Additive Manufacturing for Production

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CONNECT & CONSTRUCT SUMMIT

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About the speaker

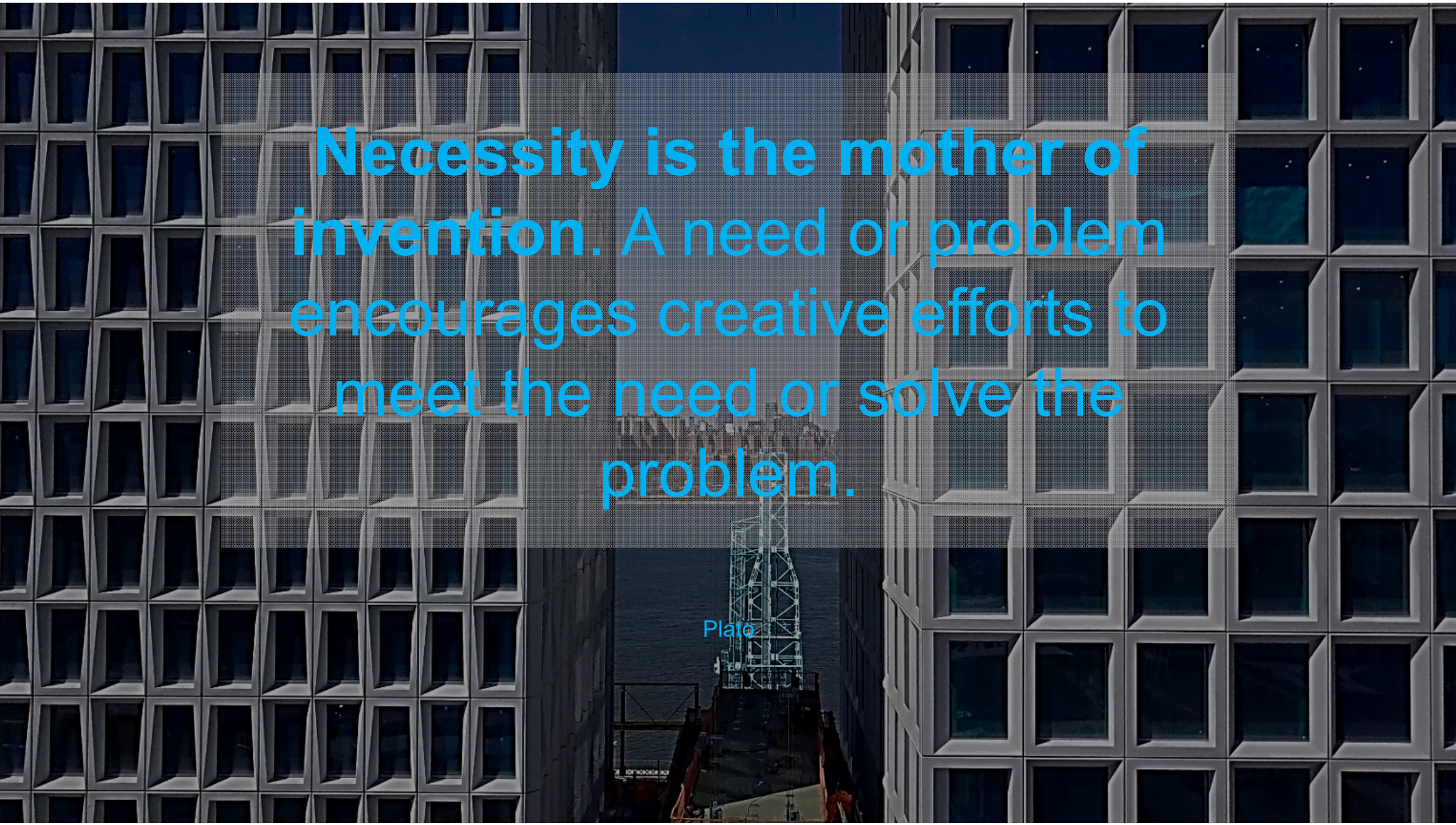
Nate Brooks – Gate Precast Company

As the BIM Managing Director at Gate Precast Company Nate Brooks brings almost 18 years of precast and detailing experience to the table. Daily working with a group of about 90 Engineers and Detailers to manage Gate's Standards, look for new technology and work on several R&D projects throughout the many departs and locations at Gate. Nate's experience with precast ranges from structural products to hollowcore and lastly at one of Gate's architectural plants. While working with all the different products I have had the pleasure of working in Production, the Field, Trucking, Finishing and Engineering.

