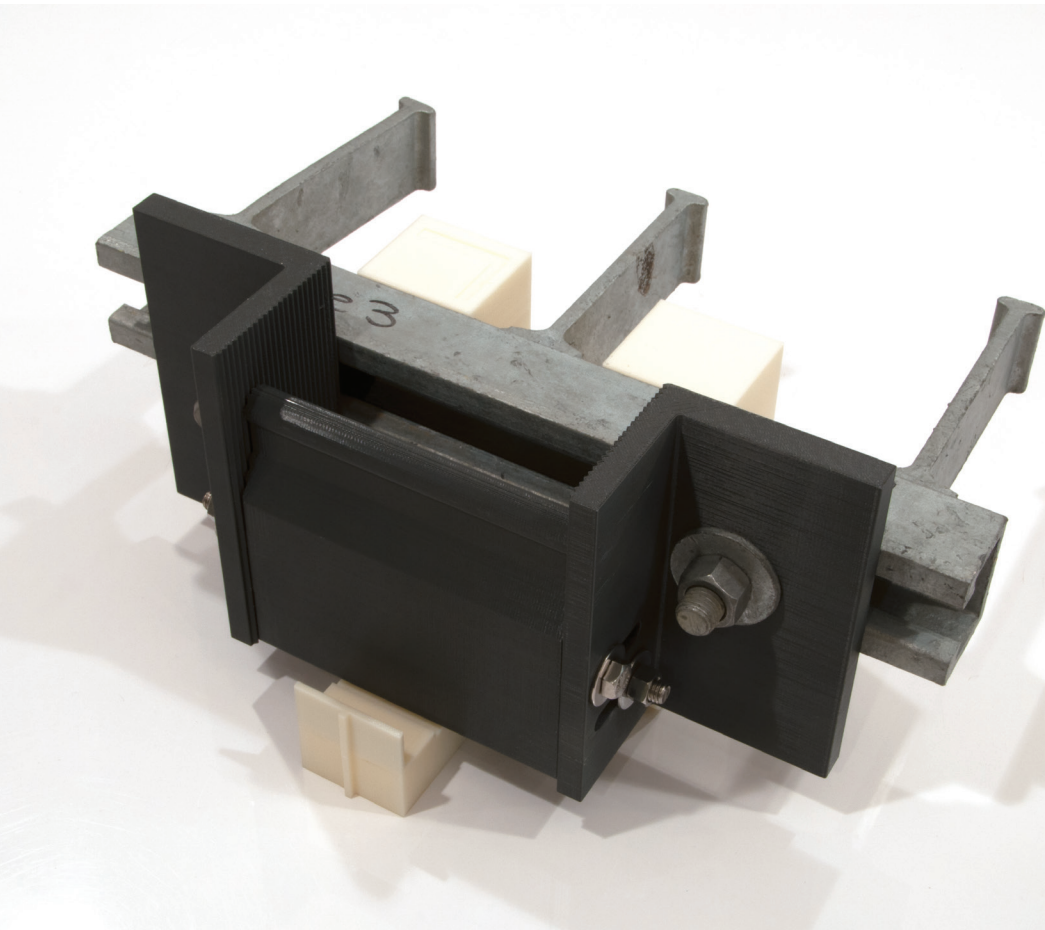
the aluminum capture. There was concern the capture would not slide into the fin and that the capture would not hold at the correct location once pressure was applied to it. These printed parts proved the capture could slide in and could hold the correct location once pressure was applied (Fig. 5-8).

FIGURE 5
Full scale extrusion demonstration: fin (bottom) and cap (right).

FIGURE 6
Full scale cap sliding into fin.

FIGURE 7
Full scale cap without pressure.

FIGURE 8
Full scale cap applying pressure.



