MANUFACTURING

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3D ADEPT MAG

3D PRINTING

MEDICAL 3D PRINTING - 3D BIOPRINTING - MATERIALS
MICRO-ADDITIVE MANUFACTURING TECHNOLOGIES - SOFTWARE

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3D ADEPT MEDIA
All about Additive Manufacturing

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Hello & Welcome

Some day, for sure

While their growth percentages often vary, market analysis firms agree with the fact that 3D printing technology has witnessed increased adoption in the healthcare sector. Growing trends can lead to a necessity for more 3D printing in hospitals but for many reasons, we are still far away from a daily use of these technologies. This can certainly be explained by the fact that 3D printing intertwines with so many technologies, and sometimes, the complexity increases tenfold in a vital sector like medicine.

To date, stakeholders currently focus their research, investments and attention on four main pillars: surgery preparation and execution, implants and 3D bioprinting, orthotics and prosthetics, as well as regulatory aspects. While all of these pillars make sense to be discussed – as a matter of fact, we discussed most of them in this edition – I would like for healthcare specialists and technology providers to know that they should not only invest extra miles to develop cutting-edge technologies, they should also invest extra miles for their accessibility. Because, sometimes along the road, one often realizes that the benefits of these technologies can far outweigh costs both for hospitals and patients, and that those who often need these solutions the most, cannot always afford to pay the bill.

So, how can we address this? Some day for sure, the market will hopefully be ready to have an open debate on this question. In the meantime, here are the latest trends, insights and analysis on how 3D printing technologies continuously advance and shape the healthcare industry.

Kety SINDZE
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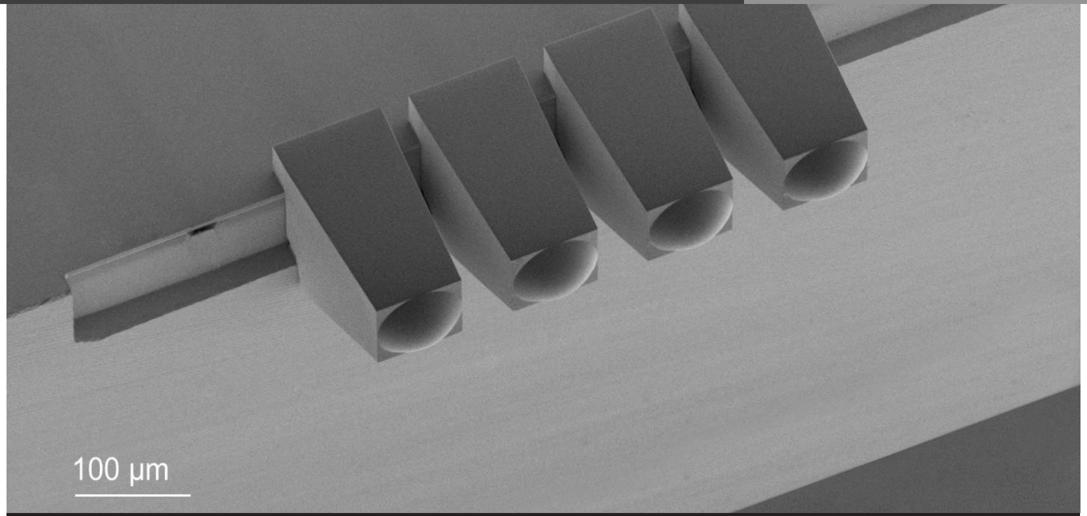
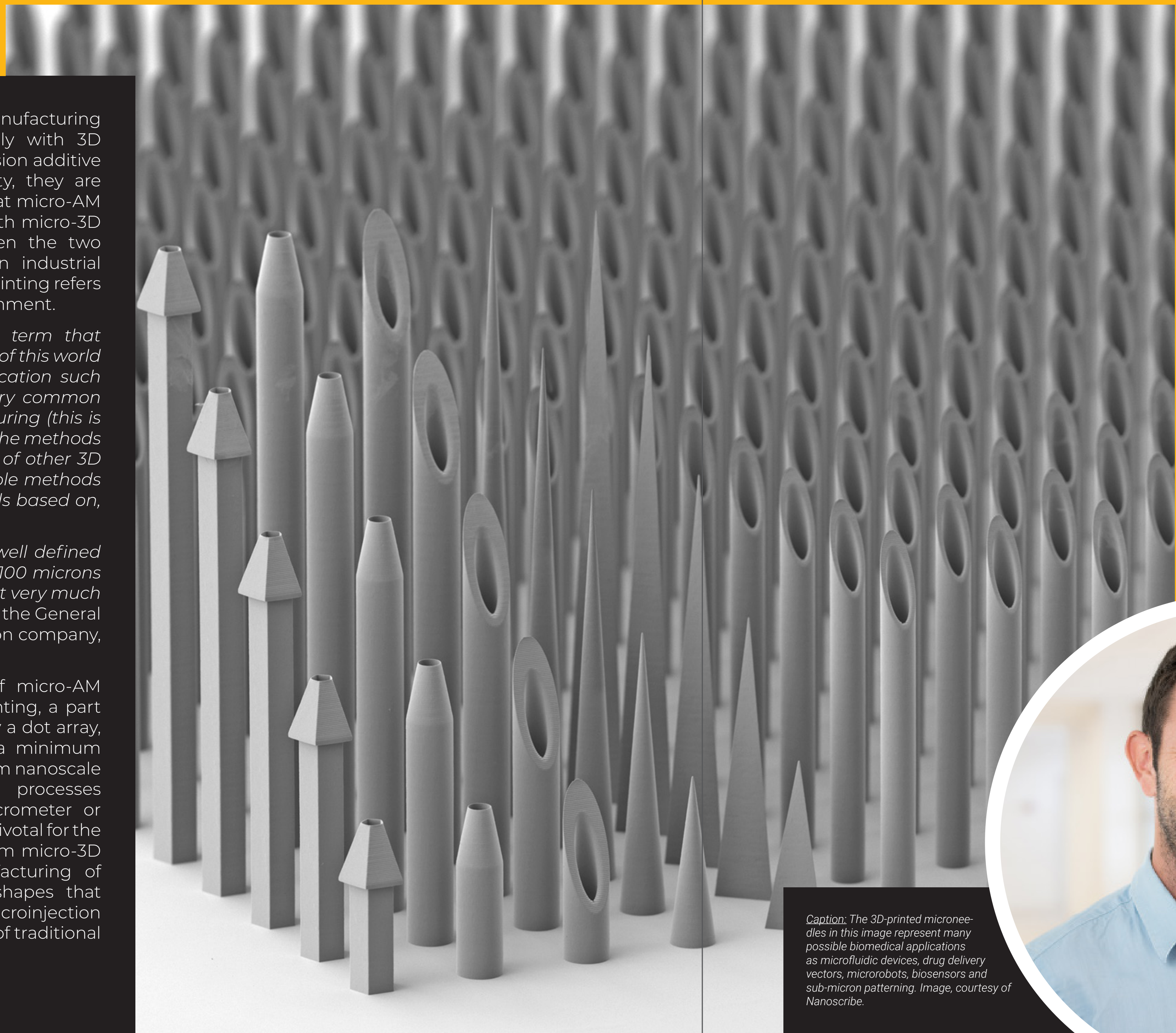
Editorial

The Tiny World of micro-additive manufacturing technologies

In the manufacturing industry in general, most innovations evolve around the ability to produce large 3D printed parts. However, with the growing demand for miniaturized devices in electronics, biotechnology, automotive, and aerospace, there is an increasing interest in micro-additive manufacturing technologies. So, how big is the market of little parts ?



Caption: SEM image of mode field shaping microoptics aligned and printed with submicron precision onto the facet of a photonic chip. Sample of the research project HandheldOCT.Image courtesy of Nanoscribe



The term micro additive manufacturing is often used interchangeably with 3D microfabrication or high-precision additive manufacturing while in reality, they are not exact synonyms. It's fair to say that micro-AM can only be used interchangeably with micro-3D printing and the difference between the two terms reveals that AM refers to an industrial manufacturing context whereas 3D printing refers to a more "maker/prototyping" environment.

*"**3D microfabrication** is a general term that describes all methods. The main part of this world would come from clean room fabrication such as lithography methods that are very common and widely used in MEMS manufacturing (this is a huge well-established market and the methods are very mature). There are a bunch of other 3D microfabrication methods, for example methods used for microfluidics, digital methods based on, say, e-beam litho, and many more.*

***High precision AM** is probably not well defined and someone who has resolution of 100 microns would market it as high precision, so it very much depends on the context"*, **Jon Donner**, the General Manager of **Fabrica**, a Nano Dimension company, states from the outset.

To provide context to the place of micro-AM technologies, let's say that in 3D printing, a part is built first and described digitally by a dot array, where a dot, i.e., voxel, represents a minimum printing unit. The voxel size ranges from nanoscale to macroscale. Micro-3D printing processes therefore require the use of a micrometer or sub-micrometer scale voxel, which is pivotal for the fabrication of microproducts. The term micro-3D printing thus refers to the manufacturing of ultra-high-precision, tiny parts in shapes that cannot be achieved using microinjection moulding processes and other types of traditional manufacturing processes.

Caption: The 3D-printed microneedles in this image represent many possible biomedical applications as microfluidic devices, drug delivery vectors, microrobots, biosensors and sub-micron patterning. Image, courtesy of Nanoscribe.

The present exclusive feature ambitions to discuss the various ways in which micro-AM challenges the traditional manufacturing status quo. It will shed light on:

- The fundamentals and different types of micro-AM technology.
- Main advantages and areas for improvement that may help this market move forward.
- The place of these processes in vertical industries, and in the medical and healthcare industries in particular.

Fundamentals and different types of micro-AM technology

An essential item that we look at, when we talk about AM on the microscale is "microns". Microns are one of the elements that help to determine whether the process refers to micro-3D printing or just 3D printing. It goes without saying that the level of microns one can reach, varies from one technology to another.

When a part is measured in single-digit microns down to a layer thickness of 5 microns and a resolution of 2 microns, then we deal with a micro-3D printing process. Interestingly, some micro-AM processes can fabricate parts measurable in nanometers (nm), which is 1,000 times smaller than a micron. To better visualize these measures and picture how small the parts can be, one often keeps in mind that the average width of a human hair is 75 microns and a strand of human DNA is 2.5 nanometers in diameter.