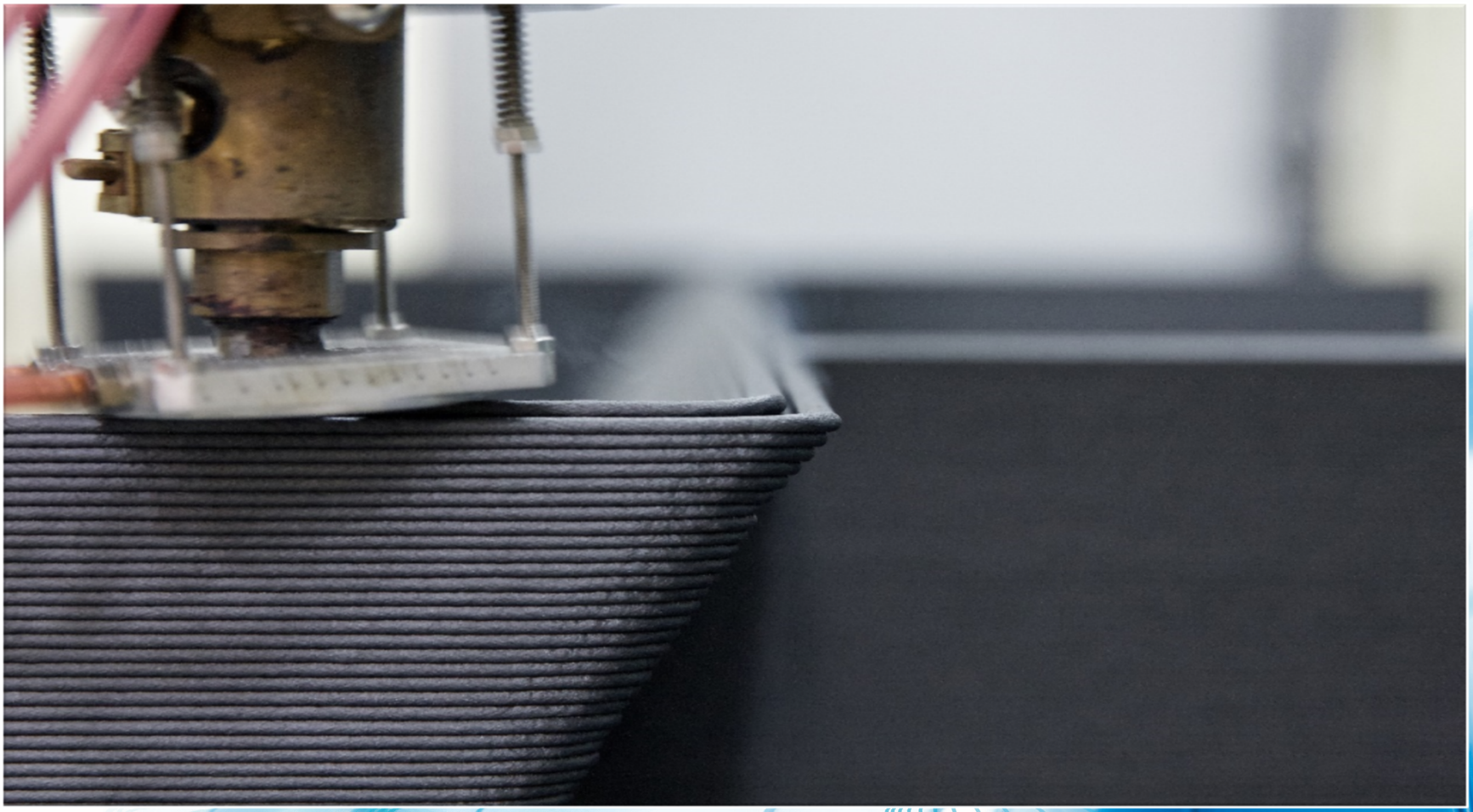
Course Description

Short version is we will show how we used our Revit models to create 3D printed molds.

This class covers the use of Revit to create 3D mold drawings that are used to produce large format 3D printed molds. Walking thru the process of going from conceptual design to production mold tickets then to program specific mold files with Revit and Inventor. We will demonstrate a real life project that went from a dream to reality on less than a year. Attendees will be able to see real world R&D project, the use of (and before) generative design and the affects in production on a project that now highlights the NY skyline.


Necessity is the mother of invention. A need or problem encourages creative efforts to meet the need or solve the problem.
Plato

How? With BAAM! Or LSAM!



How 3D printed became an option

OAK RIDGE NATIONAL LABORATORIES (ORNL)

An American multiprogram science and technology **national laboratory** sponsored by the U.S. Department of Energy (DOE) and administered, managed, and operated by UT–Battelle as a federally funded research and development center (FFRDC) under a contract with the DOE.

THAT PERFECT OPPORTUNITY

A 43 story mixed use revitalization project that utilized design assist between the owner/developer, architect and exterior subcontractors.

THE TEAM

An R&D team that was comprised of people with experience in sales, design, architecture, additive manufacturing & precast production.

