Applications in architecture and construction

by Charles Overy

Additive manufacturing applications related to architecture and construction saw growth in 2016. At the macroscale, 3D printing of full-scale buildings began to move out of the laboratory and into early stage commercialization. Fixtures (e.g., components of buildings) also saw commercial experimentation from large companies. Scale modeling for visualization gained interest from both software and hardware vendors.

Several AM methods are currently being pursued to manufacture walls, small dwellings, and even full-size residential buildings. The most promising machines for this application extrude low-slump concrete to create objects in a similar manner to polymer material extrusion systems, but at a dramatically larger scale. A wide range of local building codes and regulations must be met before innovation in the construction industry can succeed. This has often hampered the development of new products and methods. The advantage of low-slump concrete is that its material properties are well understood from its conventional use in large towers and other construction elements. New dispensing methods will require a review of structural and durability characteristics. Also, adoption on a wide scale will depend on the new processes meeting building code testing and certifications.

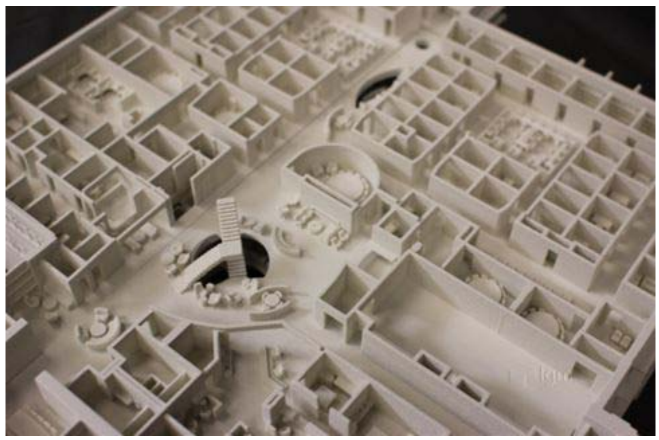
The construction industry faces substantial regulatory hurdles and market challenges, but companies continue to enter the concrete extrusion market. The Chinese company WinSun has demonstrated the use of large-scale Cartesian coordinate machines to extrude concrete to produce complete buildings. The WASP company from Italy focusing on a delta platform configuration and has machines that range from desktop size to 12 m (about 33 ft) in height. San Francisco startup Apis Cor uses a central axis gantry system to print from the inside of the structure, reducing the machine size and setup time.

Concrete extrusion of full-scale buildings attracts attention and will continue to challenge the boundaries of what is possible. However, in the near future, it will not have a substantial impact on the architecture, engineering, and construction (A/E/C) industry. Companies have realized that fabrication of building components may represent a simpler and more practical near-term market. WASP and WinSun have demonstrated the use of low-slump concrete to construct lightweight beams that can be used in more traditional construction.

The most promising A/E/C commercial AM applications come from the improvement of traditional techniques and product development workflows for building components. Innovative industries such as residential and commercial lighting, plumbing fixtures, and heating and air conditioning manufacturers now routinely use AM as part of their industrial design workflows. Additive manufacturing of end-use products becomes increasingly feasible as more machines with larger build envelopes, greater reliability, and lower costs come to market. A notable event in 2016 was a six-month trial by building supply giant Lowes of its Bespoke Designs website and New York retail store. Lowes provided a limited stock of designs that could be made custom and 3D printed in plastic. The company also partnered with ExOne to create a range of custom metal drawer pulls that can be designed and ordered online.

Despite more experimentation, acceptance of end-use products is still limited as AM production costs for larger objects cannot compete with traditional manufacturing. Near-term success in A/E/C will not be driven by using AM for end-use products but by developing machines that create a competitive advantage over traditional operations.

AM technologies continue to have a significant impact on architectural design visualization. The use of AM in the production of scaled architectural models is now a mature industry. In 2016, many regions experienced considerable growth in both residential and commercial construction. Strong demand has provided many architectural offices and design-build contractors with sufficient capital to explore new technologies. As a result, companies that were previously outsourcing 3D printing as a design tool are now acquiring low-cost or mid-range machines.



Interior space planning model for Bennett Wagner Grody Architects, courtesy of LGM

Architectural modeling has unique challenges and model appearance matters much more than mechanical properties. Models are scaled representations, but still tend to be large—traditionally 0.5 x 1.0 m (19 x 39 inches). Buildings are not the single solid objects that are optimal for AM production workflows. AM models 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 probably use the technology more frequently to iterate designs.