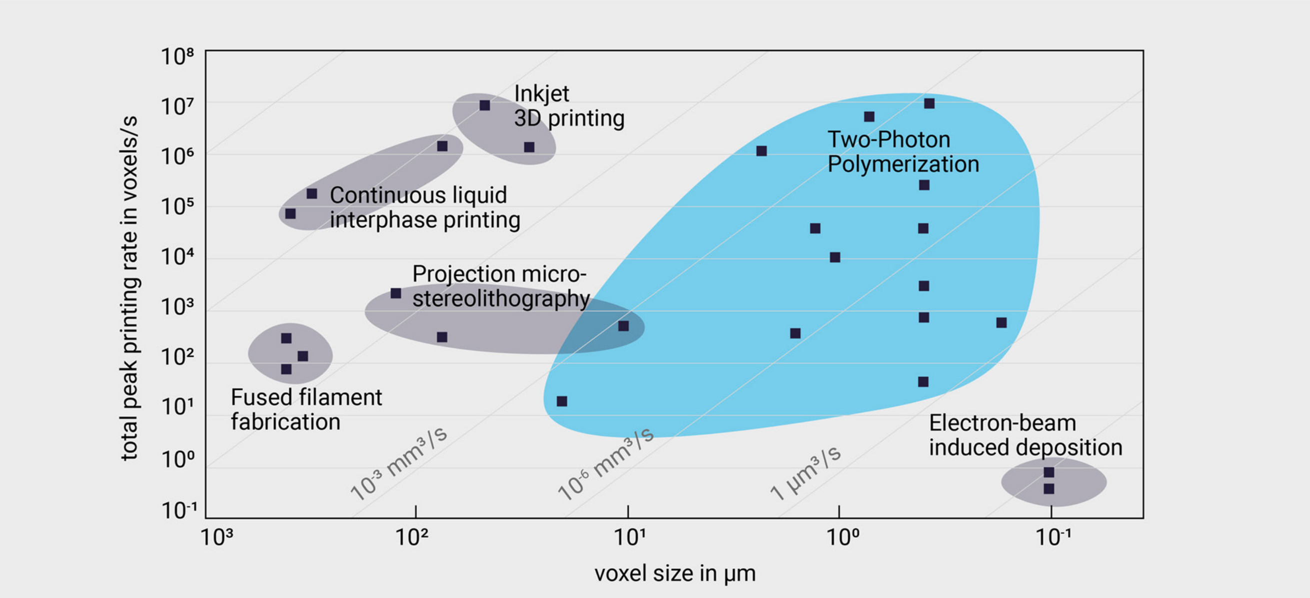
"It is hard to say but in general we consider 10 microns and below as micro-AM. Specifically one can talk about pixel size or layer height or tolerance or repeatability. For sure, if all of these are in the 1-3 micron range then it is micro-AM", **Donner** explains.

Just like there are several types of AM processes, there are also various types of micro-AM processes which include: **fused filament deposition (FFD), direct ink writing (DIW), direct energy deposition (DED), direct light projection (DLP), laminated object manufacturing (LOM), electrohydrodynamic redox printing (EHDP), powder bed fusion (PBF), photopolymerization-based 3D printing (P3DP), and laser chemical vapor deposition (LCVD).**

The table below provides a summary of micro-3D printing methods in terms of material, process, fabrication rate, and resolution.

Approach	Feedstock Material	Process	Printing Rate (mm^3 / h)	Resolution (µm)	Potential Applications
FFD	Polymer filament	Heat treatment	2×10^3–5×10^3	200–400	Prototyping, advanced composite
DIW	Liquid with dispersion of particles	Coagulation, thermal curing, gluing	2×10^{-3}–4×10^3	0.268–610	Biomedicine
DED	Metal, alloy	Focused ion/electron beam/arc/laser	7.2×10^{-10}–3.6×10^{-5}	0.008–40	Aerospace, retrofitting, biomedicine
LOM	Polymer, ceramics, metal, alloy, paper	Laminating		30	Electronics, smart structures
EHDP	Metal, alloy	Application of voltage	7.2×10^{-6}–3.60×10^{-4}	0.07–3	Retrofitting, biomedicine, electronics
PBF	Fine powder of polymer, ceramics, metal, alloy	Illumination of focused laser spot	4.5×10^6	80–250	Biomedicine, lightweight structures
P3DP	Resin (polymer, hybrid polymer-ceramic, functionalized polymer)	Illumination of focused laser spot or optical patterns	6.9×10^{-7}–5.0×10^6	0.052–200	Prototyping, biomedicine
LCVD	Gaseous reactants	Illumination of focused laser spot	3.15×10^{-1}	40	High purity/quality crystals

Micro-3D printing processes based on resin are currently the most acknowledged on the market due to their strength in resolution, quality, reproducibility and rate. Furthermore, DED and EHDP can achieve higher resolution. Nevertheless, the expensive cost and low fabrication rate associated to these processes limit their applications.



Several AM technologies' voxel sizes compared to the printing rate over eight orders of magnitude. This shows historical data of 2PP's evolution and state-of-the-art 2PP in scientific labs and commercial products. Source: This plot is an adaptation of the work in V. Hahn et al., Adv. Funct. Mater. 2020, 30, 26, (CC BY 4.0). The plot shows two instead of four scales and six instead of ten AM technologies. See [1]

Image shared by Nanoscribe.

Jörg Smolenski

"The smallest feature sizes achieved by Two-Photon Polymerization extend far into the submicrometer range. This exceeds the capabilities of conventional 3D printing technologies. For example, Fused Deposition Modeling (FDM) or Selective Laser Sintering (SLS) are typically limited in their vertical and lateral resolution. The achieved feature sizes are in the range of several hundred micrometers. Resin cross-linking technologies, such as stereolithography (SLA) and digital light processing (DLP), achieve a slightly higher precision than the above-mentioned AM technologies (in the range of 5 to 10 micrometers). However, they still have limitations in realizing small high-precision parts or structures due to their limited resolution. In contrast to these methods, 2PP enables the manufacturing of minimal feature sizes down to 100 nanometers. The printing rate of 2PP-based 3D printing processes is at least competitive with digital light projection (DLP) stereolithography. One general metric for print speed refers to the rate in voxels printed per second and is an indicator of how digital information is converted into solidified material" **Jörg Smolenski**, Business Development Manager at Nanoscribe adds.

According to research, **the development of novel optical methods** has led to the advancement of micro-AM processes, photopolymerization-based printing processes in particular. According to experts, using a light source with shorter wavelengths, e.g., UV beam, and an objective with higher **NA (Numerical aperture)** enables to achieve a higher resolution – which is often one of the most highlighted challenges to overcome in micro-AM.

The optical method renders a firmer connection of adjacent voxels as opposed to other approaches based on heat treatment and laminating. The post-processing step, such as photo-curing, also contributes to the quality of 3D printing parts. Lastly, the laser spot or optical pattern that processes the feedstock facilitates the stability and reproducibility as a result of the non-contact approach between the processing region and the illumination system, the report reads.

That being said, the most widely known micro-AM processes include DLP, Microstereolithography (µSLA), Projection Microstereolithography (PµSL), Two-Photon Polymerization (2PP or TPP), Lithography-based Metal Manufacturing (LMM), Electrochemical Deposition and Microscale Selective Laser Sintering (µSLS).

Direct Light Projection (DLP) Technology

DLP technology enables to achieve repeatable micron levels of resolution by combining DLP with the use of adaptive optics. One of the main differences with SLA with which it is often said to be very similar to, is that SLA requires the use of a laser to trace a layer, while DLP uses a projected light source to cure the entire layer at once.

Microstereolithography (µSLA)

Also based on a light-induced layer-stacking manufacturing, micro-Stereolithography (MPuSLA) is used to build physical components by exposing a photopolymer resin to an ultraviolet laser. If you are familiar with the utilization of a resin 3D printer, leveraging an **µSLA** machine shouldn't be a problem.

Projection Microstereolithography (PµSL)

PµSL is a high-resolution (up to 0.6 µm) 3D printing technology based on area projection triggered photopolymerization, and capable of fabricating complex 3D architectures covering multiple scales and with multiple materials. Machines based on this process are often said to combine the benefits of both DLP and SLA technologies. The process rapidly evolves due to its affordability, accuracy, speed and its ability to process polymers, biomaterials, and ceramics.

Lithography-based Metal Manufacturing

As extensively described in page 43 of this edition of 3D ADEPT Mag (Startup Area), this process can fabricate tiny metal components using some of the same principles of photopolymerization. After a homogeneous dispersion in a light-sensitive resin, the metal powder is thereafter selectively polymerized by exposure with blue light. The green parts should undergo a sintering process in a furnace before being ready for use.

Two-Photon Polymerization (2PP or TPP)

This process is often said to provide the highest accuracy among micro-3D printers. The manufacturing technology consists in the use of a pulsed femtosecond laser to trace 3D patterns in the depth of the vat of special photosensitive resin. Nanoscribe's **Jörg Smolenski** provides an easier explanation of the process:

"2PP unfolds its full potential at the interface between maskless lithography and high-precision additive manufacturing. The process belongs to a family of AM technologies, in which light is used to cure a liquid photoresin to create a digitally defined structure. The combination of 2PP with a robust 3D printing workflow enables multiple manufacturing scenarios. 2PP is a direct laser writing approach and works without the need of the costly generation of masks and the use of multiple lithographic steps for 3D and 2.5D microstructures. 2PP advances the microfabrication of parts on flat substrates at wafer level, but also enables to directly print complex structures on pre-existing patterns and topographies, e.g., on optical fibers, photonic chips and inside sealed microfluidic channels. 2PP requires polymer printing materials and the dedicated photoresins for an easy handling and best possible resolution and shape accuracy as well as tailor-made for different applications. This allows to benefit from submicron features, overhanging elements, optical-quality surfaces, high-speed mesoscale fabrication, biocompatibility or high refractive index. High-precision 3D printing based on Two-Photon Polymerization is ideal for rapid prototyping of application designs to realize biomedical devices, microoptics, microelectromechanical systems (MEMS), microfluidic devices, photonic packaging (e.g. PIC), surface engineering projects and many more. Wafer handling capabilities make batch processing and small series production of 3D microparts easier than ever."

Electrochemical Deposition

Electrochemical Deposition is one of those rare micro-3D printing technologies that does not require any post-processing. The process works with a little printing nozzle called **iontip**, and which is immersed in a supporting electrolyte bath. A regulated air-pressure pushes a liquid containing metal ions through a microchannel inside the iontip. At the end of the microchannel, the ion containing liquid is released onto the print surface. The dissolved metal ions are then electrodeposited into solid metal atoms. The latter grow thereafter into larger building blocks (voxels) until the part is formed.

Microscale Selective Laser Sintering (µSLS)

Also called selective laser sintering (SLS) on a micro scale, this powder bed fusion-based additive manufacturing involves coating a substrate with a layer of metal nanoparticle ink and drying it to generate a homogeneous nanoparticle layer. Thereafter, a laser light that has been patterned using a digital micromirror array sinters the nanoparticles into the desired patterns. The process is then repeated until the part is created.

So, what are the decisive factors to consider when choosing one technology over another?