3D PRINTING OF CONCRETE MOLDS

Additive manufacturing (AM), or 3D printing, consists of adding material layer by layer to produce the targeted final shape. In the early 1980s, AM processes were primarily used for rapid prototyping; that is, quickly "print" a part for rapid development of prototypes so these could be tested for form, fit, and function. In 2014, ORNL conducted evaluations in which it reinforced polymers for AM with carbon fiber (CF) to significantly improve the polymer properties (Love et al 2014)[1]. More specifically, ORNL selected acrylonitrile butadiene styrene (ABS) because it was widely used with 3D printers and reinforced the ABS with 13% CF. The carbon fiber altered in-plane properties of 3D-printed ABS; that is, it increased the strength and modulus of elasticity, reduced the coefficient of thermal expansion (CTE), and increased the thermal conductivity. The last two significantly improve geometric accuracy because they minimize thermal gradients that lead to distortions (e.g., curl and warp) in the printed part. This in turn made large-scale AM feasible, because cumbersome mechanisms to reduce thermal gradients, such as printing inside ovens, were no longer needed. Subsequently, ORNL collaborated with many industry partners to print large parts such as a Shelby Cobra[2], molds for wind turbines (Post et al 2017)[3], and a house and an electric vehicle (Biswas et al 2016)[4] among other projects (Figure 3).

Figure 3. 3D printed Shelby Cobra (right) and mold for wind turbine (left).

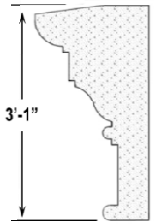


Figure 5

In 2015, ORNL and PCI were awarded funds to develop the next generation of precast insulated wall panels. A component of this project included evaluating the feasibility of printing molds for precast concrete because the precast industry was facing a shortage of skilled carpenters that could manufacture molds out of traditional materials such as plywood. PCI selected the cornice shown in Figure 5 as the design that it wanted to assess. Thermwood and TruDesign manufactured the prototype 12-inch deep mold shown in Figure 6 by printing ABS that was reinforced with 20% CF, and machining the "corduroy" finish with a computer numeric control (CNC) router. Figure 7 shows the final prototype mold and the quality of the smooth surfaces. Gate Precast cast more than 40 concrete parts with this mold (Figure 8) and determined ABS/CF to be a highly durable material.

Testing Molds

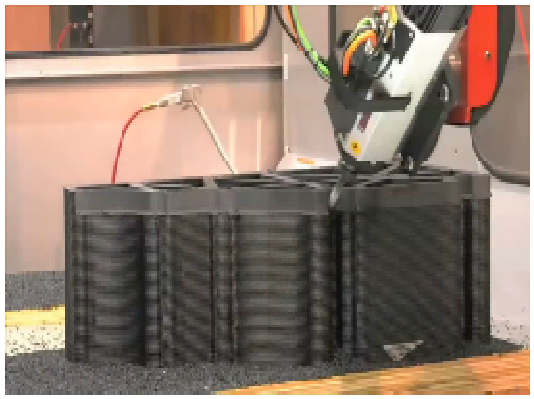
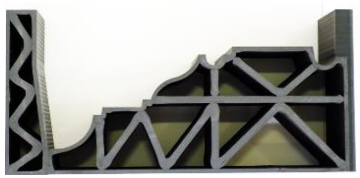
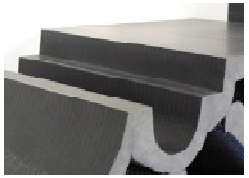


Figure 6. Left: printing of the two pieces needed for a prototype 12-inch deep cornice mold using ABS and 20% carbon fiber. Right: machining of the surface of the 3D printed mold to remove the “corduroy” surface with a CNC router.





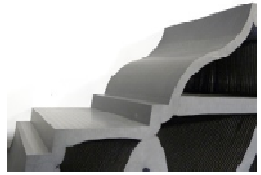


Figure 7. Prototype 12-inch deep cornice mold. Middle and right images illustrate the smooth surfaces, sharp angles, and tight radius that were achieved in the prototype mold.

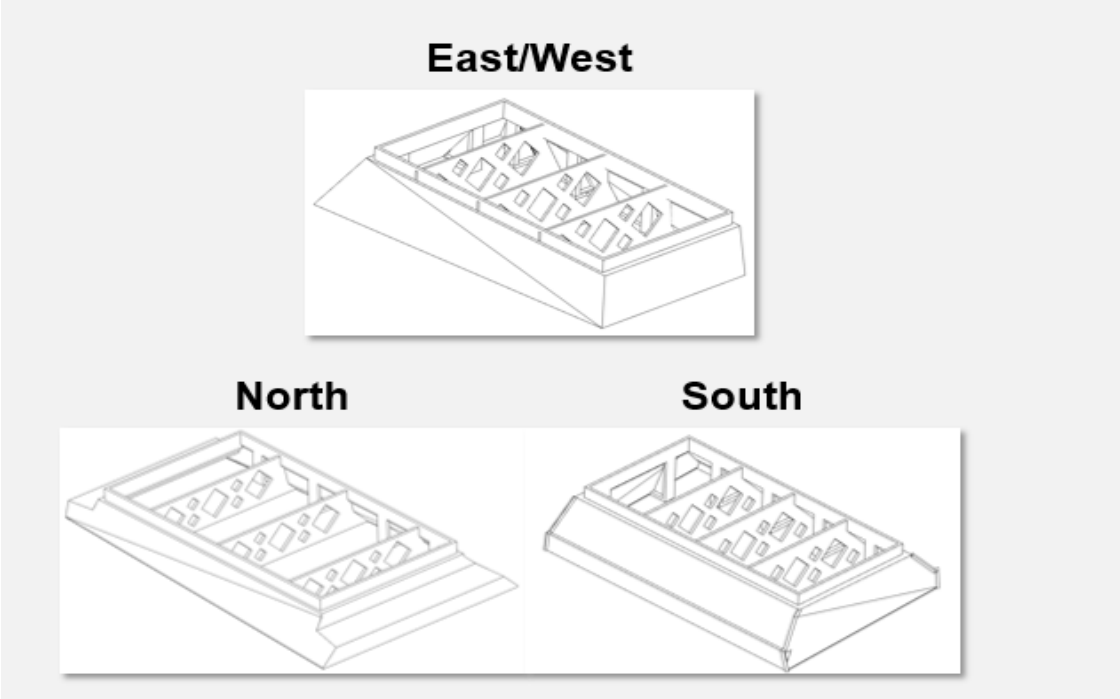
Figure 8. Precast cornice cast by Gate Precast using the prototype 12-inch deep cornice mold.