SHIM FREE FACE-OF-SLAB ANCHOR

This face-of-slab anchor was developed to solve two problems with two common face-of-slab anchors; the "U" anchors enter the spandrel cavity and the "Z" or "J" anchors require a lot of shimming or multiple anchor profiles once one profile exceeds structural tolerances. This anchor design provides a full inch of adjustability in-and-out as well as side-to-side

without entering the cavity or requiring shims. Printing a prototype of this anchor was ideal because fabricating the parts from the actual material, aluminum would have been expensive. Communicating the design and how to handle the parts did not require using the actual material of the final anchor (Fig. 9-11).

FIGURE 9
Assembled full scale 3D printed anchor prototype.

FIGURE 10
3D printed anchor part

FIGURE 11
Aluminum anchor part.

PACIFIC GATE

owner
BOSA Development Corp

architect
Chris Dikeakos Architects
Kohn Pedersen Fox Associates

building type
Residential

gc
Bosa Development Corp

program
41 stories (458ft), 514,000 sqft

completion
2017

FIELD TOOLS

PACIFIC GATE ANCHOR ALIGNMENT TOOL

Pacific Gate is a 41-story residential tower in downtown San Diego, California (Fig. 1). A typical floor plan of the tower resembles an ellipse. The ellipse is composed of a series of tangent arcs. The curtainwall module width is short enough that the curtainwall units are flat while the split-mullion die profiles are angled. There is a series of angled mullion profiles. Different mullion angles correspond to different arcs that compose the floor plan ellipse.

While the mullion profiles allow the face of glass to align close to parallel to the floor slab, the mullions do not align the anchor hooks perpendicular to the face-of-slab anchors. To compensate, the inside of the anchor hook is rounded. This allows the hook to engage the face-of-slab anchor at a slight angle. The rounded hooks give a little bit of installation tolerance but the anchor still needs to be very close to parallel to the slab face. If an anchor deviates too much from parallel, the anchor can force the curtainwall unit out of alignment. If the unit is far enough out of alignment, the anchor hooks on the unit miss the next face-of-slab anchor.

When both unit anchor hooks cannot engage both face-of-slab anchors it means that the anchor must be adjusted. That anchor is already holding an adjacent unit. This means the adjacent unit must be taken off to realign the anchor. So while there is some installation tolerance due to the mullion die angles and rounded hooks, exceeding the tolerance can create delays.

To aid in aligning the face-of-slab anchors, radial lines from the center of the arcs that compose the floor plan ellipse were drawn in chalk on the floor slab. In theory the crew would set the

face-of-slab anchors perpendicular to the chalk lines. In practice this was a difficult task. Because the anchors were face-of-slab, assessing the angle of the anchor angle meant a crew member needed to see the anchor and chalk line on the slab at the same time. This could only be done looking down over the anchor while over the edge of the floor. This forced crew members into a precarious situation and did not guarantee proper anchor alignment (Figs. 16-17).

At this point it is important to mention that there is nothing wrong with the design of the units or how they are meant to be installed. Most of the installation issues were considered during design and engineering. However, once this opportunity to optimize the field install process became clear, it was important to identify a solution quickly. This is when designing a printed tool made a lot of sense. A gap in the installation process was discovered and a printed tool was ideal for closing that gap.

The tool's primary function was to use the chalk lines to align the face-of-slab anchor. Additionally, it was an opportunity to make the task safe, for the crew members. It had to be easy to use while keeping the crew members away from the slab edge.

Apparatus in the plate of the tool allow the crew member to locate the chalk line below; large openings for gross placement, and a narrow opening for fine placement. Grooves in the plate at the middle of the window allow the tool to be placed exactly centered on the chalk line (Figs. 16-17). Additional grooves perpendicular to the chalk line were placed at key dimensions relative to the back of the system.