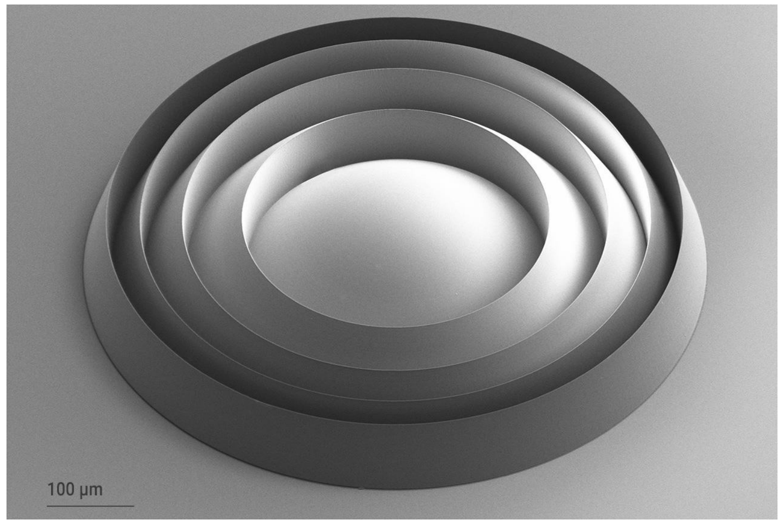
A quick search on the market players developing micro-AM processes reveals that the market is still nascent. As a matter of fact, we usually found that only one or two players develop each process.

Nevertheless, some of the key items that could tilt the balance in favour of one technology, may include **materials** (obviously), **robustness, speed, quality** and **size**.

"First and foremost, the materials each technology enables are key factors in any choice. Second is how robust and precise the system is and specifically the speed and tolerances you can reach. Another critical factor is the size you can print in the bounding box. Finally, throughput and repeatability are key decision points", Jon Donner comments.

Needless to say that each process cannot deliver the same advantages or have the same limitations. Sometimes, the choice of the user will be based on the sought advantages for a given application or the limitations to avoid for another one.

For example, *"Two-Photon Polymerization is a new technology known in the industrial context primarily for its quality and high precision. Similar to DLP, it uses light to crosslink a photosensitive resin to fabricate nano-, micro- and mesoscale structures, but it does so only in a very small volume of significantly less than 1 micrometer in diameter. 2PP is said to be slow when it comes to micro- and mesoscale structures. This has changed recently with the advance of new processing technologies such as Two Photon Grayscale Lithography (2GL ®) and the combination of higher power laser that have come on the market and improved hardware such as stages and scanners. Other conventional AM technologies such as DLP, SLA, and Projection Micro Stereolithography (PµSL) can only fabricate larger structures with less filigree feature details in the range of several micrometers. These technologies are clearly suitable for some microfabrication tasks. However, they encounter geometric limitations when it comes to high- resolution (<1 micrometer) 3D Microfabrication. Resolution and design geometry are limited due to the inherent direct illumination with UV light. 2PP provides the freedom of full 3D design to fabricate freeform, porous and even organic 3D geometries with excellent shape accuracy in the submicrometer to millimeter range. The inherent geometric limitations associated with subtractive methods are overcome with 2PP due to the additive approach."*, **Smolenski states**, reflecting on the advantages and limitations of some of the aforementioned technologies.



Caption: Fresnel lenses enable high optical quality even for planar optics. Quantum X's integrated Two-Photon Grayscale Lithography (2GL ®) and its underlying voxel tuning technology enables the fabrication of 2.5D microstructures with submicron shape accuracy and surface roughness of less than 5 nanometers (Ra).

In general, here are the key benefits and areas for improvement we will keep in mind when exploring micro-3D printing technologies:

Benefits	Areas for improvement
Low cost: compared to micro-injection moulding processes, leveraging a micro-3D printing process remains affordable for those who are looking to achieve prototypes or serial production.	Materials: like in traditional AM technologies, materials remain the hurdle that continuously requires advancements. *"As new materials are developed, as yields increase, we will see many new areas where micro-AM will be applied"*, Donner comments.
Greater design possibilities: As any 3D printing process, micro-3D printing allows its user to benefit from design freedom.	*"A challenge in the fields of photonic integration, optical computing and data communications is to advance the alignment and packaging of photonic components. Specialized hardware- and software-based printing solutions can in turn enable efficient microoptical coupling. That's why we have recently introduced and will continue to develop precisely aligned 3D printing on optical fibers and photonic chips"*, Smolenski adds.
Speed: it's quite captivating to see how fast one can manufacture a small part compared to the same part manufactured via traditional manufacturing processes.	Time: Micro-AM remains a relatively new entrant on the market and as seen with any new technology, it takes time to convince companies to use it.

The place of these processes in vertical industries, and in the medical and healthcare industries in particular.

As stated in the very first paragraph, micro-3D printing first found its use in the electronics industry. With the advancements of miniaturized microproducts, the technology increasingly positions itself as the way to go for other applications.

To date, *"all industries that deal with small and precision parts are applicable. Making small parts traditionally has always been expensive, and Micro-AM is now delivering much cheaper and accessible solutions. In miniaturization, control over form factor is critical and enables a "next level" of miniaturization. Specifically: electronics, optics, semicon, medical devices, medical tooling, micro-injection molding, microfluidics, sensors, and then these applications of course are found in auto, aerospace, consumer goods, etc."* Fabrica's expert points out.

Furthermore, **medical device research** is the strongest field where micro-AM can reveal its potential (Fabrica's opinion).

Jon Donner

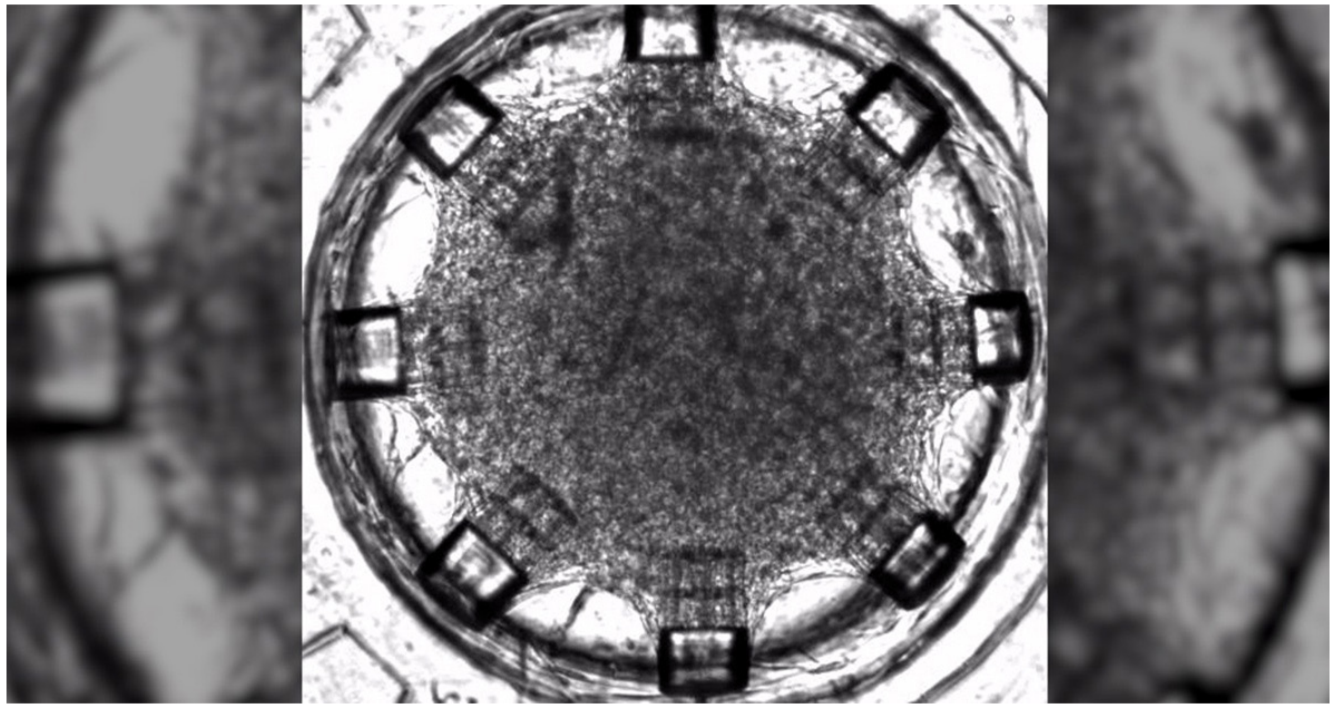
"As micro-AM is a "new" field it is currently only used for prototyping. But we see many opportunities. Some examples are micro-needles, parts for small blood vessels like blood clot-related tooling, tooling for ophthalmology, and many more. We are also seeing many miniaturized medical devices", Donner notes.

Nanoscribe goes one step further and highlights the fact that it has recently made 2PP accessible for high-precision 3D bioprinting:

"High-precision 3D bioprinting enables to create advanced microenvironments for tissue engineering, custom scaffolds for cell studies, and many other innovative biomedical applications where precision, speed, material diversity, and sterility matter. In cell cultivation or cell seeding applications, microstructures are first printed using a material such as hydrogels or one of Nanoscribe's biocompatible IP Photoresins. After printing, the structures are rinsed and cells are seeded onto the structures. Typically, the substrates are kept in incubators to monitor cell behavior over time. Cell seeding is the most common technique to combine 2PP microfabrication with cell research. Moreover, the dedicated high-precision bioprinter Quantum X bio covers biomedical applications like customized microfluidic elements and microneedle arrays or microrobots for drug delivery. Connecting the micro to the macro world, 3D structures can be placed intuitively and with highest precision into microfluidic channels or wells by simply tapping on the machine's touchscreen."

Lastly, 3D Microfabrication can bring life science research a big step closer to the concept of regenerative medicine for the curing of diseases in this field.

For example, Boston University scientists contributed to this goal with a microfluidic heart-on-a chip platform fabricated by Two-Photon Polymerization (2PP). The research team developed a soft and mechanically active cell culture platform to study heart muscle tissue in a customizable 3D microenvironment. This multifunctional toolbox allows cardiac tissue to be grown in a 3D environment and its self-assembly to be observed at cell attachment sites on the vertical walls of the chip. An integrated electronic sensor measures the forces generated by the contractions of the cultivated heart cells. Furthermore, the researchers integrated a mechanical actuator into the chip to passively stretch the cultivated tissue. With this actuator, the scientists investigated the influence of constant and dynamic mechanical strain on the heart tissue. The scale of biological tissue and submicron resolution of 2PP-based 3D printing are perfectly suited to mimic the natural environment. Coupled with the development of biocompatible materials for 2PP-based 3D printing, many other exciting applications in tissue engineering, cell biology and regenerative medicine can be expected, Nanoscribe's expert concludes.



Caption: Microscopic top view of the heart-on-a-chip platform with eight cell attachment sites loaded with cardiac tissue. The tissue aligns with the printed microstructures and synchronizes its spontaneous contractions with a stimulated beat. Video: M. Çağatay Karakan, Boston University

Concluding thoughts

Micro-AM's ability to solve "small" problems can definitely have a big impact across industries. There might be several processes for microscale 3D printing but two photon polymerisation, projection µSL, and DLP would currently be the most promising. This field of activity currently faces some of the main challenges we observed with traditional AM processes, and as observed in that market, one of the fastest ways to drive this niche market forward is by improving process efficiency so that the methods allow for more applications, and obviously by putting the machines to work through collaborations.