Our Goal

Determine if additive manufacturing was a viable concept for use in the precast manufacturing industry while building a project that required complex varying shapes.

AND oh yeah you only have 2 months to go from concept to full production!

- The project
  - 993 punch window units
  - Sugar cube design
  - Varying window sizes and floor to floor heights.



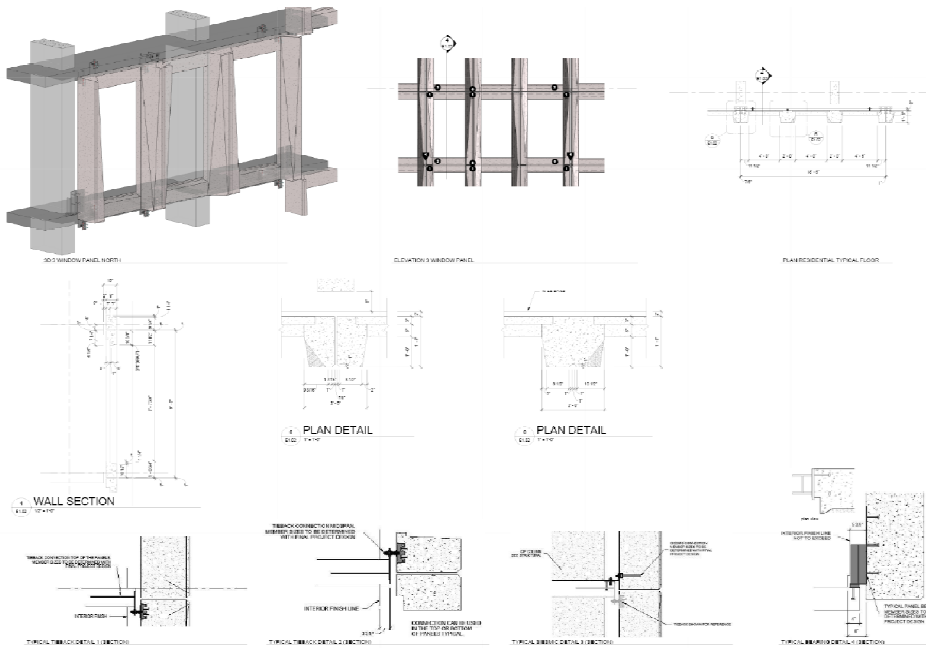
How to get the design “right”

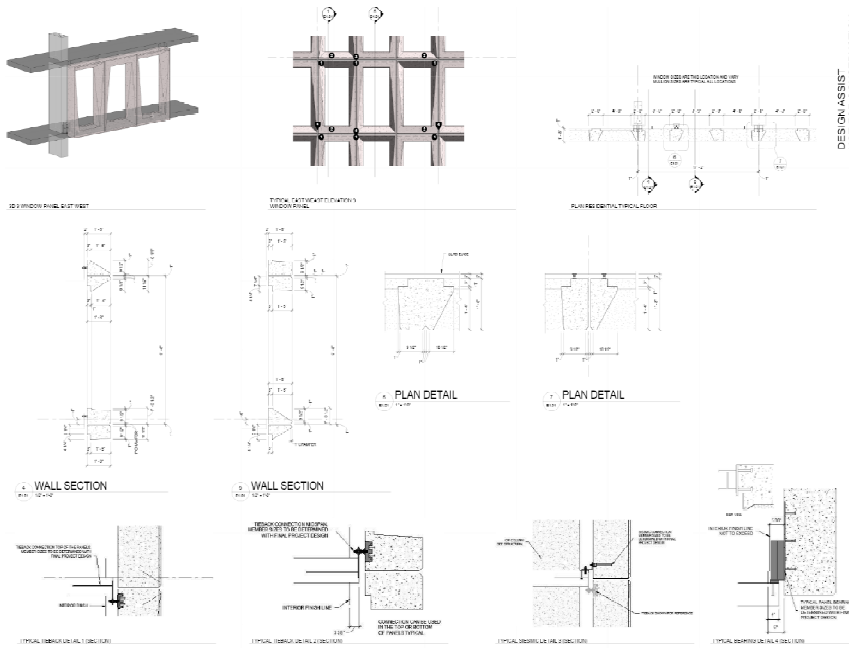
3D Printing has been around for quite a while BUT Large Scale Additive Manufacturing has not. A no one had tried to build a mold for concrete production of this magnitude before. Therefore, the R & D process needed to be very well thought out and painstakingly coordinated. When what we thought was a 3 month time schedule turned into just over a 2 month schedule we all knew there was a second to loose. Fortunately CNC technology had been around for a while and many ahead of us in that field had started to pave the way.