A leg at the front of the plate dropped below the face of the slab. This leg was used to align the face-of-slab anchor. The groove in the center of the narrow window continued down the leg and

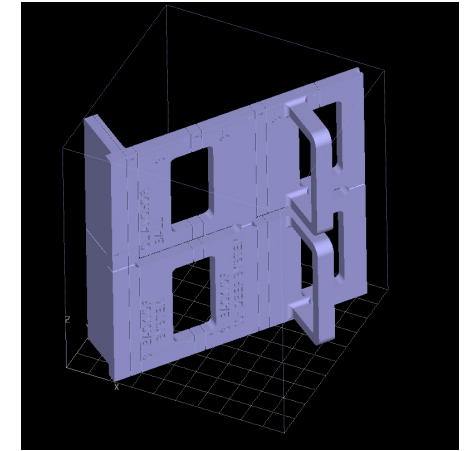
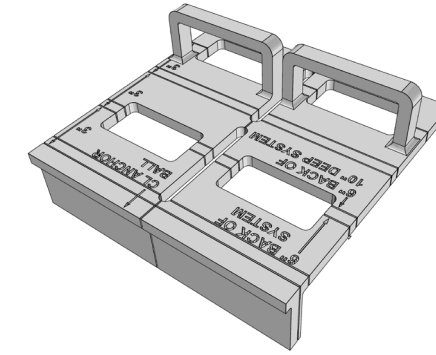


FIGURE 12
Screen capture of 3D anchor tool model.

FIGURE 13
Anchor tool model in 3D printer analysis software.

FIGURE 14
Anchor tool during print with support.

FIGURE 15
Anchor tool after support cleaning.

FIGURE 16
Pacific Gate floor slab with anchor chalk reference lines.

FIGURE 17
Anchor tool aligned with slab chalk lines.





was used to center the anchor. With this tool, a crew member carried the module information from the chalk line directly to the face-of-slab anchor quickly and accurately.

The handle bars were not in the original sketch. They were added to the tool for an obvious reason: this tool is used by humans with hands. Handling this tool as just a plate with a dropped leg would have been frustrating and would have taken more time. The handles facilitated easier use. It also gave the crew members a way to secure the tool to a rope. The tool is of no use if it is dropped off the edge of the building. It might seem unnecessary to mention the handles, but it is important because it can make the difference between an effective or frustrating tool.

AUGMENTED LASER TRACKING TOOLS

Due to the high level of accuracy, printed tools were used to augment laser tracking equipment. Laser tracking equipment measures distance and location by following a mirror, but the equipment cannot be moved relative to the structure it is measuring. Printed parts were designed to hold the tracking mirror at specific distances and locations so the equipment could better measure components at controlling geometry work-points (Fig. 18). One printed tool keeps the tracking mirror on center of HSS beams while another allows the equipment to measure tabs and holes behind beams that were out of sight to the laser camera.

These printed tools are covered in more detail in Tyler Tucker's article *Novel Uses of Metrology on Geometrically Complex Facades*.

FIELD COMMUNICATION

WINDOW WALL HEAD ANCHOR MOCK-UP

The head anchor for the window wall units on Park Lane was complex. There were many parts in a small amount of space and the different parts had to be installed in a specific sequence. The design was so complex that the drawn details of the head anchor were difficult to understand. To resolve any confusion, a mock-up of the head anchor was printed (Figs. 19-20). The project manager used the printed parts to demonstrate to the crew the different parts of the head anchor and the installation sequence.