Resources

This exclusive feature has been written thanks to several external resources and main contributions from industry insiders. Exclusive interviews have been conducted with **Fabrica**, a Nano Dimension company as well as **Nanoscribe**.

Fabrica 2.0 by Nano Dimension is a leading-edge hardware and software solution for Micro-AM delivering 1-5 micron additive layers for high precision in miniature parts. Fabrica 2.0 enables in-house part prototyping without the need for costly tooling and setup, delivering parts within hours using a digital light protection technology. Fabrica 2.0 currently works with the Precision N-800 ABS-like material and the Performance N-900 reinforced composite material for harsh and high temperature environments.

Nanoscribe works closely with high-tech companies and partners from research institutes and universities to continuously advance 3D Microfabrication, shaping pioneering research fields and industries. With the recently introduced Quantum X align, Nanoscribe thus offers a novel industrial solution for photonic packaging by precisely aligned 3D printing on optical fibers and photonic chips. This reduces coupling losses by mode field matching at the component level instead of the chip level. High- precision 3D printing with automatic alignment in nanoprecision advances the fabrication of microoptical components directly on photonic chips and fiber cores. The spatial orientation of the fiber cores or photonic chips is automatically detected, and freeform microoptical components or diffractive optical elements (DOEs) are printed directly in place, facilitating optimized optical coupling on photonic platforms. Nanoscribe's proprietary Two-Photon Grayscale Lithography (2GL ®) significantly speeds up the high-precision microfabrication of 2.5D structures for optical applications, such as prototyping or mastering of freeform microoptics, microlens arrays, and multilevel diffractive optical elements with the highest shape accuracy and optical-grade surfaces (Ra ≤ 5 nanometers). To scale up production even further, the combination of 2GL mastering with replication technologies comes into play. With nanoimprint lithography (NIL) and injection molding (IM), Nanoscribe has already piloted two reliable and proven replication strategies together with EV Group and kdg opticomp.

This allows to benefit from short design iteration cycles of the 2GL additive manufacturing process and then via replication to move optical-grade microoptics manufacturing into mass production.

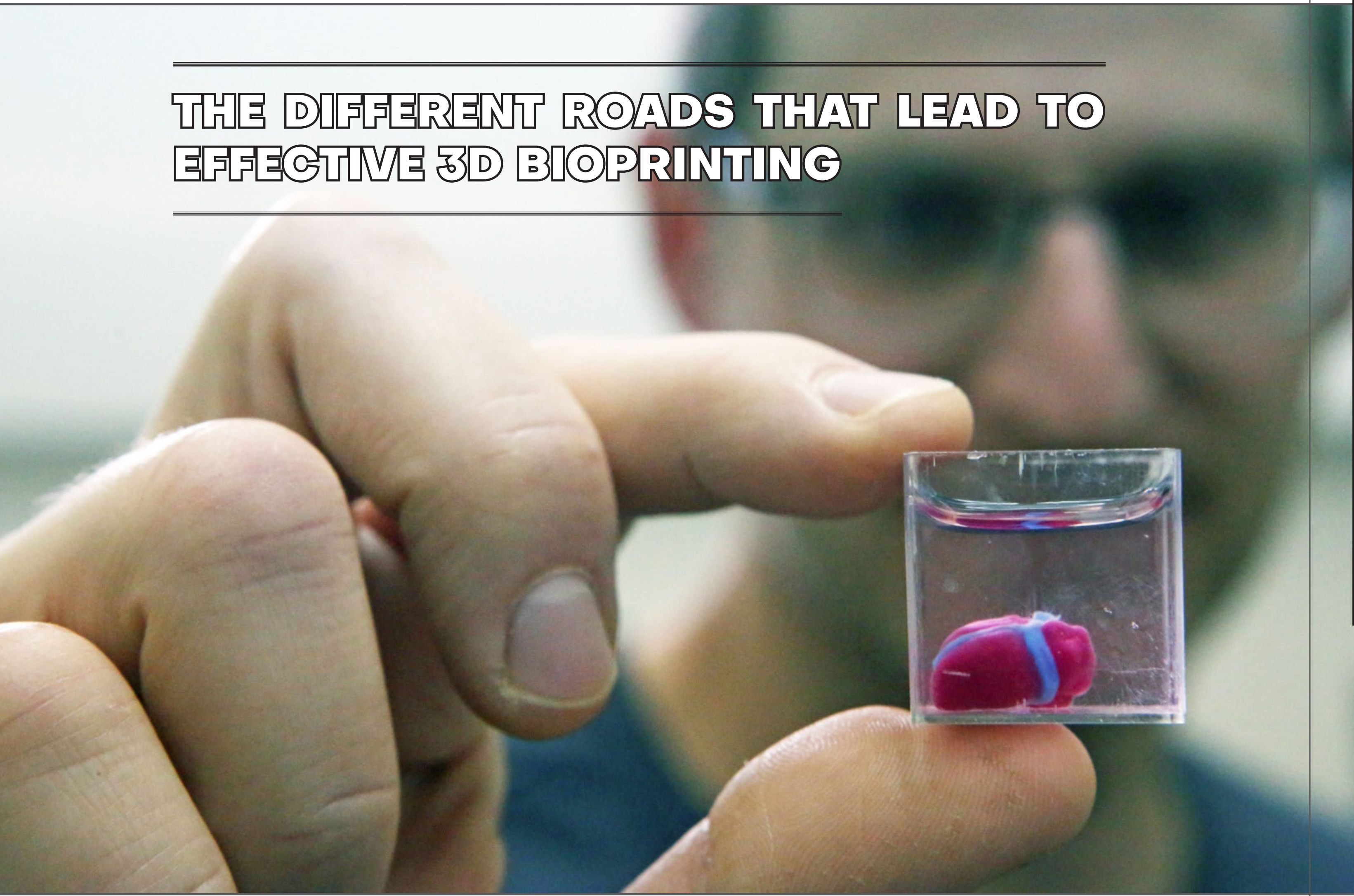
Projection micro stereolithography based 3D printing and its applications, IOP Publishing Ltd on behalf of the IMMT.

Bert Huis in 't Veld, Micro additive manufacturing using ultra short laser pulses

Wei Lin, Dihan Chen, and Shih-Chi Chen, Emerging micro-additive manufacturing technologies enabled by novel optical methods

V. Hahn, P. Kiefer, T. Frenzel, J. Qu, E. Blasco, C. Barner-Kowollik, & M. Wegener (2020). Rapid Assembly of Small Materials Building Blocks (Voxels) into Large Functional 3D Metamaterials. Advanced Functional Materials, Vol. 30, June 2020, 1907795.

THE DIFFERENT ROADS THAT LEAD TO EFFECTIVE 3D BIOPRINTING



Whenever one reads an announcement that highlights 3D printed organs, one can easily be tempted to think that these organs can already be implanted within a human body but reality shows that there is a large gap between the capabilities and limitations encountered with 3D bioprinting.

3D bioprinting is an emerging technology in which biomaterials or biomaterials combined with cells are deposited in predefined patterns, layer-by-layer using a bottom-up assembly approach to create 3D constructs that are functional 3D tissues.

This type of additive manufacturing is truly one of its kind. Fascinating for many reasons, especially for the promises it holds for transplant organs, food industry, and its ability to act as a replacement for animals in tests of cosmetic, chemical, and pharmaceutical products, 3D bioprinting could produce anything from bone tissue and blood vessels to living tissues.

"One of the ultimate goals of 3D bioprinting is to develop a viable solution that will be able to realize 3D functional complex organs but there is more than that. Research around 3D bioprinting has evolved and has started to move to industrial-based applications. One of the clear goals of 3D bioprinting is organ and tissue replacement. The other one is to create complex cell discoveries for making better medicine and quicker", **Dr. Simon Mackenzie**, CEO of **REGENHU** told 3D ADEPT Media.

Yet, the reality, as per the words of **Stephen Gray**, cofounder of Ourobionics, is that *"we should arrive to a solution where we merge human tissue with bioelectronics and biosensors to improve or to try to create models for drug discovery. Ultimately, we should be able to develop human electronics that could be used for implants or other medical devices. Realistically, printing an organ is a topic that we could [objectively] discuss in 10+ years, but exploring human tissue options with bioelectronics and sensors is something we can do now; it's something that can lead to tangible improvements across segments such as drug discovery."*

"This means, the first area of focus right now is outside the body and the second stage will be replacing [or transferring] the applications inside the body" **John Zandbergen**, CEO of **Ourobionics** adds.

In fine, the significant advancements that occurred over the last decade gave a certain legitimacy to 3D bioprinting.