First we needed to get the mold quantity down to a manageable count and most importantly the molds had to be reused multiple times. This was achieved by making features in the molds that allowed them to be flipped 180 degrees and still work with the design, making common slopes on the North elevation and adjusting the south elevation’s pattern. The east and west elevations had the most opportunity for optimization since these walls were the largest and required the largest number of different molds due to varying window widths. Window widths varied by only a ½” or an inch in some instances, but still required separate molds. Working with the design team we were able to eliminate the over 100 mold times.

Spoiler alert!

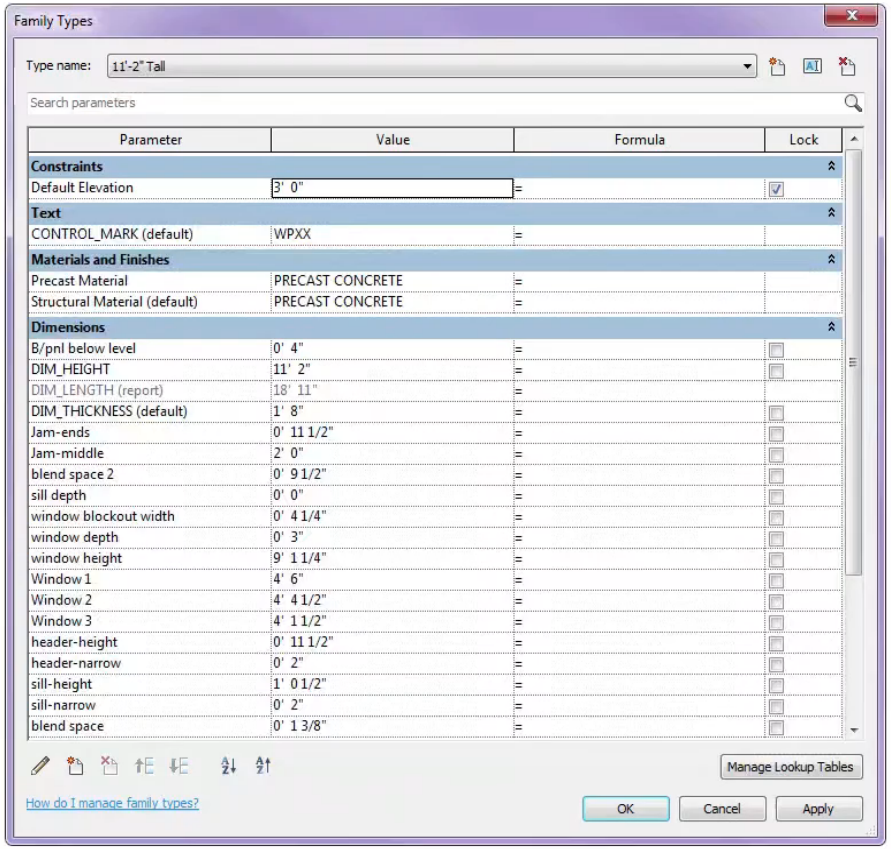
We were able to find 37 mold types that fit the bill for 3D printing mold materials. Allowing us to essentially cut over 2000 hours out of mold building. So we saved a carpenter crew 1 years worth of work.

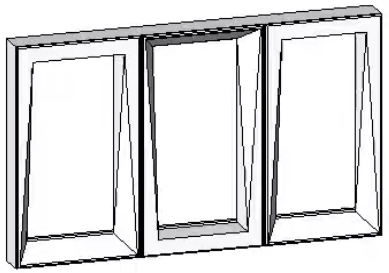


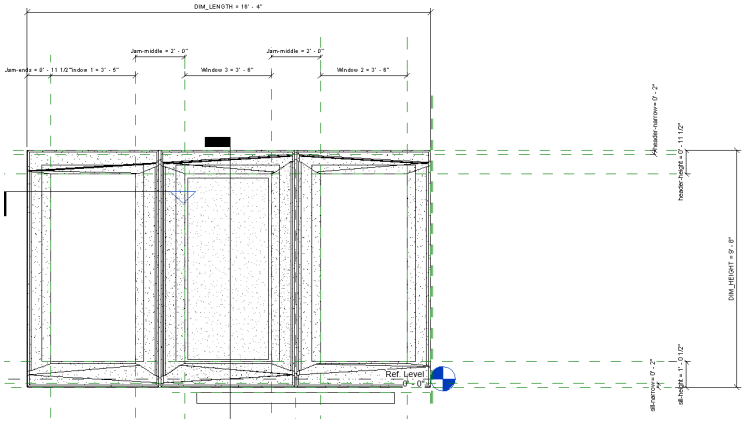


Design for production

We worked with the architect to build families that worked both with their model and with ours. The team built model families as the design took shape locking certain area and allowing others change as the overall size and design of the panels materialized. Working together thru Revit on the same platform and year was critical. Utilizing a team that was already using BIM (Revit) was the only way we could coordinate all of the trades and make changes on the fly meeting the extremely tight deadlines.