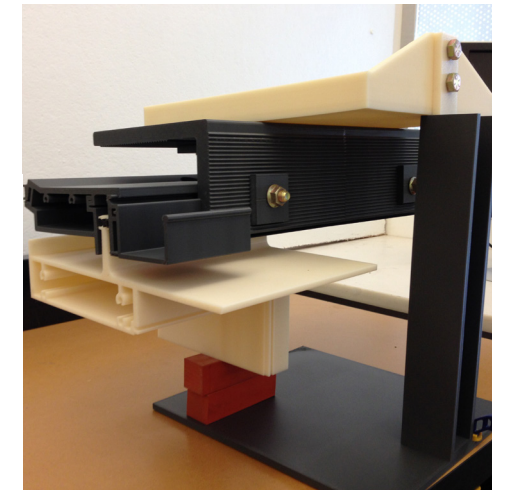
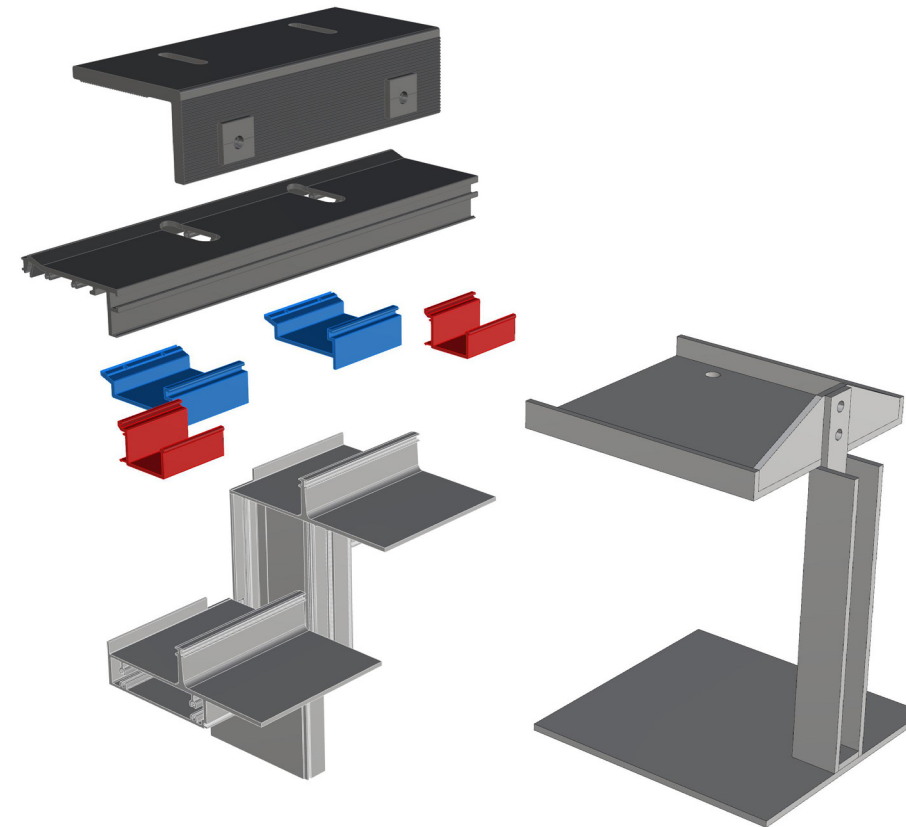
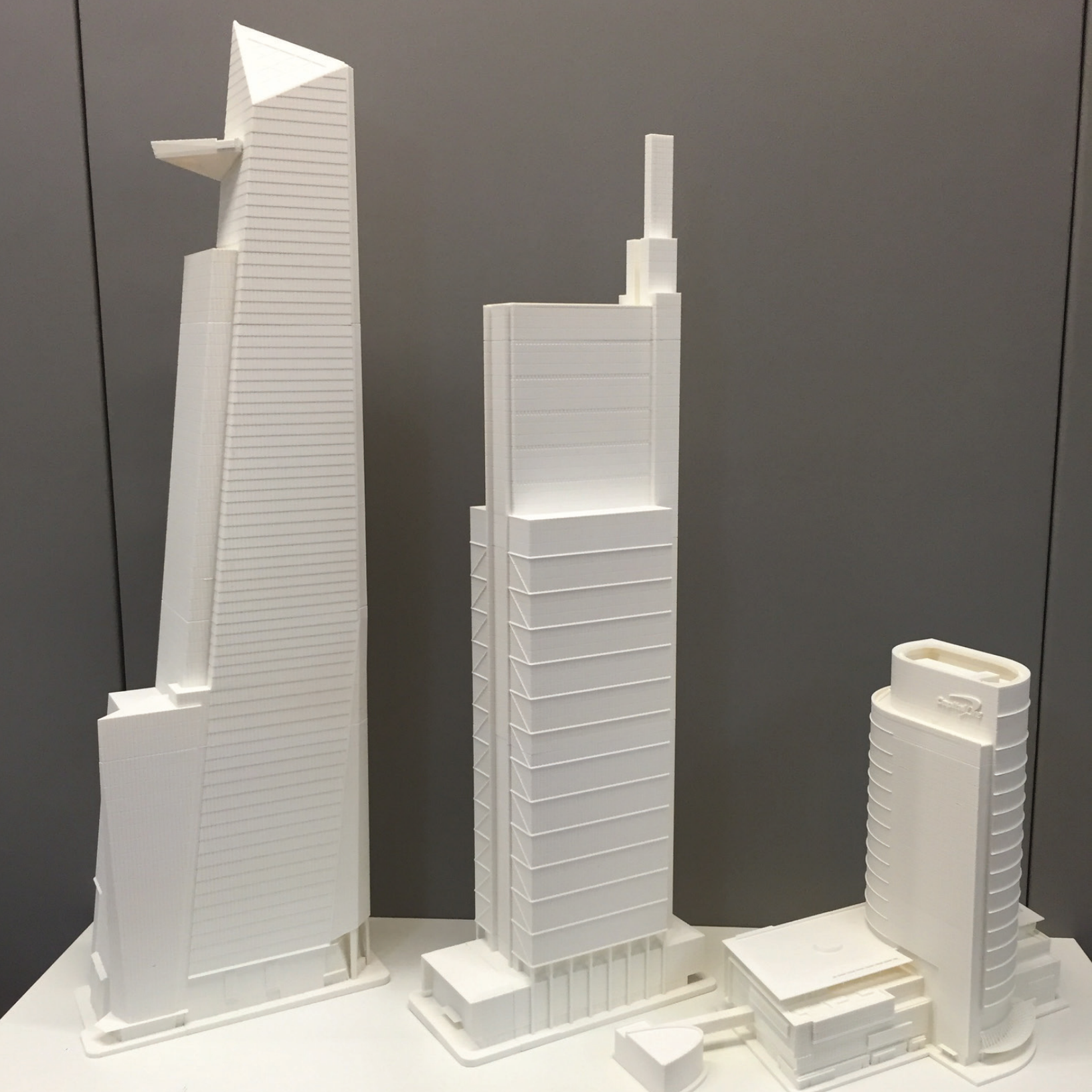