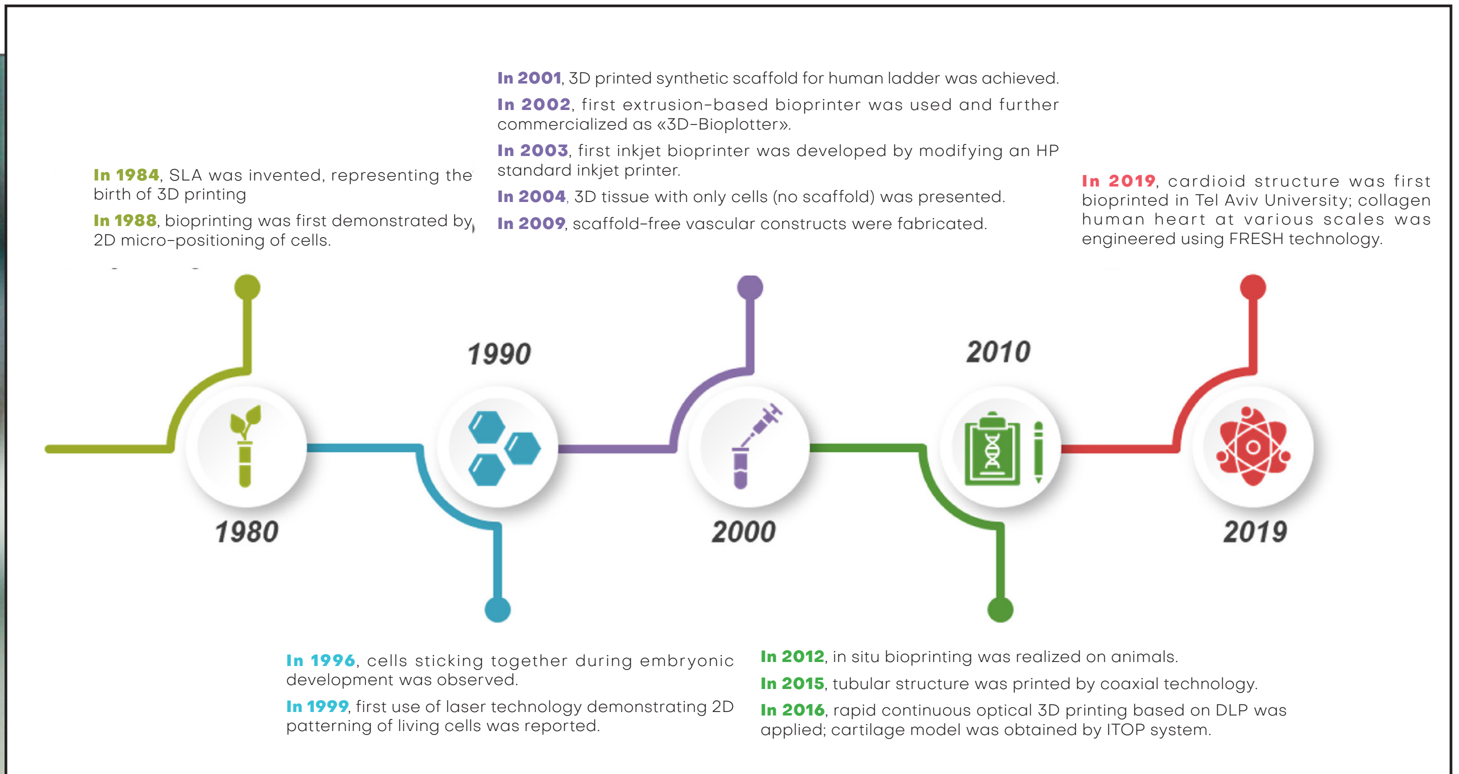
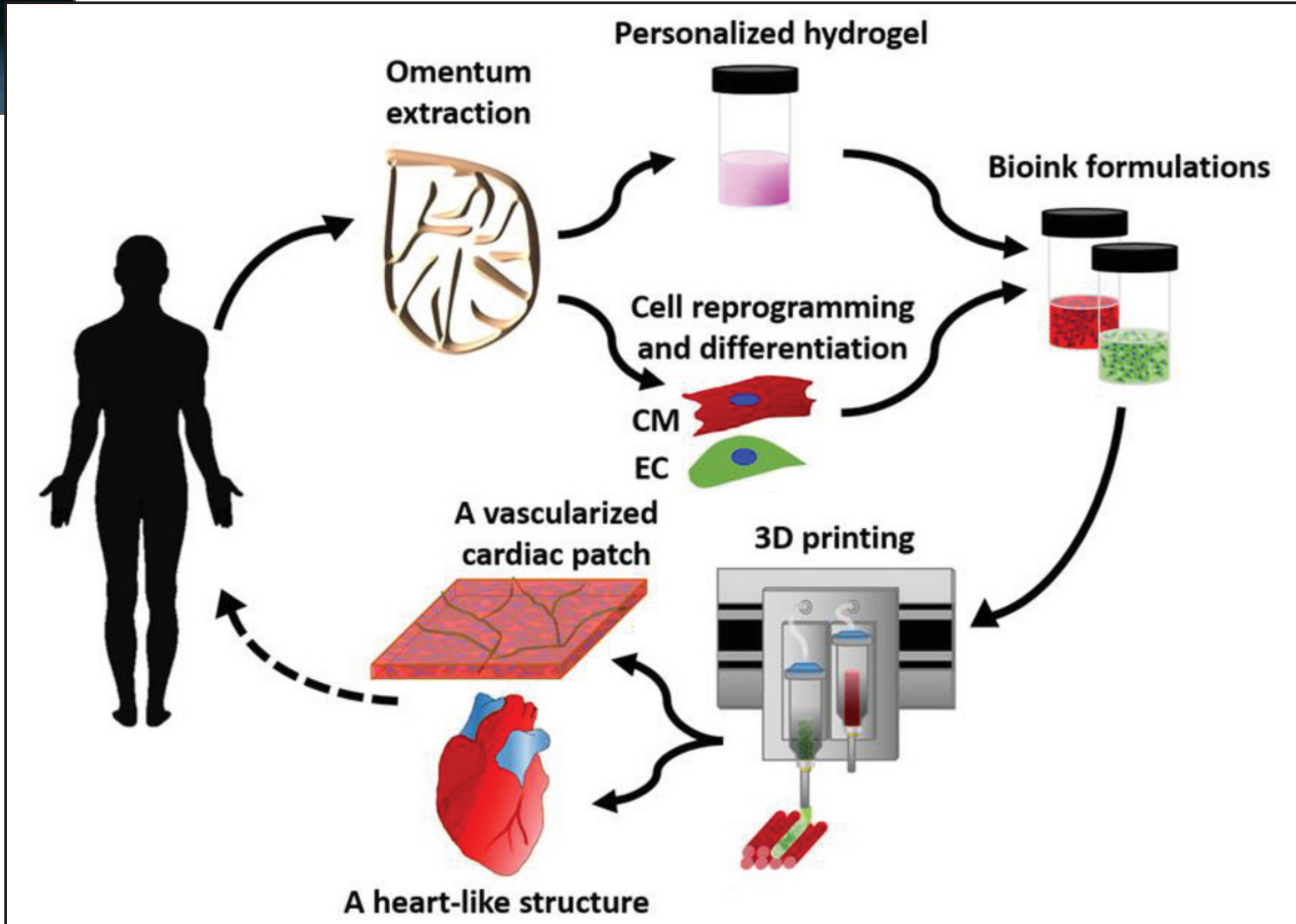


Image: A brief history of bioprinting.

While that decade was one of awareness, we are currently living in an era where the main stakeholders strive for actions to advance this technology that is still described as "futuristic". Where is the current market of 3D bioprinting headed? What are the current limitations of these technologies and what should be the next area of focus? These are some of the questions that this exclusive feature ambitions to address.



The process of 3D printing a heart. Source: Wiley Online Library

How does 3D bioprinting work?

When we look at 3D bioprinting processes, at how 3D bioprinting is defined and described, it's easy to think that 3D bioprinting has benefited from several technologies such as tissue engineering, synthetic biology, micro/nanofabrication, and bioprocessing biomaterial production. Surprisingly, amid the most mentioned technologies, 3D printing does not often make that list, yet the technology should be on the top of this list.

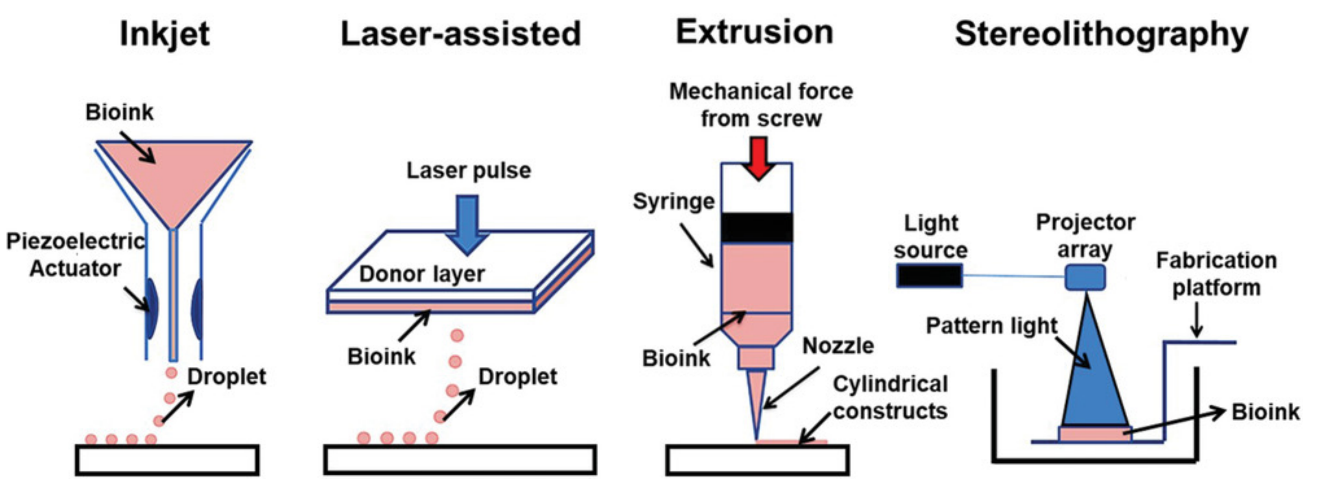
The truth is, *"the 3D printing world solved a lot of issues; we have learned [and we continue to learn] a lot from these companies. They may think it's not their path, but they are wrong. We are just many years behind them"*, **Mackenzie** outlines.

One of the first lessons the 3D printing world inspired, is a manufacturing process that follows the steps you probably already know: **preparation** (3D imaging, 3D modeling, Bioink preparation), **printing process, post-bioprinting** (cross-linking, maturation).

It all starts with a model of a structure that can come from anywhere – a CT or MRI scan, a computer-generated design (CAD) program, or a file downloaded from the internet. Once the 3D model file is fed into a slicer, the latter generates a series of thin layers, or slices, which form the shape of the original model when stacked vertically. The slices are thereafter transformed into path data, stored as a G-code file, which can be sent to a 3D bioprinter for printing. The constructed tissue can thereafter be post-processed in a bioreactor to recreate the required in vivo environment to maintain tissue viability during the maturation period.

Needless to say, variations in these stages may occur depending on the type of 3D bioprinting process the operator leverages and as seen with conventional additive manufacturing processes, there are also several types of 3D bioprinting processes.

Currently, scientists seem to agree on these four main categories: **Microextrusion 3D bioprinting, Inkjet 3D bioprinting, Laser-assisted 3D bioprinting (LAB) and Stereolithography-based bioprinting (SLB)**.



Legend: Bioprinting techniques. Inkjet deposits the ink using a piezoelectric actuator; in laser-assisted method, the laser stimulates an energy-absorbing donor layer coated with the ink which creates bubbles at the interface of the ink layer resulting in its deposition in the form of droplets; in extrusion mechanical force use to deposit the ink, and in stereolithography exposure of a light-curable resin to a precise source of light with a patterned binary image result in the 3D structure. (Source: Shavandi et al. via Wiley)

Each 3D bioprinting process comes with its share of advantages and limitations:

Bioprinting process	Description	Advantages	Limitations
Microextrusion 3D bioprinting	Continuous dispensing of the bioink through a nozzle that is driven by a pneumatic or mechanical (piston or screw-driven) method and controlled by a computerized robotic arm.	Possibility to print high-viscosity bioinks by adjusting the driving pressure; Possibility to print tissues with very high cell densities and scaffold-free bioink; Delivers good structural integrity due to the continuous deposition of filaments	The pressure-driven dispensing results in high shear stress on the cells; which dramatically affects the cell viability; Limited resolution: inability to construct a microcapillary network.
Inkjet 3D printing	Droplets of cell-containing bioink (each contains 10000-30000 cells) is formed through a non-contact nozzle	Non-contact based which reduces the chance of contamination; Possibility to integrate multi-printing heads for heterogeneous tissue structures; Fabrication of a vasculature-like structure; High-speed printing	Non-uniform droplet size; Requires bioink with low viscosity (<0.1 Pa s-1)
Laser-assisted 3D bioprinting (LAB)	A focused laser pulse creates a bubble and shock waves that force cells to transfer toward the collector substrate. The step is repeatedly performed to create predesigned 3D structures	High precision and resolution for the printed structures which make it possible for bioprinting of micro-patterned peptides, DNA, and cells with single-cell resolution; Ability to print tissues with very high cell densities; No viscosity limitations.	The heat generated from laser energy may affect the cell viability.
Stereolithography-based bioprinting (SLB)	UV light or laser is directed in a pattern over a photopolymerizable polymer or bioink that leads to cross-linking of the polymers into a hardened layer to form a 3D tissue	High resolution; no clogging during the printing process	Needs an intense radiation for the cross-linking; Slow process

This table is based on the research "3D Bioprinting at the Frontier of Regenerative Medicine, Pharmaceutical, and Food Industries."

