Applications in architecture and construction

by Charles Overy

There are three broad categories of additive manufacturing applications in the built environment. At the macro scale, experiments with 3D printing full-scale buildings are underway. At an intermediate level, AM is providing a benefit for a variety of structural components. Meanwhile, the fabrication of small-scale visualization models using a wide variety of AM machinery is a mature industry.

Several interesting recent projects used large AM machines to make walls, small dwellings, and even full-sized residential buildings. The most promising class of machines for this application uses an extruded low-slump concrete to create objects in a manner very similar to the way material extrusion machines use thermoplastic filament. A diverse set of local building codes and regulation must be met for innovation in the construction industry. This has traditionally hampered for the development of new products and methods. The advantage of low-slump concrete is that its 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 applications.

The pace of experimentation with the fabrication of complete buildings slowed in 2015. However, an application that received a great deal of attention was MX3D's use of robotic wire-fed welding to create extruded metal objects. The rough metal shape is extruded, full scale, without supports into open air. The metal deposition is relatively poor quality and difficult to control, however. Full-sized 3D printing applications will continue to challenge the boundaries of what is possible. In the near future, they will not have a substantial impact on the architecture, engineering, and construction (A/E/C) industry or the AM industry.

Of greater near-term commercial interest is the use of AM to create innovative and unique parts for buildings. Several construction engineering firms are experimenting with the use of AM to create either aesthetic or structural building components. A notable example is announcement in 2014 was Arup's redesigned, 3D-printedcomplex structural bridge "nodes," which ara support terminators. Given the increasing complexity of many high-profile architectural designs, the ability to customize large numbers of complex parts holds great promise. The challenges for this application in A/E/C 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.

Near-term success in this market will probably 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. Machine size, reliability, and cost have all created challenges. Some foundries use older Z Corp. binder jetting 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.

Structural study for Arup; 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 since 2000 by leading firms including Foster + Partners and Morphosis, as well as our firm LGM.

If HP's Multi Jet Fusion is priced appropriately, the company stands to make substantial and rapid inroads with its 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 volume and a significantly lower total cost per part than 3D Systems' ProJet 4500. Surface finish and a clean white model will be more important than durability for A/E/C users.

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 some popularity, particularly the Stratasys PolyJet and 3D Systems 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 can be problematic. 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 vat photopolymer systems.

The Stratasys FDM systems initially sold well into A/E/C. The primary barriers to acceptance are 1) the long build times for large parts and 2) aesthetics that are better suited for industrial parts, rather than artistic forms. FDM machines do provide a good next step for customers looking for higher quality but relatively low-cost A/E/C parts.

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.

Many new A/E/C users are experimenting with the low-cost desktop material extrusion machines and the smaller DLP-type vat photopolymer systems. These machines are very useful for new entrants to gain an understanding of AM and the unique A/E/C workflow challenges. 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 has seen some fallout from unsuccessful adoption of low-cost machines by customers. We believe a new market opportunity exists for a second printer at these companies that uses well-generated or non-contact supports and produces robust, high-quality output.

Model of residential tower in New York City for real estate sales; model by LGM, courtesy of LGM

The use of color in A/E/C visualization may be reaching a turning point in 2016. A variety of factors are driving this, including the maturity and low-cost of the 3D Systems powder process, faster computing, and more robust workflows. The paper-based Mcor printers are adding some impetus to this drive, but the small build volume and slow build times make it difficult to adopt for any volume use. The imminent arrival of a true full-color photopolymer printer from Stratasys, 3D Systems, or HP will have a significant impact. If the price is even higher than the current offerings, however, the use in A/E/C will likely be limited.

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 but also one with a large number of established participants.