Tools for architecture

by Charles Overy

The architecture, engineering, and construction market (A/E/C) has not been immune to the tremendous media storm surrounding 3D printing in the recent past. The spotlight has been on both large-scale applications of 3D printing as well as new machines to make models and prototypes. However, despite the attention, the fundamentals in the marketplace have not changed substantially over previous years. Challenges, opportunities, and potential growth exist for old and new players in this market segment.

There have been several interesting projects where large AM machines have been used to make walls, small dwellings, and even full-sized residential buildings. The most promising class of machines uses an extruded low-slump concrete to create objects in a manner very similar to the way FDM, RepRap, and derivative machines use thermoplastic filament. Innovation in the construction industry has traditionally been hampered by the need for new products and methods to meet a diverse set of local building codes and regulations. The benefit of low-slump concrete is that the material properties are well understood in slip form and formless concrete construction, which are used for structures like large towers and curbing. New dispensing methods will necessitate review of structural and durability characteristics. Also, adoption on a wide scale will depend on the new processes meeting building code testing and certifications. As a result, these developments, while intriguing, currently have limited applicability. Full-sized 3D printing applications will continue to challenge the boundaries of what is possible. However, in the near future, they will not have a substantial impact on either the A/E/C industry or the AM industry.

Several construction engineering firms are also experimenting with the use of AM technologies to create either aesthetic or structural building components. A notable announcement in 2014 was Arup's redesign and 3D printing of a complex structural bridge "node." Given the increasing complexity of many high-profile architectural designs, the ability to customize large numbers of complex components holds tremendous promise. The challenges in this market include building code certification and cost. Construction design companies will have difficulty getting production costs down to a point where AM can compete with traditional manufacturing.

Most likely, near-term success in this market will not be driven by AM technologies that create final objects. Success will come by supplying machines that create a competitive advantage to traditional foundries and casting operations. The use of AM to directly create casting molds has had its ups and downs in the past 15 years, with machine size, reliability, and cost all creating challenges. Some foundries use older Z Corp. equipment with 3D Systems or aftermarket materials to fill this niche. ExOne and other machine manufacturers are looking to take advantage of this opportunity, but must insure that their offerings make competitive economic sense for mainstream adoption.

AM technologies continue to have an immediate impact on architectural design visualization. The fabrication of architectural models is a mature industry and AM has a successful history creating scaled models and parts for scaled models. This activity takes place inside A/E/C firms as well as in specialized shops. Physical models in A/E/C are an accepted and in some cases required method of design communication.

Emaar Square by Nelsen Partners; model by LGM, courtesy of LGM

Architectural modeling is quite different from other applications for AM, and has its own array of unique challenges. In A/E/C, appearance matters much more than mechanical properties. Models are scaled representations, yet still tend to be large—traditionally 500 x 1,000 mm (19 x 39 inches). Buildings are not the single solid objects that are optimal for AM production workflows. 3D prints used for visualization and iteration typically have a very short lifespan. Architects usually make only one final model, but if costs were lower, they would also use the technology more frequently to iterate designs.

Traditionally, relatively large model sizes and resulting high material costs have led architects to favor systems with large build volumes and lower overall operating costs. 3D Systems' ProJet x60 machines, which employ the binder jetting process originally developed by Z Corp., are particularly useful at the conceptual design stage, when innovative forms are being explored. These machines have been used for a number of years by leading firms including Foster + Partners and Morphosis, as well as our own firm, LGM.

If Multi Jet Fusion is priced appropriately, HP stands to make substantial and rapid inroads with their new machines. HP already has the marketing and distribution in place to reach A/E/C customers because of its long history as a plotter supplier. To be successful, though, the machine must have a larger build envelope and a significantly lower total cost per part than 3D Systems' ProJet 4500.

ProJet x60 parts have a grainy appearance and are incapable of showing ultra-fine detail at scales of 1:500 or smaller. For this reason, other technologies have gained acceptance, particularly the Objet and ProJet material jetting machines. One primary drawback of jetted photopolymer systems is the high cost of materials on large models.

AM technologies that use support structures that must be physically removed from the model have been less popular. Manual post-processing labor is required on complex overhangs. However, new support strategies are substantially improving these processes. They include 3D Systems' ultra-fine supports in the high-end SLA systems and more widely available branching support algorithms for small SLA systems.

The Stratasys FDM material extrusion systems initially sold well into A/E/C, but failed to take hold. The primary barriers to acceptance are the long build times for large parts and aesthetics that are better suited for industrial parts, rather than artistic forms.

Laser sintering (LS) and laser-based vat photopolymerization systems are attractive for A/E/C applications primarily because of material durability and accuracy. However, machine cost puts these systems out of reach for all but a few large architecture firms. Large service providers are able to compete because of their technical expertise and efficient cost structure. Shapeways' low cost and improved delivery schedule makes it attractive for some applications and projects.

A/E/C users are in a rush to buy and understand the new RepRap derivative extrusion machines and the smaller DLP-type vat photopolymer machines like Formlab's Form 1 and Autodesk's Ember. These machines will be successful at introducing a wide range of architecture firms to the benefits of AM as a design validation and communication tool. However, the capabilities of these machines to rapidly serve architecture firms' needs have been oversold. Some method of support for overhanging geometry is a necessity for reliable builds in A/E/C projects. To use these machines successfully, firms and individuals must develop skills in data preparation and other AM competencies. Our company is seeing some fallout from unsuccessful adoption of low-cost machines by our customers. We believe there is a new market opportunity to sell firms a second printer that uses well-generated or non-contact supports and produces robust, high-quality output.

Waldorf Astoria Hotel models for Bowman Consulting; data processing and models by LGM, courtesy of LGM

The CAD input for 3D printing in A/E/C continues to improve, but challenges remain. Most firms are now using 3D CAD software. Autodesk Revit is fast becoming the U.S. standard for large projects. Other parametric and database-driven CAD programs, known in A/E/C as building information modeling (BIM), include Bentley MicroStation and Nemetschek Vectorworks. Smaller firms tend toward less expensive, non-parametric CAD products such as Rhino and SketchUp. Google Earth and the widespread availability of other geospatial data are also transforming the methods by which the built environment is planned and visualized. This data and its ease of use are both an opportunity and a threat to the AM market.

The fact that A/E/C models are scaled representations of very large and complex structures creates significant data challenges. The print processing software for AM machines requires very good triangular mesh data to successfully build a part. A/E/C data typically consists of hundreds (or in the case of Revit data, tens of thousands) of discrete objects or shells. Boolean operations with high shell counts and many coplanar or nearly coplanar surfaces rarely result in useable data. This problem has not been addressed well, and few industry-specific solutions have emerged. Geometry modification and repair tools such as Materialise Magics or Netfabb Professional are a necessity for any serious investment in AM by an A/E/C firm. The integration of new tools into programs like Rhino offer promise, but fast and robust repurposing of A/E/C CAD for AM remains a stumbling block.

The outlook for increased A/E/C adoption of 3D printing technologies is strong. Long-term market opportunities exist for the fabrication of full-scale building components for companies that can disrupt the current cost model on high-volume objects. In visualization, the production of scale models is a proven market that has challenges, but is largely open to new participants with the right offering.