Large model sizes and resulting high material costs have typically led architects to favor systems with large build volumes and lower overall operating costs. The recent widespread availability of polymer material extrusion systems means that more architectural models are being made with this type of system. However, material extrusion technology is not ideal for this application. Powder bed fusion systems are more compatible with A/E/C printing requirements and binder jetting technology is particularly useful. These systems have been used since 2000 by several companies including Foster + Partners, Morphosis, and LGM.

Large planning model at 25.4 mm = 4.9 m (1 inch = 16 ft) scale, printed on ProJet x60 from 3D Systems, courtesy of LGM

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. The ProJet MJP 2500 series machine based on material jetting technology is a good fit for many applications. One primary drawback of using jetted photopolymer systems for large models is the high cost of materials.

HP, with its first-generation Multi Jet Fusion system, has the marketing and distribution in place to reach A/E/C customers because of its long history as a plotter supplier. However, the current HP system may not be targeted at the architectural office. Currently, the parts are only offered in black and the system is better suited to large-scale industrial applications.

Stratasys' material extrusion 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 to industrial parts, rather than artistic forms. Professional model shop Zoyes East in Detroit used Stratasys' online AM service to rapidly fabricate large numbers of scale buildings on a tight deadline. The availability of substantial fabrication capacity using Internet tools is a transformative development.

Laser-based powder bed fusion and vat photopolymerization systems are attractive for A/E/C applications because of material durability and dimensional accuracy. However, machine cost puts these systems out of reach for all but a few large architectural 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 its service attractive for some applications and projects.

Roof studies for Miami Dolphins stadium designed by 360 Architecture/HOK, courtesy of LGM

A/E/C users continue to experiment 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. When selecting a low-cost machine, it is important to note that some method of support for overhanging features is required for reliable builds. Low-cost but relatively robust dual-extruder machines, such as the Ultimaker 3, offer wash-away supports that were previously only available from Stratasys.

To use AM machines successfully, firms and individuals must develop skills in data preparation and other related competencies. Unsuccessful adoption of low-cost machines can be caused by a lack of investment in the resources needed to develop new workflows. It can also be the result of inflated expectations for what a low cost machine can deliver. There is a significant opportunity to serve the mid-range market with professional-grade machines in the $20,000 to $90,000 price bracket. However, material costs cannot exceed that of binder jetting systems.

Color AM for A/E/C visualization is still moving slowly, despite advances in 2016. The demand for full color is strong, but the cost and difficulty of achieving good results is limiting applications. Material extrusion machines that use different colors of filament do not provide the resolution necessary for most A/E/C applications. Mcor sheet lamination machines are useful in some applications but support material removal can be problematic with complex shapes and features. The Stratasys J750 full-color material jetting system should be useful for architectural visualization. However, the high volumetric price and new requirements for color data may contribute to slower than expected adoption. As a result, color binder jetting systems (for example, the ProJet x60 from 3D Systems) remain the only widely used color system in architectural visualization.

Color 3D-printed model of a multi-family residential project, printed on a ProJet 660 from 3D Systems, courtesy of LGM

The CAD data input route for 3D printing in A/E/C continues to improve. Autodesk Revit is fast becoming the U.S. standard for large projects. Other parametric and database-driven CAD software, 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. A/E/C models are scaled representations of very large and complex structures, resulting in significant data challenges. Despite improvements in CAD, it is not yet possible to 3D print most scaled architectural models directly from CAD. You cannot print the same way you can with most mechanical parts. The industry standard workflow for architectural models is to export the data in a mesh format and then modify it using Magics, Netfabb, Blender, or another product. Also, these software tools require quality 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 well-addressed, but the influx of new customers means that the problem is attracting renewed attention. Most of the innovation is coming from new entries into the AM software field. Model modification and repair tools such as Magics from Materialise or Netfabb Professional from Autodesk are still a necessity for any serious investment in AM by an A/E/C firm. However, new work on voxel-based solutions, as well as more robust Boolean and repair algorithms means that other solutions may soon be available.

The outlook for increased A/E/C adoption of 3D printing technologies is promising. 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. For visualization, the production of scale models is a proven market with a large number of established participants.