Technique enables mass production of custom concrete building components from digital designs

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Researchers in Georgia Tech's College of Architecture are helping automate the process of turning CAD designs into manufactured products. Here, professor Tristan Al-Haddad and undergraduate students Sam Kim and Patrick di Rito are evaluating custom wall structures manufactured using a new process. Credit: Georgia Tech Photo: Gary Meek

Like other professionals, architects have used computer-aided design (CAD) software in their work for decades. Typically, the resulting digital files are converted to hard-copy plans, which are then used to support traditional construction practices.

Researchers in the College of Architecture at the Georgia Institute of Technology are now automating some of the processes by which computer-based designs are turned into real world entities. They're developing techniques that fabricate building elements directly from digital designs, allowing custom concrete components to be manufactured rapidly and at low cost.

"We're developing the research and the protocols to manufacture high-end customized architectural products economically, safely and with environmental responsibility," said Tristan Al-Haddad, an assistant professor in the College of Architecture who is a leader in this effort. "We think this work offers opportunities for architectural creativity at a new level and with tremendously increased efficiency."

- In one recent project, Al-Haddad and a College of Architecture team collaborated with Lafarge North America to fabricate an award-winning building-element concept called a "Liquid Wall." The Georgia Tech team employed digital techniques to help construct a prototype wall, using ultra high-performance concrete; the result was displayed by the New York Chapter of the American Institute of Architects (AIANY) in the "Innovate:Integrate" exhibition.
- In another Lafarge-sponsored project, Al-Haddad and a College of Architecture team are developing a complete free-standing structure using ultra high-performance concrete elements fabricated directly from digital designs.

The Liquid Wall, originated by Peter Arbour of Paris-based RFR Consulting Engineers, won the 2010 Open Call for Innovative Curtain-Wall Design competition conducted by the AIA. The concept advanced a novel approach to curtain walls, which are building coverings that keep out weather but are non-structural and lightweight.

RFR's plans called for the Liquid Wall to be constructed of stainless steel and Ductal®, a light and strong ultra-high-performance concrete

(UHPC) that is produced by Lafarge. Moreover, the new building enclosure was conceived as an entire system, including integrated louver systems, solar shading, integrated passive solar collectors and other advanced features.

Tristan Al-Haddad, left, assistant professor in the Georgia Tech College of Architecture, and College of Architecture research scientist Karl Brohammer, examine architectural cladding prototypes that have been digitally fabricated using ultra-high-performance concrete. Credit: Georgia Tech Photo: Gary Meek

Georgia Tech became involved in the Liquid Wall project when RFR decided to built a full-scale prototype of the complex concept. RFR asked Al-Haddad to help turn Arbour's original parametric sketches into a manufacturable design.

Supported by the College of Architecture's Digital Building and Digital Fabrication laboratories, the researchers refined the geometry of the original sketches for manufacturability and developed the techniques required for fabricating a full-size curtain wall.

Then, working from their digital models and using a five-axis CNC router – a device capable of machining material directly from a digital design – the Georgia Tech team milled a full-scale model of the wall. The model was made from a lightweight polymer material, expanded polystyrene (EPS) closed-cell foam, which was then given a polyurea coating.

The digitally milled foam model created an exact replica – a positive -- of the final wall. The lightweight positive could then be used to produce a negative capable of forming the actual prototype. In this case, the collaborators used the positive to produce a rubber mold – the negative – from which the final wall was cast.

The foam positive was shipped to Coreslab Structures Inc., a large corporation that specializes in industrial-scale casting. The Georgia Tech team then worked with Coreslab to identify the best techniques for creating the rubber mold and for pouring in Ductal to form the concrete wall.

"It was a very collaborative process – the four major players were Peter Arbour and RFR, Georgia Tech, Coreslab and Lafarge," Al-Haddad said. "And we had all of three weeks to finish the work before the exhibition deadline – so it was pretty intense."

Other College of Architecture people involved in the collaboration included graduate student Andres Cavieres, associate professor Russell Gentry and professor Charles Eastman, director of the Digital Building Laboratory. The resulting full-size Liquid Wall prototype was installed at the Center for Architecture in New York City as part of the AIANY's "Innovate: Integrate" exhibition, and was on view for several months in 2010 and 2011.

The Liquid Wall project was challenging, said Eastman, who holds joint appointments in the College of Architecture and the College of Computing. The process involved not only producing rubber negatives using wall-form designs created with CAD and parametric-modeling software, but also required identifying the right production procedures and finding effective ways of installing a completed full-size wall on a building.

"When you're creating a completely new process like the Liquid Wall, you're faced with developing a whole new manufacturing process for this kind of material," Eastman said.

A future project, expected to be about 20 by 20 feet square and 15 feet high, will be built using Ductal UHPC, principally or entirely. A central technical challenge will involve molding the many custom elements so that all edges fit together and form a structure that is stable, practical and esthetically pleasing.

"We understand the structural side of a project like this quite well -- the difficulty comes in the actual manufacturing of the elements," Al-Haddad said. "We want to advance the use of digital parametric models with custom molding systems, and create a free-form manufacturing system that can produce many variations quickly and accurately."

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