Experts agree on the fact that microextrusion 3D bioprinting and Inkjet 3D bioprinting are the most popular processes – microextrusion being the easiest one to fabricate. Each of these processes often include a wide range of sub-processes that have their own specifications. Not to mention that the new emerging processes that have been developed during the recent years have not found a defined category yet. Some of them are categorized as **hybrid technologies** since they rely on multiple technology innovations. They include for instance, 3D Electrohydrodynamic Jet Bioprinting (which merges electric, magnetic, & microfluidic 3D biofabrication technology with cyborganic technology) and Melt Electro Writing. Other technologies that may not have a direct link with the aforementioned processes include magnetic 3D cell culture, acoustic assembly, micro needle array or freeform reversible embedding of suspended hydrogels.

"Those other processes that are not often found in the main categories are much more niche technologies. They are often combined with extrusion and inkjet to create better processes", the CEO of REGENHU explains.

At the end of the day, most of these processes (if not all of them) seem to be trying to solve a pivotal issue during the printing process:

"One of the main problems with 3D bioprinting is that everything gets damage during the process. In order to create human tissue,

you need something that keeps the cells alive otherwise they don't form the tissue you are looking for. With extrusion bioprinting you can get some basic structures, but you can't go to the next level", **Stephen Gray**, cofounder of Ourobionics told 3D ADEPT Media.

Another aspect we should take into account is the **level of complexity,** Zandbergen says. *"You cannot create different kinds of complexity with the same tissue. Each tissue presents its array of limitations depending on its purpose. The level of complexity you are able to create inside the 3D structure determines the level of functionality of the tissue you are making. Don't expect a huge level of complexity when it comes to the depth of the tissue when using basic bioprinting processes"*, he points out.

So, what are some of the key criteria that may lead to the choice of one process over another?

Let's remember that given the relatively "nascent" nature of this field of activity, most of the criteria that may help scientists to go for one process over another often depends on several experiences gathered from different users. In this specific case, our interviews and research reveal that a few criteria tend to come back in the decision-making process of scientists.

The first one is cells. As speakers from Ourobionics said, the goal here is to keep the cells alive while working on them. Tissue printing requires a large number of cells. *"It's a very crucial problem because you cannot create a human tissue if everything is dying in the process. One of the recent improvements in this area has been to add a volumetric principle to the printing process of some technologies. Light-based technologies are also getting to a level where they are slightly better but the problem here remains inside the resin – which in my opinion – cannot deliver a functional organ"*, Zandbergen lays emphasis on.

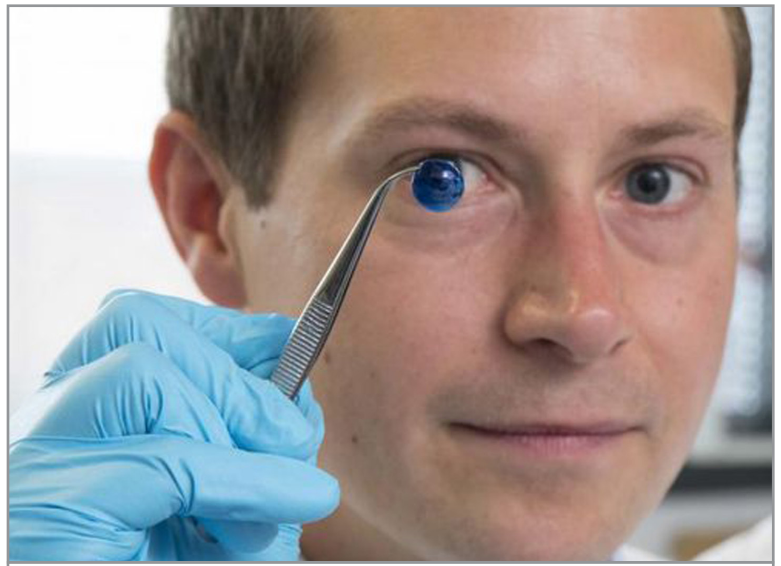
Another criteria is **speed/time**. Based on **Mackenzie**'s explanation, we quickly understand that it is also linked to cells, as he explains that when they do not have the ideal speed, some technologies can destroy cells during the printing process. The thing is, created structures can change their morphology in time once they are in contact with certain stimuli (water, heat, and light) but the embedded cells can also proliferate, migrate, and differentiate along the time, forming more mature tissues with higher resemblances with the native tissue.

No matter what number of criteria we will mention, one that should never be underestimated is the **final purpose**. At the end of the day, each 3D bioprinting process has its share of pros and cons – and some work well for certain purposes. Extrusion-based desktop printers that integrate small syringes for example, can only be used to deposit bioinks and hydrogels with incredible precision (up to 1 µm) while machines that combine different bioprinting deposition methods in one single technology can be dedicated to producing artificial human tissues for research and development.

3D renders of a cell structure – Image: Unsplash

Applications and areas for improvement

"While many technologies touch upon organ and tissue replacement, we are still very far away from commercial applications. On the current market, the cell biology side is gaining momentum, especially for complex cell models as they ambition to reduce the need to use animals for testing products. Applications that are closed to market include the printing of beta cells for diabetes", Mackenzie's points out.



First 3D printed human corneas held by Dr Steve Swioklo. Courtesy of Newcastle University

Bioprinting paves the way for creating biomimetic structures and environment that support in vivo-like cell–cell and cell–matrix interactions with high-resolution vascularized tissue. In this regard, Bioprinted tissue would represent powerful tools to provide physiologically relevant in vitro human organ models for drug toxicity assays and disease modeling that faithfully reproduces the complex human's key physiological aspects.

Another promising application of the future is ***In situ Bioprinting***, which might enable bi-layered skin to be printed directly into a wound.

Lastly, applications that are already commercialized can be seen in the food industry with **cultivated meat**. Alternative meat is currently trendy in the 3D printing industry as people are increasingly aware of the ethical and environmental issues surrounding conventional animal husbandry. A few companies like MeaTech or Redefine Meat that have dedicated their core business to this market have already started commercializing their meat alternative in select restaurants across Europe.

However, there are a number of limitations that remain to address to help the market move forward efficiently:

Areas for improvement	Why?
Complexity	There is a complex process to bring together the instruments and the cells. And set out protocols can take a long time.
Biomaterials	Current available printable materials are not capable of fully mimicking the native ECM compositions to support the cellular structure. Therefore, it is crucial to develop new printable biomaterials that can be printed together with live cells and possess adequate mechanical properties for cell handling.
Biomaterials	A lot of them are still not optimal. The hardware is capable of much more than the biomaterials are capable today.
Software	Software is quite complex and there is no area of control that we might see for complex structures.
Files	Everyone uses their own files. There is an urgent need of standardization.
Price	A technology with such ambitious goals should be accessible in order to achieve them. Tissue engineering is a larger market and the lack of accessibility to hardware does not enable some institutes to advance this technology. They only have access to basic extrusion for education purpose which is not the right route to go to address the challenges on the road.

Table: Limitations outlined based on interviews with REGENHU and Ourobionics

Concluding thoughts

Our experience in the industry taught us one lesson: there are many technologies that promise a lot and deliver little. That's why we do not usually highlight or discuss a technology that is not commercialized yet or that has not demonstrated viable commercial applications. Yet most 3D bioprinting technologies are currently being used for research purpose – for now.

When you know that each day, 17 people die waiting for a life-saving organ transplant and a new name is added to the transplant waiting list every 9 minutes. Currently, there are more than 100,000 people waiting for a second chance; not to mention those who experience chronic problems due to the long-term damaging effects of post-transplant immunosuppression.

When you know that, and you realize that 3D bioprinting can be the alternative solution these people are waiting for, when you know that the technology can do more than that, you can't help but highlight the areas for improvement that should be the next focus of (3D bioprinting) companies – hoping that this might urge some of them to explore new solutions and others to continue the battle.

Resources and contributors:

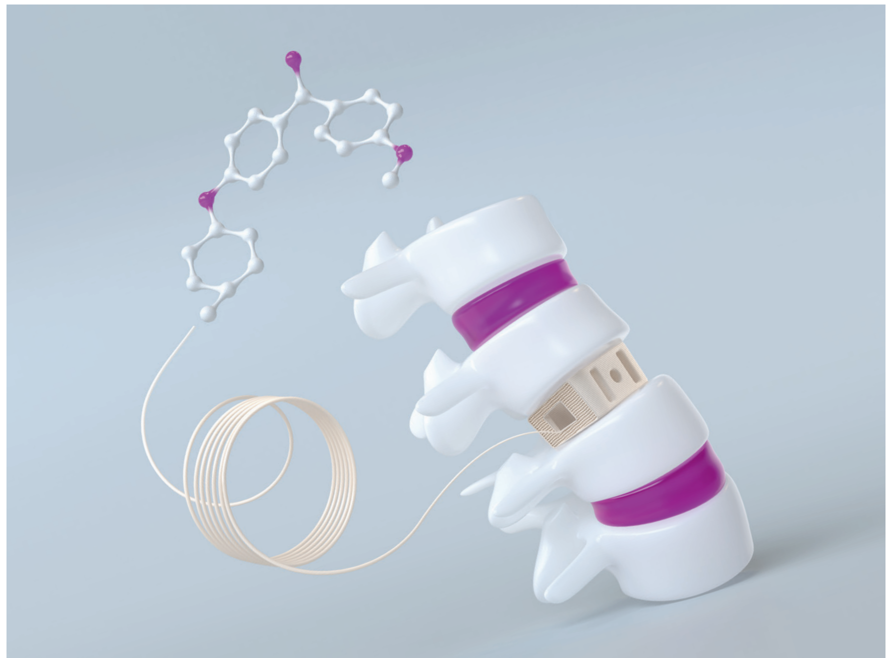
REGENHU started in 2007 with a goal to create and develop bioprinting technologies that will positively impact many medical fields. The company's R-GEN 100 and the R-GEN 200 consolidate 14 years of bioprinting technology and development based on incorporating industry knowledge, integrating user feedback, and responding to market requests.