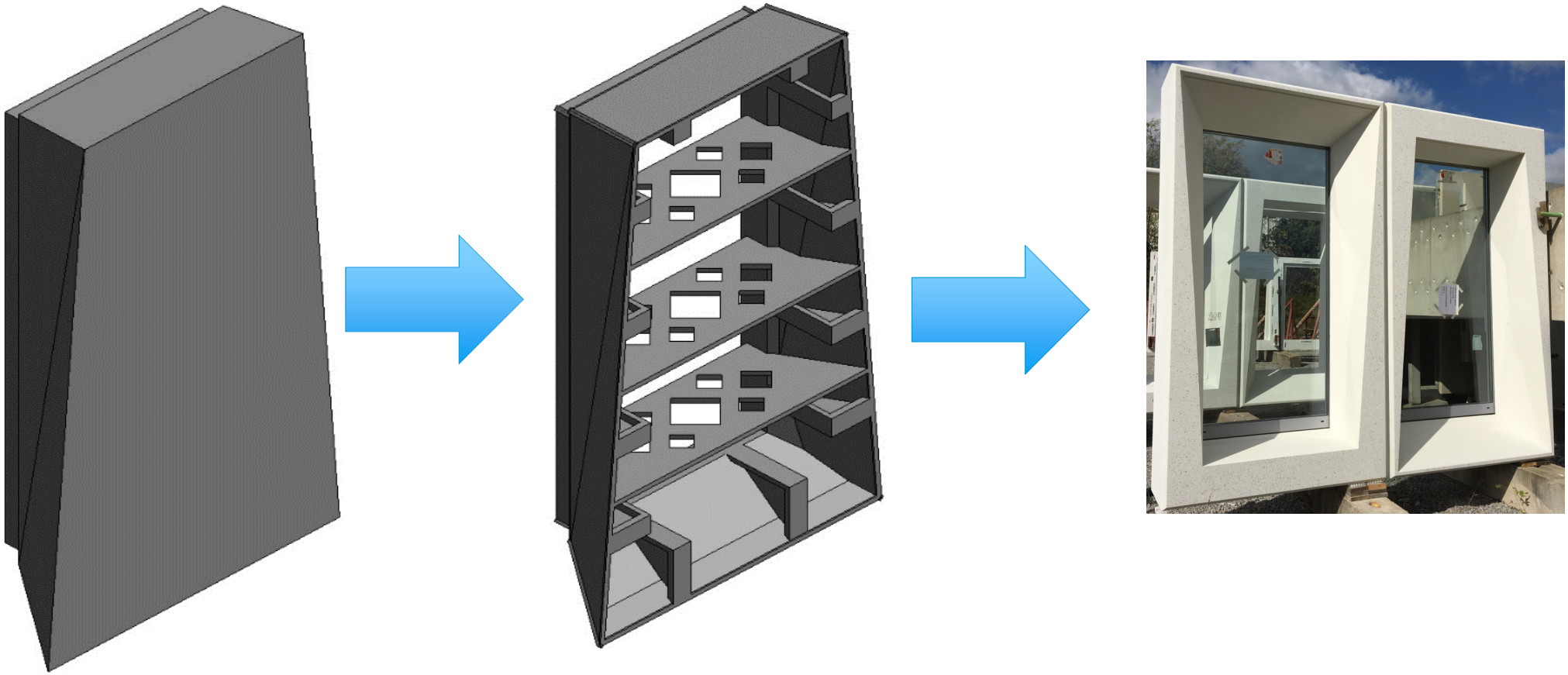






Adding Parameters

We added parameters to areas we thought and/or knew would be changing around the building and to the areas that would need to either change with before mentioned parameters to stay locked. Parameters are a great tool but you can over constrain the family very quickly.

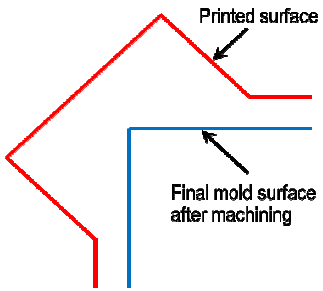


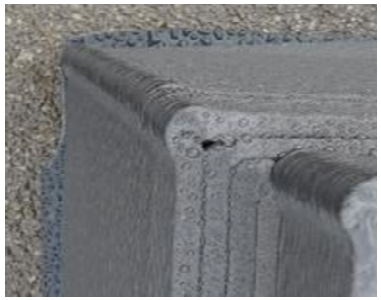
Using the Model

Starting from left to right – the void family used by the design team AND by the production team to convert into a mold model that has places to hold the mold onto the pad, mold vibrator mounts, and bracing moving to the final product at the far right.

