DIGITAL METAL: AM FOR CASTING METAL PARTS IN ARCHITECTURE

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BESPOKE METAL ELEMENTS IN ARCHITECTURE

Cast metal has been widely used in architecture - for facades, bridges, beams, columns and connections. An historical example is the exposed cast-iron arches and columns in the Sainte-Geneviève Library France built by architect Henri Labrouste.

Cast metal can find application in architecture wherever strong parts with three-dimensional geometry are needed. Through casting, molten metal can be shaped into any desired shape. Casting allows fabrication of intricate, integral elements with design features that cannot be obtained by other fabrication methods, such as undercuts, overhangs, internal structures and the three-dimensional differentiation in thickness of parts. However, the degree of geometric complexity achievable in a metal part is still constrained by our ability to fabricate the necessary mold, which is traditionally very labor and time intensive.

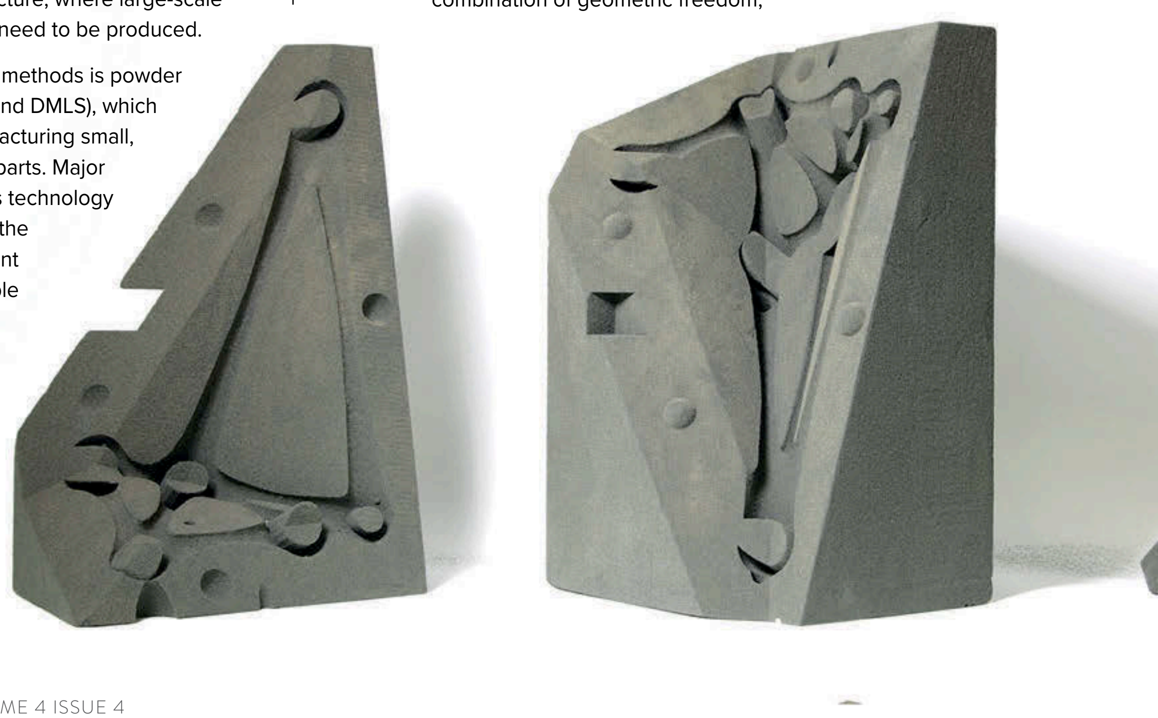
Today, additive manufacturing (AM) of metal can bypass mold making and offers the ability to produce customized lightweight parts with complex geometry without molds. Multiple technologies of metal 3D printing exist. However, each have major shortcomings for the application in architecture, where large-scale parts with detailed surfaces need to be produced.

One of the most common methods is powder bed fusion (e.g. SLM, EBM, and DMLS), which is commonly used for manufacturing small, low volume, complex metal parts. Major drawbacks of employing this technology for the building industry are the small build volumes, long print times and the limited available metal materials that can be printed. Printing methods for larger dimensions, such as robotic metal arc welding-based AM — where stainless-steel rods are printed through welding layer by layer — have recently developed. However, this technique is still limited in printable forms and requires expensive post-processing to reach a high-quality surface finish.

OUR APPROACH: COMBINING THE ADVANTAGES OF 3D PRINTING AND METAL-CASTING

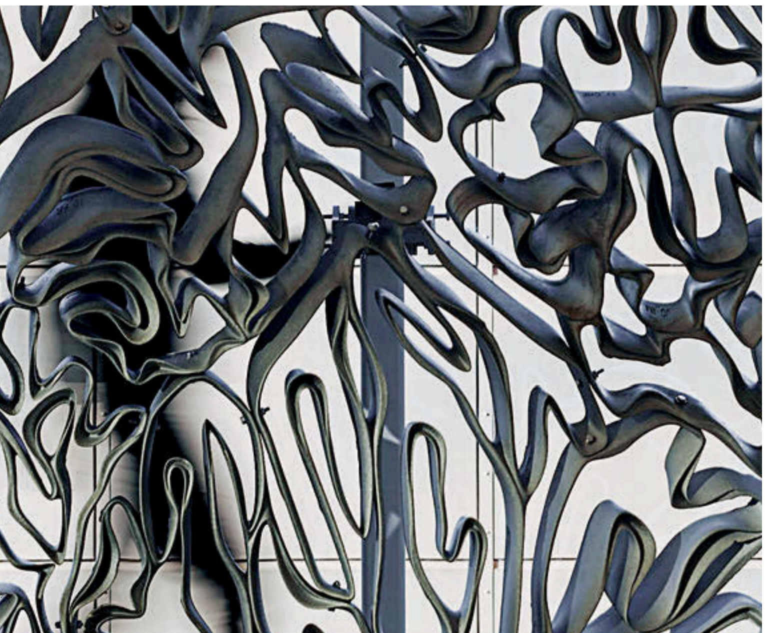
To overcome these challenges, in our research at DBT, we employ AM to 3D print the sand-molds for metal casting rather than 3D printing the metal part directly. We do this to benefit from the geometric freedom offered by 3D printing and the flexibility of metal casting. When combining 3D printed sand-molds with metal casting, we can efficiently create large bespoke elements without being limited to specific metals or alloys – we can cast practically any kind of metal.

