MX3D

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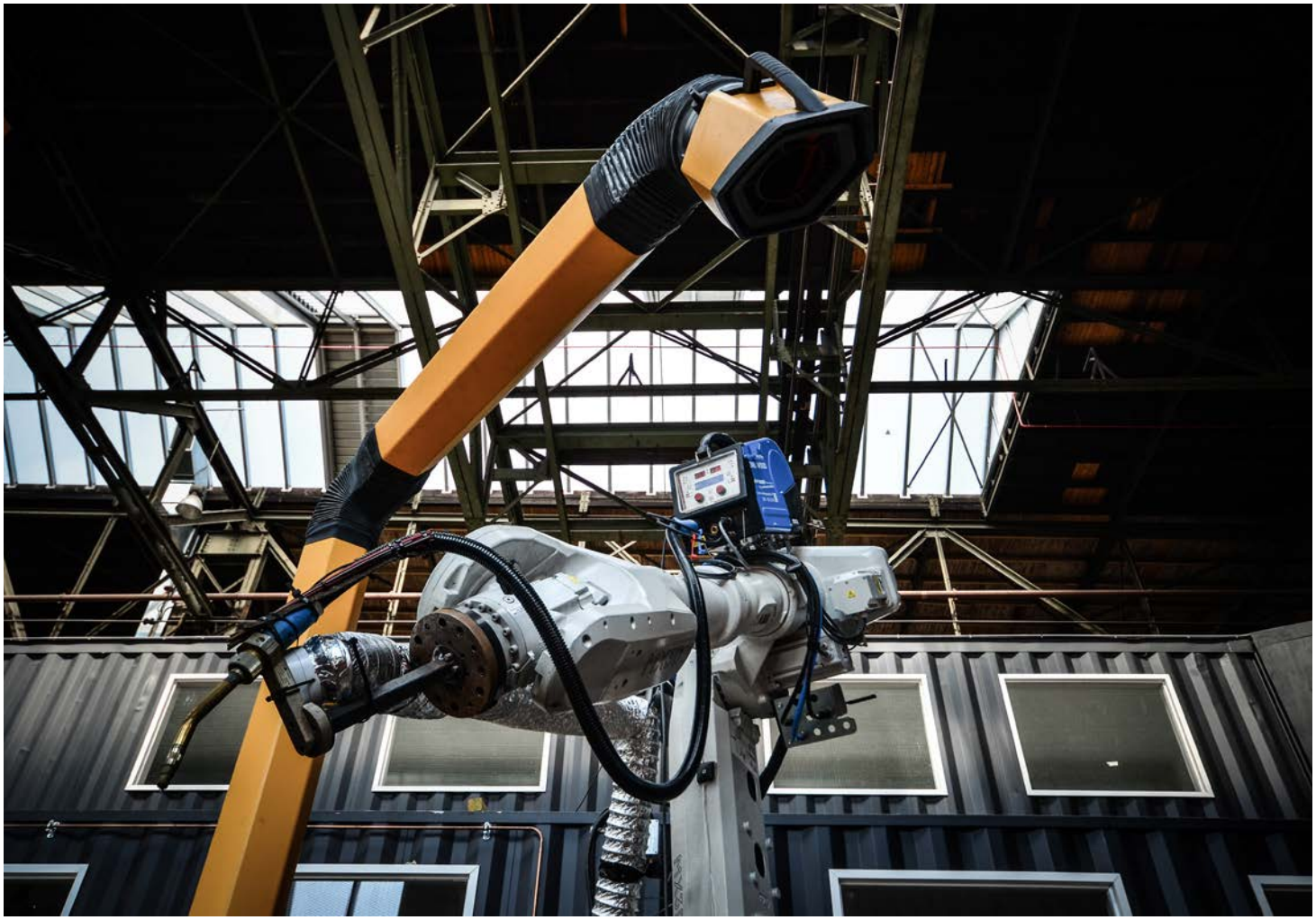
MX3D

Collaborating with key industry partners to advance on-site fully autonomous robotic 3D printing in the E&C sector



The challenge

While other industries have been eagerly embracing automation and the autonomation of equipment, the engineering and construction (E&C) sector has been hesitant

Over the past 50 years, the productivity of most industries has surged but it has virtually been at a standstill in construction. One of the main reasons for this is the difference in degree of automation. Manufacturing industries are currently experiencing the Fourth Industrial Revolution, with the autonomation of production and smart factories. Even the fragmented agricultural industry has adopted autonomous equipment (by leveraging geographic information systems (GIS) data). The construction industry has been very slow to follow the trend but is at last beginning to catch up. Companies are now making use of autonomous bulldozers or welder robots. However, apart from these dirty, dull and dangerous applications, the construction process remains heavily reliant on low-skilled workers, especially in developing and emerging countries.