Summary of steps for this project

1. What areas are you going to print. All, some most? What?
2. Create the model families that match the overall thickness of the panel
3. Use voids families (very important) to cut out the punch window systems with parameters to help constrain future panels
4. Copy the void families and convert the void family to a solid family. Save 2 copies of the solid family
   A. Print family
   B. Machine family
5. Coordinate with the Additive manufacture on what areas need extra thickness, overruns and what the maximum angle the printer can handle.
6. Copy the void and offset 1” inside, cut out the inside of the Machine mold model.
7. Add bracing and any other hold down areas to the machine mold model.
8. For the print version you need overruns in the corners, and a predetermined extra thickness that will be milled off.
9. The mold files are opened with Fusion and convert to STL files and sent to the printer specific slicer program.

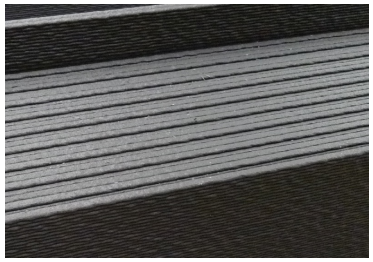


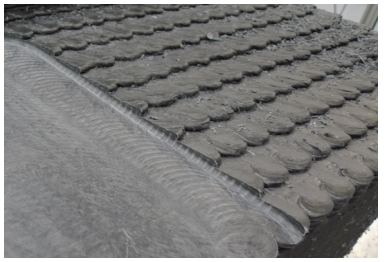


Findings

Printing Material

Horizontal Surfaces

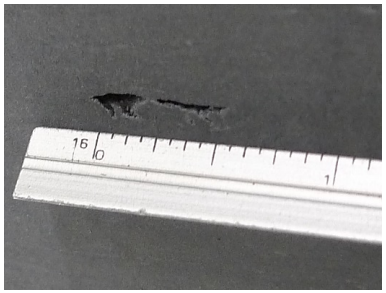




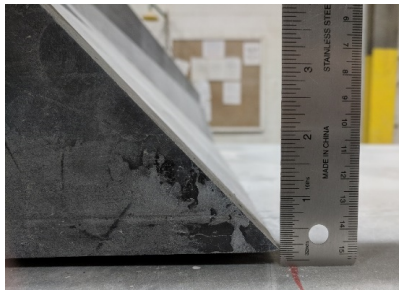
Printing pattern that decreases underfilling and voids