To fabricate sand-molds, we use binder-jetting technology where a liquid agent is selectively dropped on thin layers of sand to bind it. For applications in architecture, binder-jetting technology offers a unique combination of geometric freedom,



BELOW: "DEEP FAÇADE" BY STUDENTS OF MAS DFAB AT ETH ZURICH 2018

IMAGE BY JETANA RUANGIUN



intricate detailing and large print-bed dimension. Molds can be printed at a precision in the range of a tenth of a millimeter and in dimensions of up to 4 x 2 x 1 meters.

In our research, we develop computational methods to design and optimize bespoke metal elements which integrate the casting constraints. An important aspect is to facilitate the design of molds and casting system for any given shape. We try to automatically integrate details such as the gating system which channels the molten metal to the mold cavity. Ideally, we can generate the required fabrication data for any geometry of a part at the push of a button and send it directly to the 3D printer. The casting process itself can follow the traditional setup and can be done within a short period of time.

TWO EXPERIMENTAL PROJECTS

To demonstrate and evaluate the proposed method in an architectural context, two 1:1 scale projects were designed and built together with the students of the Master of Advanced Studies in Digital Fabrication (MAS DFAB) at ETH Zurich. These projects highlight possible application of the proposed fabrication method for structural metal nodes and three dimensionally articulated façade elements.

The metal connection in combination with standard tubular profiles enables the construction of a large freeform spaceframe structure. The facade elements allow precise control of transparency and shading properties though porous 3D structures.

In 2017, "Liquid Pavilion", a five-meter high space-frame structure was designed and built from 182 non-repetitive lightweight joints in combination with off-the-shelf metal profiles. All nodes were digitally designed and digitally fabricated using 3D printed molds, reducing the overall fabrication time and effort.

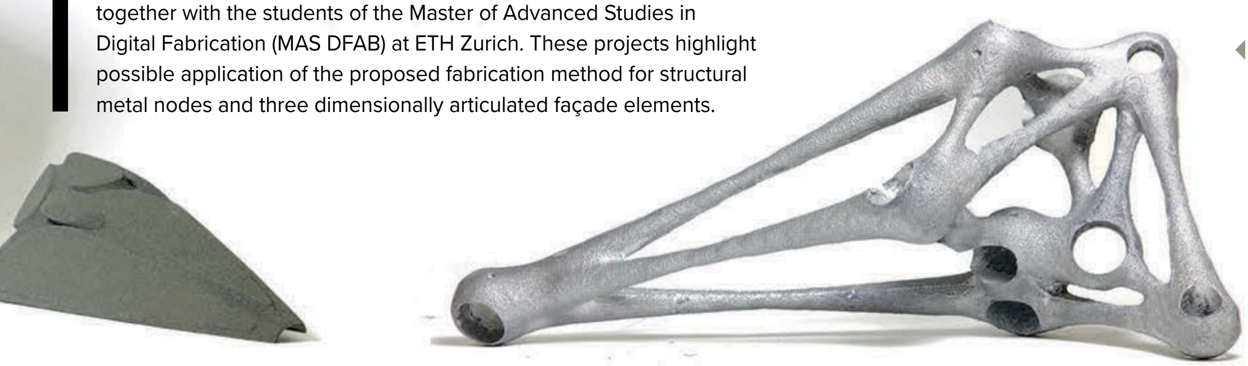
The constraints of metal casting were encoded in the algorithm that generates the geometry of the nodes and their molds, which then ensure cast-ability, dimensional-accuracy and good surface finish. AM allowed integration of a gating system for the liquid metal into the mold, thus considerably reduced tolerances and fabrication time.

As a result, the fabrication of all nodes took less than two weeks, which is considerably faster than casting with the traditional process of mold-making or direct 3D metal printing. With commercially available metal printers, large connections would even have to be split into smaller parts to fit into the build space.

In 2018, a six-meter high and four-meter wide "Deep Facade" was designed and constructed from 26 three-dimensionally articulated panels up to the size of 2 sqm, that were also cast using 3D printed sand-molds. A modified differential-growth algorithm was used to generate the ornamented structure that expresses the liquidity and strength of metal as a building material. Here we used an open cast principle, which helped us to reduce the size of the necessary printed sand-molds.

OUTLOOK

Linking the ancient fabrication method of casting to state of the art 3D printing opens the door for a revival of cast metal in architecture. It will allow us to structurally optimize metal components and reduce the amount of material. Coupling this fabrication approach with computational design, we can unlock an entirely new vocabulary of shapes for architecturally exposed metal structures, previously unavailable with traditional mold making systems. We can design and produce parts in a new and radically expressive aesthetic.



LEFT: 3D PRINTED SAND MOLD AND ALUMINIUM CAST JOINT (MAS DFAB AT ETH ZURICH 2017)

IMAGE BY MA XIJIE