FIGURE 18
Augmented laser tracking tool.

FIGURE 19
Screen capture of 3D printed head anchor components (exploded).

FIGURE 20
Full scale 3D printed head anchor components (assembled).



WHOLE BUILDING SCALED MODELS

The geometry on 30 Hudson Yards (aka Tower A) is complex, which makes understanding and communicating the project challenging. As a result, Enclos' Operations team requested scaled models of the entire tower (Fig. 21). The models were easy reference for anyone not fully versed in the project. One model was color-coded with paint based on wall types. The other model was left white, the color it was printed, and labeled. Labels included floors and elevations, leave-out locations, unit module height portions and stack joint floor transitions, mechanical floors, and plenum locations. The models are also helpful for means and methods discussions involving crane picks, floor loading, and leave-out locations.

AN INVITATION

Understanding how to combine different processes takes expertise. While designers are responsible for having an in-depth knowledge of curtainwall, we rarely have to cope with the day to day issues on the job site. The challenges in engineering and operations present different opportunities. If you see an opportunity to integrate printed parts to achieve a difficult task, please reach out to us. We welcome industry collaborations because solving problems in the construction of curtainwall makes for smarter designers in the engineering of such systems.



FIGURE 21
3D printed whole building models of
30 Hudson Yards, Comcast Technology
Center, and Capital One Headquarters
Block B.