Warping

Nozzle/Bead Size

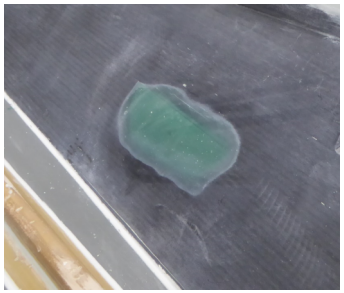


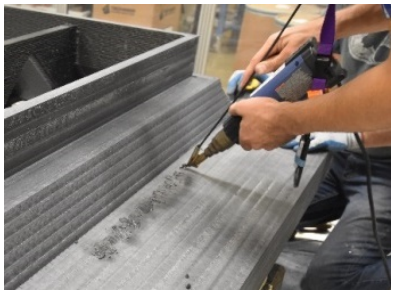
0.4” nozzle, 0.5” bead



Overprint and machine

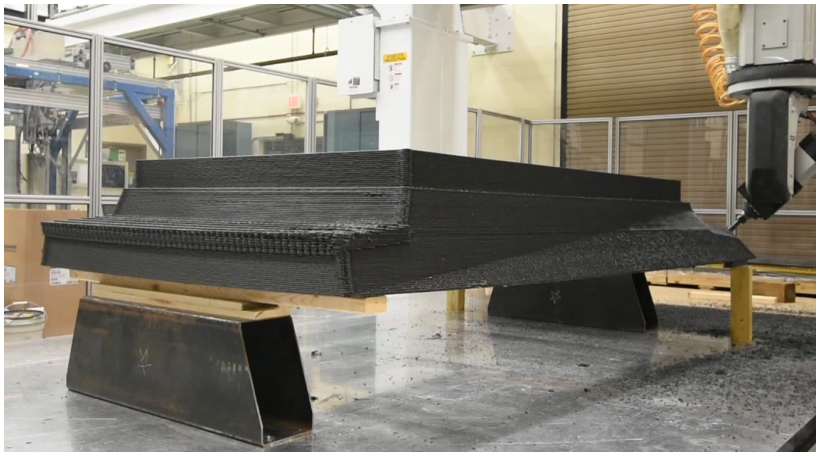
Repairs at Precast Plant

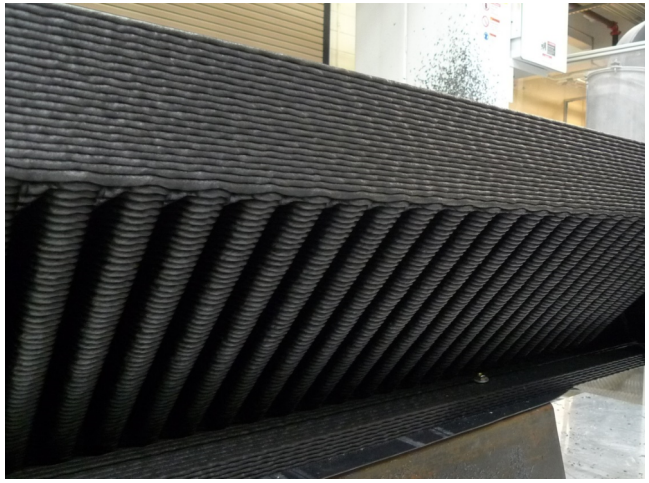




Bondo or plastic welding gun

Creating the mold

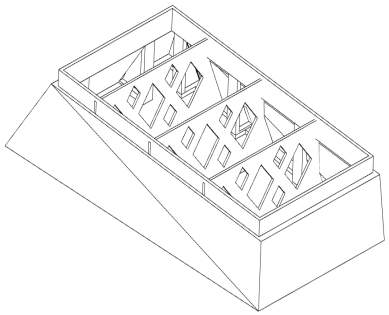




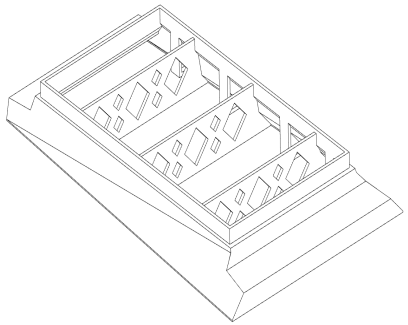
Summary of 3D Printed Molds

Parameter	East/West	North	South
Size	5’-9” × 8’-8” × 1’-4”	5’-9” × 9’-8” × 0’-10”	5’-9” × 9’-0” × 1’-4”
Printed material (lb)	540	450	610
Printing time (h)	~8	~8	~8.5
Machining time (h)	~6	~7	~7

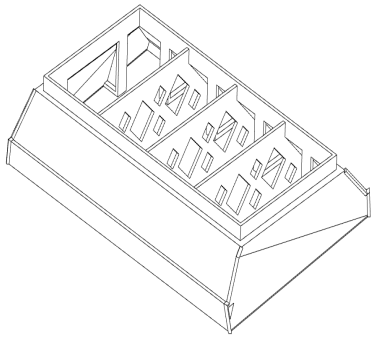
East/West



North



South



CONCLUSIONS:

Additional benefits of Additive Manufacturing over wood forms:

- Faster Production of Molds
- Molds can be printed off site and not disrupt production area
- Crisper edges
- Better vibration to consolidate the concrete leaving minimal bug holes in the finished concrete and less repair work
- Better suited for today's younger generation, technology-savvy workforce

Areas where Additive Manufacturing can be cost effective:

- On highly repetitive, relatively simple shapes where the expense of steel forms cannot be justified.
- On complex forms where repetition is higher than what you'd normally get from wood molds, i.e. Domino.
- On highly ornate shapes where a precaster cannot afford to tie up master mold builders for minimal concrete volume.

Acknowledgments & References

1. Diana Hun – Oak Ridge Nation Laboratories – Documentation and research
   A. In collaboration with Lonnie Love & Brian Post also of ORNL
2. Mo Wright – Gate Precast Company - Domino photos
3. Steve Brock – Gate Precast Company - Engineering and design documentation
4. Russ Vines – Gate Precast Company - Engineering and design documentation

1. Love L, Kunc V, Rios O, Duty C, Elliott A, Post B, Smith R. 2014. The importance of carbon fiber to polymer additive manufacturing. J Mater. Res. 29(17):1893-1898.
2. https://www.energy.gov/eere/amo/3d-printed-shelby-cobra
3. Post B, Richardson B, Lloyd P, Love L, Nolet S, (TPI), Hannan J. 2017. Additive Manufacturing of Wind Turbine Molds. CRADA NFE-16-06051. ORNL/TM-2017/290
4. Biswas K, Lind RF, Post BK, Jackson RK, Love L, et al. 2016. Big Area Additive Manufacturing Applied To Buildings. Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference. Clearwater, FL.
5. https://en.wikiquote.org/wiki/Donald_Rumsfeld
6. ACI Committee 224. 2001. Control of Cracking in Concrete Structures. ACI Committee 224-01, May 16, 2001, pp 17-21
7. PCI Design Handbook Precast and Prestressed Concrete, Eight Edition, 2017, p 8-9
8. Love L, Post B, Roschli A, Chesser P 2017. Manufacturing Demonstration Facility: Gate Precast Phase 1. ORNL/TM-2017/468

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