The idea

Apply robotic 3D metal printing to the construction process

MX3D is a technology start-up that is developing an easy-to-use “plug & print” robotic additive manufacturing software platform to transform standard industrial robots (six-axis robotic arms) into a large-scale, mobile, 3D printer for construction.

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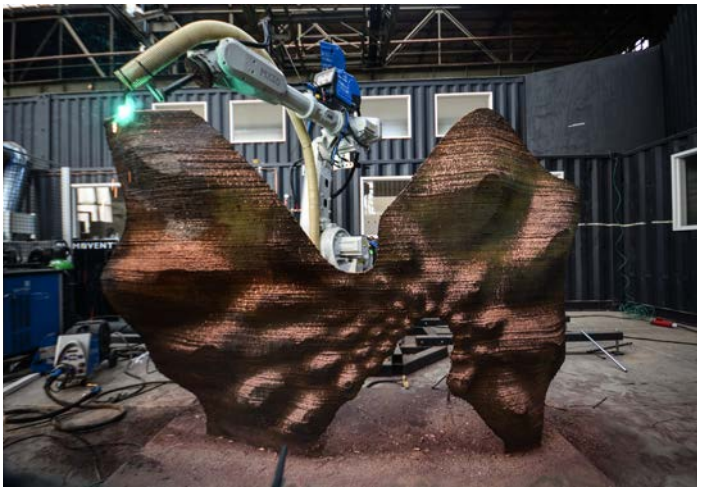
MX3D’s particular interest is metals, and the company specializes in wire-arc additive manufacturing (WAAM) technology, which uses standard welding wire and is faster, cheaper and easier to scale than rival additive manufacturing technologies, such as selective laser melting or powder-bed printing. In principle, however, the MX3D software can be applied to other materials as well, such as concrete, plastics and resins.

MX3D was founded by four innovation entrepreneurs as a spin-off start-up of the Amsterdam design studio Joris Laarman Lab. In 2004, the lab started experimenting with new technologies such as 3D printing for complex artworks (their works are featured in leading museums such as MoMa, the Pompidou Centre and the Rijksmuseum in Amsterdam).

MX3D was set up in 2014 and turned its full attention to venturing into large-size robotic additive manufacturing. Its flagship project, The Bridge – printing a steel pedestrian bridge in Amsterdam – will demonstrate the technology’s viability and power, as well as attracting the attention of potential customers and suppliers. In addition, the aim is to develop a supply chain strong enough to fulfil large orders for steel wire, specialized welding gases, software and other essential input factors. The bridge is scheduled to be printed by the end of 2017 and installed at the beginning of 2018.

The project has brought MX3D into a creative collaboration with some major industry players, enhancing the technology with their complementary competencies. These partners include the industrial-robot specialist ABB, the design- and engineering-software provider Autodesk, the Dutch E&C company Heijmans, the specialist gas supplier Air Liquide, and the steel producer ArcelorMittal. Other stakeholders in the project include the Amsterdam City Government and Delft University of Technology (with the aid of AMS, the Amsterdam Institute for Advanced Metropolitan Solutions).

The vision for the future is to develop and market the software for fully autonomous robotic 3D printers – printers that can move freely, for example, on construction sites and shipyards, to create printed structures by adding layers from below, from above, or from the side, and can supplement the workforce by completing tasks during off-hours.



The impact

The construction industry can at last enjoy the freedom of design that 3D printing affords

The main advantage of 3D printing technology is that it allows freedom of design to be a practical option at last. E&C companies can now utilize algorithm-based or "generative" software to optimize the design of buildings and to design special lightweight beams and other components – in short, to "build what we could not build before". By no means do E&C companies try to replace standard parts but instead they leverage 3D printing for very complex components that can be combined with traditional construction methods – that is, to "add to the tools that the E&C industry already has". In fact, if the entire building design takes account of it from the outset, the technology has even far greater potential.