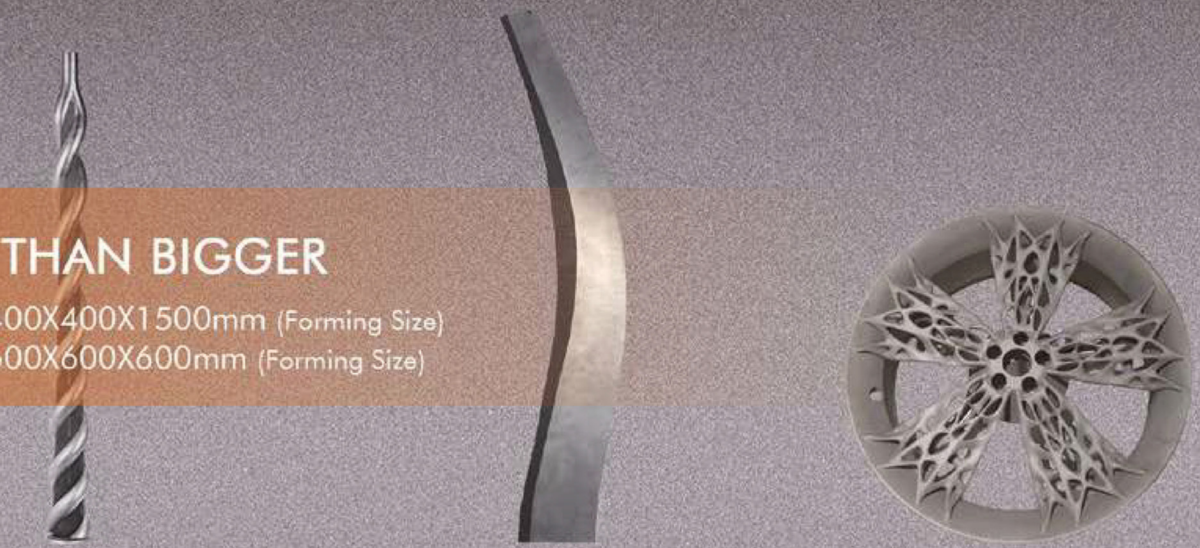
Ourobionics is a startup that merges advanced electric, magnetic, & microfluidic 3D biofabrication technology with novel cyborganic technology to create high throughput tissues & organs with embedded bioelectronics, biosensors, and therapeutic agents. The company ambitions to enable next generation applications in regenerative medicine, medical devices, & human-machine interfaces.

3D Bioprinting at the Frontier of Regenerative Medicine, Pharmaceutical, and Food Industries, Front. Med. Technol., 28 January 2021 | https://doi.org/10.3389/fmedt.2020.607648

Development of 3D bioprinting: From printing methods to biomedical applications, research, Asian Journal of Pharmaceutical Sciences

3D Bioprinting of Lignocellulosic Biomaterials, https://doi.org/10.1002/adhm.202001472





LITHOZ ON THE FACTORS TO CONSIDER WHEN EXPLORING TECHNICAL CERAMICS IN MEDICAL AM AND WHY THEY ARE A GOOD FIT FOR DENTAL APPLICATIONS

On the heels of a dossier that highlights "the current manufacturing landscape of Ceramic 3D printing and the business model that drives industrial applications" (March/April edition of 3D ADEPT Mag – pp 6-12), it feels right to focus on a vertical industry where there is still a long way to go for industry professionals to fully exploit the potential of ceramic 3D printing: the healthcare and medical industries.

There are dozens of publications and research that have analyzed and forecasted the growth rates of the use of additive manufacturing in the healthcare industry or the ceramic 3D printing market as a whole, but it's hard to find the weight of ceramic additive manufacturing alone in the healthcare industry. Yet we know that ceramics are an integral part of the medical field, and given the range of applications and processes associated with the most and custom-made medical products, they can be the best part of it.

Indeed, ceramics' outstanding properties is ideal for a number of applications across the healthcare industry. A few examples of applications that have already been achieved, include but are not limited to medical implants (ear, femoral head implant for hip replacement, implants for neurology), CAT scans, pacemakers, components for cardiology, hand tools, valves and filters, pressure sensors, X-ray tubes, laser and reconstructive surgery and obviously, dental applications.

Moreover, ceramics are also ideal to help diagnose ailments. Medical centers and laboratories rely on ceramic and glass lab ware for chemical analyses and electronic components.

The truth is, the various uses of ceramics are evolving all the time as new technologies emerge. Furthermore, applications and advantages of ceramics are often more highlighted at the expense of their limitations and solutions to overcome them, most importantly, at the expense of key elements industry professionals should consider when leveraging ceramic AM for medical devices and healthcare applications. And these are some of the key areas this exclusive feature ambitions to address.

Use of AM in the healthcare industry: ceramic 3D printing vs other AM processes?

Most applications that are successfully completed via AM are usually described and highlighted through the lens of conventional manufacturing processes as the primary angle of comparison. Over time, with the advancements of AM technologies and their ability to meet the production requirements of several industries, we increasingly see the advantages of certain AM technologies more highlighted for certain applications. This can be seen in the healthcare industry as well, where we have seen applications made possible with various types of metal AM processes or polymer 3D printing.

Courtesy of Lithoz – Applications in the medical and dental industries

"Usually, when we talk about ceramic 3D printing applications, the comparison is easily made with conventional manufacturing processes such as injection moulding and milling", **Dr. Daniel Bomze**, Director Medical Solutions at **Lithoz** lays emphasis on, from the outset.

"However, when we look at the broad range of AM processes that can address the production requirements of various industries, ceramics are likely to compete with metals such as Titanium, cobalt chrome which is used in orthopedic and dental applications, and high-performance polymers like PEEK which can be 3D printed in different ways and resorbable materials. The choice of an additive manufacturing material will therefore depend on where we want to provide a solution. In resorbable applications for instance, metals will not be the ideal choice in terms of materials, while in the polymeric side of the business, there are already materials that are already resorbable", he continues.

Dr. Daniel Bomze

Lithoz is one of the companies you easily come across when you have a slight interest in ceramic 3D printing. The AM company headquartered in Austria is known for a comprehensive range of solutions (machines, software and materials) for 3D printing high-performance ceramics. At the heart of this expertise lies a proprietary lithography-based ceramic manufacturing process; a fabrication process where ceramic particles are dispersed in a photosensitive resin and this dispersion is thereafter solidified by light layer-by-layer to form a part. Then the part undergoes a sintering process to develop its ceramic properties and can be used for its final purpose.

As said during a conversation with Lithoz' CEO & co-founder, Dr Johannes Homa, the company's technology has been validated in three main vertical industries; medical, aerospace & space, and energy. However, the medical applications enabled by their ceramic 3D printing are the ones that have always struck my attention the most. And for good reasons, the use of ceramics in medical devices is changing rapidly as the development of this market is mainly linked to the development of technical ceramics. This urges healthcare professionals to pay more attention to changing factors that may influence their decision-making process when exploring ceramic AM for patient-specific applications.

CeraFab System

The development of technical ceramics in both healthcare and medical applications is quite modern. To make it easy to understand for users, technical ceramics have been categorized into four main groups: **oxide ceramics, non-oxide ceramics, bioceramics** and **other types of materials** that are not found in the aforementioned three categories.

Oxide ceramics have popularized ceramic 3D printing thanks to their affordable cost and ability to be easily processed. Categorized as non-metallic mineral materials, they do not contain more than 15% silica with little or no glass phase. These binary oxides include for instance alumina and zirconia. Known for the applications they enable in medical implants and dentistry – outside of AM –, they have quickly become some of the most popular ceramic 3D printing materials available on the market.

Bioceramics are a class of advanced ceramics that increasingly raise the interest of healthcare professionals due to their ability to be used within the body. They are often employed in medical and dental applications, mainly as implants and replacements. Not only for their biocompatibility, but also for their ability to help the body repair itself. Promising applications of bioceramics are therefore seen in reconstructive surgery. According to Bomze, one of their biggest advantage is their *unlimited availability*. For reconstructive surgeries where bone graft is needed, it may happen that the surgeon requires a large area of extraction to achieve better results. In that case, the bone tissue might require a separate procedure, which means double surgery, and increased risks of complications for both the patient and the surgeon. Whereas artificial bones created using bioceramics may lead to patient-specific 3D printed solutions while *"removing the need for further surgeries."* Although they might lead to more brittleness as they do not have the elasticity of bone tissues, Bomze outlines that *"with artificial bones, the chemical composition is exactly the same than the mineral fraction of the bone."* Lastly, their utilization also reduces *"the surgery time in the operating room and a better patient experience."*

Although they will not raise our interest that much in this feature, let's note that **non-oxide ceramics**, such as silicon nitride (available for the LCM technology) and aluminum nitride, are useful in extreme environments given their high heat and corrosion resistance. However, compared to oxide ceramics, they are quite expensive and difficult to print.

Interestingly, Lithoz has built up extensive expertise in the development of materials for these three categories. For the Director Medical Solutions at Lithoz, the first criteria that should be assessed when exploring technical ceramics in medical 3D printing, is the **properties of the selected material** for a given application.

"Ceramics have outstanding properties and in some cases, they can be the only option for specific applications and requirements. However, as all materials, they cannot be the solution for all issues. What's really important here is to understand first the customer requirements and to select the materials that best meet these requirements. In industrial applications for instance, aluminum nitride may be the ideal ceramic to go with, but you won't probably use it to create a crown – dental part – because it's more brittle than zirconia.

And if you do not look at the materials side first when you explore ceramic 3D printing, then I would recommend to assess other details. Almost all technologies' providers are looking to print the part that looks at first glance to the geometry that the customer requests – This part is often called 'green part' –. However, it's only after sintering that you will be able to tell if you can rely on the part's properties, or if the machine you invested in, can produce green parts, you will never be able to manufacture ceramic parts because there will be cracks, and other issues related to size and dimensions.

Therefore, before investing in a production technology, it's important to understand all the consequences that may result from every type of production and the details that are often least highlighted."

Material: LithaCore – Silica – Image: Courtesy of Lithoz

Bomze's statement is quite interesting to the extent that it brings forward the fact that we do not often talk about the limitations of AM technologies and/or materials and how they can be addressed in manufacturing. This applies to technical ceramics that are usually highlighted for their ability to deliver performance that other materials simply cannot, which is true. As a matter of fact, they are robust, and can survive extreme stresses, temperatures, nuclear radiation or highly aggressive chemicals. But that is not all because most ceramics are generally brittle. That's why they are not always self-sufficient.

"The original fact of ceramics' brittleness, in my opinion, can be directly addressed by developing new types of ceramics. At Lithoz, we have developed a solid area of expertise in the development of new types of printable ceramic materials which led our customers to develop various forms of 3D objects. Also Lithoz works very closely with ceramic powder manufacturers to offer newly developed ceramic materials for additive manufacturing on the market. Furthermore, with the advancements we made in multi-material 3D printing, we came to realize that combining different kinds of materials enable to address most of the disadvantages raised by technical ceramics.

Let's take the example of two kinds of ceramics: bioresorbable materials – osseoconductive materials that facilitate bone regeneration – and zirconia oxide, a high-performance ceramic. The combination of these materials allows to fulfill the requirements of a critical size-effect in load-bearing body implants.