Traditionally, 3D printing technology has been used only for complex, high-value, low-volume products. And indeed, that is how MX3D technology generates its highest value currently – by significantly reducing lead times and costs for casting complex structures that would otherwise take up to several months. But MX3D is also becoming increasingly competitive at making or installing standard parts, thanks to its technology that transforms standard industrial welder robots into 3D printers – with large cost savings.

MX3D's 3D printing technology offers environmental benefits, too. Being fully integrated into digital construction models and tools, it provides a very accurate method of producing structures, with zero waste and minimal, and costly rework. What's more, by allowing material savings through optimized shapes (if the weight reduction is at least 7%), 3D printing technology emerges as the most eco-friendly technology in a Lifecycle Analysis by the TU Delft.[1]

The technology has now moved beyond the prototype stage. MX3D has just signed its first deal for a museum pavilion in the United States, where its proposed solution was judged the best and cheapest for realizing the architect's distinctive vision. This success bodes well for the company's strategy of initially targeting unique architecture projects to accumulate experience and then expanding into large-scale construction projects.

MX3D was fortunate in having as a springboard the reputation of Joris Laarman Lab, so it quickly attracted global media attention (from *Time*, *The Economist* and FastCompany, among others) and was able to establish its brand as a leader in autonomous metal printing.

> **"Using technology "to build what we could not build before"**
>
> Gijs van der Velden, Co-Founder and Chief Operating Officer

1 Anne C.M. Bekker (2016): *Intermediate results of the sustainability comparison between WAAM, Green-sand casting, and CNC milling, by means of an LCA*, TU Delft (forthcoming).

The barriers to innovation, and the solutions

The persistent conservatism of the E&C sector creates difficulties for new technologies in regards to fundraising, regulation and attracting clientele. Rather than trying to meet these challenges by going it alone, MX3D has engaged in various imaginative and rewarding collaborations.

One of the main barriers that the fledgling MX3D encountered was the difficulty in securing seed-financing for its innovation venture. Seed capital in the construction sector is rare: *technology venture capital firms* tend to avoid the E&C sector because it is large and slow-moving. *General venture capital firms* tend to avoid it because they lack industry know-how. And construction companies themselves are hesitant to invest in any emerging technology. Traditionally conservative and risk-averse, they prefer to wait for a technology to prove itself before adopting it. They see little appeal in the strategy of developing a minimum viable product for later scale-up, since industry is heavily regulated for reliability and safety, and it tends to think in large-scale rather than small-scale owing to the generally low margins.

Mindful of these barriers, MX3D decided to seek its initial financing (a modest $1.5 million) not from construction companies but from equipment specialists and technology providers – funding sources that are known to be more innovation-friendly.

The construction industry conservatism was alien to MX3D's founders, who have a background in technology, arts and design. They "were lucky not to have too many builders in the group" and brought together an interdisciplinary team of experts in metal printing and 3D design, capable of creative thinking and revolutionizing aspects of the industry.

In keeping with the more open culture of arts and design, and lacking the expertise and skills anyway to develop its solution solely in-house, the MX3D team opted to design and market The Bridge as an open innovation challenge – a specific and tangible project that others in the E&C space could immediately relate to. Sure enough, companies approached MX3D to participate in the project, to advance their R&D on 3D printing and accumulate knowledge jointly with MX3D and with one another. MX3D's collaboration with some high-profile industry names has given the project considerable credibility.

The collaborators help to resource the project, through cash or in kind, but their most important contribution is complementary expertise: ABB enables MX3D to realize the full potential of its robots; Autodesk develops the underlying generative design and optimization software; ArcelorMittal provides its metallurgical expertise; Heijmans supplies building expertise; Air Liquide contributes its welding experience; and the University of Delft, as a research partner, is conducting several scientific research projects, such as developing an independent lifecycle analysis of the technology and a methodology for mechanical property testing of complicated shapes.

The project has a core team of seven to eight people, mainly innovation managers or R&D specialists. Although the intellectual property is owned and will remain with MX3D, the collaborative approach enables the partner companies, jointly and individually, to extend their knowledge, and to explore and develop new solutions. MX3D serves as a hub, organizing regular informal meetings. But the partner companies are now also collaborating on other projects beyond The Bridge and, by publicizing these joint projects, have generated interest and demand from their respective customers. Additionally, the open-innovation approach is prompting creative challenges in other industries. For instance, MX3D's technology raises the possibility of quick-print spare parts for propellers or rudders in the (sub-)marine industry, thereby reducing the vessels' downtime, or repairing dredging equipment on-site, thereby requiring a smaller stock of spare parts and inventory cost and potential downtime.

Another barrier to the realization of the The Bridge project – and, more generally, to the advance of 3D printing in construction – is the absence of authorization and clear regulation. In response, MX3D decided to involve the Amsterdam City Government early on and thereby enhance the dialogue and smooth the review process. The city government has come to regard The Bridge as a prestige project, which helps to define

Amsterdam as a hub for innovation. As MX3D's co-founder and chief operation officer Gijs van der Velden says: "The first step was to make everybody want this project." The result is that the city government is open to discuss the conditions for such a permit and does this only under strict supervision of Heijmans – taking a performance-based standards approach that guarantees safety. Despite the lack of certification and the difficulty of modelling the 3D-designed structure with traditional engineering software, the completed bridge will be load-tested in a controlled environment before its final set-up.

More broadly, MX3D is shaping the regulatory environment, working closely with Lloyd's Register to certify the process. In the absence of official public regulation, Lloyd's will offer a private form of guarantee (based on the engineers' and in situ testing of the first bridge) based on existing WAAM regulations and on lessons from other additive manufacturing processes. As a further step, Lloyd's is working with the ASTM/ISO[2] joint working group to advance industry standards (towards ASTM F-42 on Additive Manufacturing and ISO Technical Committee 261 on AM).

One related challenge is this: although the 3D printing process can be certified, the demands for each industry vary; in terms of materials and applications the outputs are always unique and, therefore, cannot be certified in a similar way. To move forward, MX3D has designed a base method that facilitates different certification processes and its technology as a minimum viable product which stores the entire process digitally, enabling later certification and quality control. Accordingly, the innovation and certification processes are conducted in parallel.

The field of application of MX3D's technology is very diverse, going beyond vertical and horizontal construction to include other engineering industries such as shipbuilding. To secure maximum benefit from these opportunities, and to scale up the technology, requires very specific expertise. MX3D plans to form strategic partnerships with key clients from relevant industries to integrate WAAM tools into their workflow and to improve the software continuously. As a software and technology provider, MX3D can concentrate on R&D to refine its products, while its strategic partners can focus on ways of exploiting those products, given their specific industry challenges. The actual use of the products should present few problems to clients, as the software itself is deliberately designed for ease of use – so friendly that it can be mastered within a day.

Lessons learned

- **Seek alternative sources of financing**
  A serious impediment to MX3D's efforts to develop its innovations was the shortage of seed financing in the construction industry. Venture capital is wary of getting involved and incumbents obviously have little incentive to fund their potential disruptors. Determined not to forfeit their products' potential, MX3D turned instead to technology and equipment companies for funding.
- **Leverage open innovation to foster industry collaboration**
  By setting an ambitious and well-defined challenge and publicizing it broadly, MX3D tempted several key industry participants into collaborating to advance the technology and accumulate knowledge. These partners have brought complementary competencies and fostered cooperation, not just on The Bridge project but beyond.
- **Collaborate closely with government regarding approvals and regulation, starting in the design phase**
  By engaging with the Amsterdam City Government at an early stage, MX3D facilitated approval negotiations and created a sense of trust and shared ownership of the project. The project duly got the official go-ahead, and both company and the city will benefit from the global media attention.
- **Pursue innovation in parallel with the certification process**
  MX3D has developed a minimum viable product that is already being commercialized and marketed. And while refining this product, the company is at the same time pushing for the certification and regulation of the technology. The company is also digitally collecting and storing information that can be used later for certification and quality control.
- **Create multi-disciplinary teams to allow creative thinking**
  With its origins in art and design, and by bringing together experts in robotics, 3D printing and metallurgy, MX3D was not bound by the conservatism and risk aversion in the E&C industry.

2 American Society for Testing and Materials (ASTM) and International Standards Organization (ISO)

Case Study prepared by the Boston Consulting Group as part of the Future of Construction Project at the World Economic Forum

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