In certain applications for instance, you might want to combine zirconia with some types of metals in order to have the elastic properties of a metal with for example, some wear resistance properties of ceramics. Ceramics could be used as a cover to protect the part and metals as a electrical conductive element. At the end, the part created, benefits from the combination of each material selected.

Another solution that is worth mentioning might be to go with non-sintered ceramics. If you use for example, a highly-filled resorbable polymer material with a certain ceramic, you would not come up with a pure ceramic in the end, but rather a composite material that could address the brittleness of ceramics.

At Lithoz, we have also tried the combination of glass fiber and carbon fiber which works well. However, it might come with some limitations and our R&D team is currently working on them" Bomze explains.

Lithoz's representative also raised our attention on the fact that limitations of technical ceramics may also depend on the manufacturing technology you use to process them.

"For every manufacturing process used for medical devices, you need to adapt your processes. At first glance, this might sound like extra work but if it allows you to benefit from the design freedom of AM, then you should do it properly. In this case for instance, it's crucial to understand the design rules in ceramic AM to know exactly all the advantages that may result from a given application versus the disadvantages. I believe that understanding these design rules are essential to get out the most of the technology", he adds.

Focus on applications: digital dentistry

Lithoz' technology may have proven itself in various fields of the medical and healthcare industries, but the most prominent advancements are currently seen in dental applications. As a reminder, it's been a while that the company has been working on the development of 3D printed ceramic dental implants alongside Dr. Jens Tartsch, the founder and president of the European Society for Ceramic Implantology (ESCI) and Metoxit, a Swiss high-tech ceramics company that develops oxide ceramics.

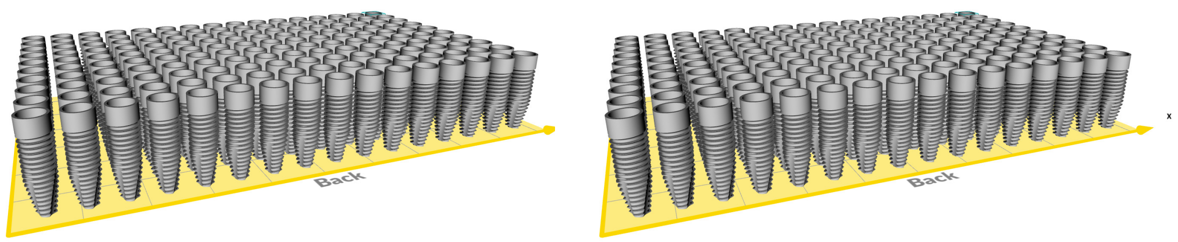
Today, the company prides itself on the ability to deliver mass production of complex shaped implants based on patient-specific designs using Lithography-based Ceramic Manufacturing (LCM) technology. Currently in its portfolio, materials that can enable dental 3D printed productions include Zirconia, ATZ and ZTA.

"Zirconia (3 mol% yttria partially-stabilized) offers excellent strength without having to make major compromises on aesthetics. Another newly emerged material in this context is silicon nitride. It provides an exceptional combination of biocompatibility, antibacterial and high-mechanical performances. Another advantage of using silicon nitride for implants is the good nano-roughness of the surface, which strongly facilitates bone attachment. By processing this material with the LCM technology, the micro-roughness can be varied by using different layer heights and helping to produce an implant on which bone cells can anchor and grow on. Materials such as ATZ (alumina toughened zirconia) and ZTA (zirconia toughened alumina) are also suitable for dental applications. Unlike metals, there is no debate around ion release or corrosion and they have long-term stability both in soft and in hard tissue", the company points out.

In dental applications especially, LCM makes it easy to scale up the production compared to milling, not to mention that the fact that the platform uses 95% of the material used, does not prevent the reproducibility of the layers.

	CF System S65	4 x CF System S65
Implants per run	153	612
Production time	5,6 hours	5,6
Building time per implant	3 min	0,5 min
Implants produced in 24h	656	2624

Table: the table below reveals the productivity of CeraFab System S65 (103x64x320 mm³) (standalone and modular) for the production of dental implants and how the shift can easily be made from prototyping to serial production.



That being said, dental implants may be the most highlighted applications in digital dentistry, but it should be noted that LCM can also be a great fit for **dental restorations** (Bruxism, a medical term that describes a condition in which somebody grinds, gnashes or clenches his/her teeth.).

In this case, unlike conventional manufacturing processes, AM has the unique advantage to achieve thin, 'tabletop' veneers, with unprecedented accuracy.

"The process starts with a scan of the tooth, from which a digital model is created. This model is then accurately and efficiently 3D printed, minimizing material consumption compared to milling or heat pressing. Once debinded and sintered, the restoration is ready to be fitted, avoiding the removal of the healthy tooth material and therefore fulfilling the principles of minimal invasive treatment and maximum patient satisfaction", a Lithoz report reads.

And right now…?

The use of technical ceramics in medical additive manufacturing applications is quite fascinating. As a ceramic 3D printing technology company that has built its success on its close collaborations with academics, I am not surprised to hear Lithoz genuinely talks about the pros and cons of using technical ceramics and most importantly, how the limitations could be addressed. Nonetheless, what I would like to keep in mind is the various ways this conversation has shed light on the ability of LCM to deliver patient-specific solutions.

Be it through the combination of LCM and dual-material implants in bone regeneration applications or through the use of LCM for dental implants and dental restorations, Lithoz has ticked the right boxes by addressing the most significant hurdles that were slowing down the use of technical ceramics in the healthcare field, thus opened up possibilities that led to a confident use of this technology. While advancements will surely continue to be made in the field, the next urgent step might be on the side of medical and healthcare professionals. A step that consists in extensively experiencing the capabilities of these processes in order to testify to their veracity.

This content has been created in collaboration with Lithoz.

Materials

Powder Jar. Image via Sandvik

Using Hardmetals in Additive Manufacturing: Why? How? And What are the areas for improvement?

Over 75% of the 118 elements on the periodic table are made of metals. There are so many different types of metals, all of which depend on whether they are elements, compounds or alloys. In the non-exhaustive list of these materials, only a short group has the luxury to be processed by additive manufacturing technologies. Amid them, hardmetals seem to struggle to carve out a place in this niche market.

Often called cemented carbides or sintered carbides, – often written "hard metals", hardmetals are simply composite materials that are made up of a hard phase embedded in a metal matrix. Their development within the additive manufacturing sphere is a hot topic right now and before we delve into its technical advancements, it feels right to clarify that their appellation often varies from one region to another. *"In the US, the wording "cemented carbides" and "cermets" are often the most-widely used ones while hard metals or hardmetals are the preferred wording in Europe"*, **Dr. Johannes Pötschke**, Group leader hardmetals and cermets at Fraunhofer IKTS told us from the outset.

However, with the goal of remaining faithful to its origins, we would keep the wording **"hardmetals"** in this feature – which comes from the German word *"Hartmetall"*.

Anyway, these pioneering powder metallurgical materials refer to a category of materials that are sintered, hard, and wear-resisting. They are based on the carbides of one or more of the elements tungsten, tantalum, titanium, molybdenum, niobium and vanadium, bonded with a metal of lower melting point usually cobalt. Here, **Tungsten carbide-cobalt (WC-Co)** remains the most widely used hardmetal. *"It is an alloy of a hard ceramic phase, tungsten carbide (WC) and a ductile metallic phase, cobalt (Co). In other words, this metal matrix composite is made up of cobalt particles embedded in a tungsten carbide matrix"*, **Pötschke** adds.

As their word implies, what might raise the interest in a specific hardmetal over another one is the level of hardness that it integrates – unlike soft metals that are characterized by their low **hardness** and ductility, becoming therefore the materials of choice for reducing friction and improving anti-wear ability as well as increasing equipment service lifetime.

Hardness is a vital property of hardmetals. It defines their ability to withstand localized permanent or plastic deformation, penetration, scratching or bending. This means that, a material with a high level of hardness will deliver a part that will present a strong resistance to wear. Other key properties for which they are known for, include **toughness** and **strength**.

Research reveals that high hardness can reach up to 20 GPa, high bending strength up to 5000 MPa and high fracture toughness values up to 20 MPa*m1/2. Also, it should be noted that those properties can be attained if the three elements (tungsten, carbon and cobalt) are present in the two-phase state of tungsten carbide and cobalt alloy (WC-Co) and not in any possible the phase state. The route to achieve this, is therefore an entirely different matter.

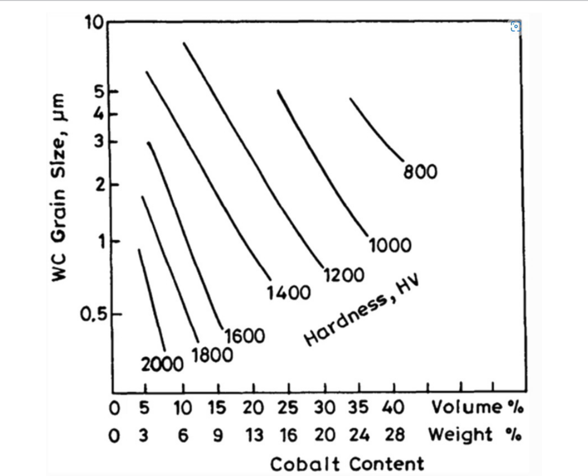


Figure shows the relationship between hardness of WC-Co samples and WC distance size and Co content.

That being said, hardmetals have often been the way to go in traditional manufacturing. They are used to be processed by a standard Powder Metallurgy shaping process which delivers green parts first, that should undergo some post-processing before getting the desired part. (The manufacturing process is similar for some technical ceramics leveraged in AM).

Furthermore, when they process hardmetals by conventional pressing, operators cannot achieve parts with complex geometries, and the manufacturing process will still require some post-processing such as machining. In any case, there is often a chance that the operator ends up with a part that delivers low porosity.

In AM on the other hand, the potential has yet to be unleashed, but given the capabilities that the technology enables across various fields of activity, organizations are currently exploring various routes that may lead to viable applications of hardmetals.

Types of AM processes that can process hardmetals - tungsten carbide-cobalt in particular.

Cemented carbide nozzle. Image: Sandvik.

It's easy to talk about AM in general because the same advantages tend to come back. What makes the conversation about AM captivating, is the nuances that may occur during the use of a specific AM process with a certain material, or for a given application.

Metals in general, are usually processed by selective laser melting (SLM), selective electron beam melting, laser powder deposition, binder jet 3D printing, and wire arc additive manufacturing (WAAM) to name a few. While stainless steels, Ni alloys, Ti alloys and some refractory metals & Al alloys are often the most highlighted in metal AM applications, it should be noted that tungsten carbide-cobalt still remains very challenging to be processed by AM technologies due to its very high melting temperature.

According to **Dr. Johannes Pötschke**, there are a lot of projects that are being conducted on the topic right now, and most of them involve the use of WC-Co hard metals on **binder jet 3D printing and sinter-based AM processes in general**.

Interestingly, with binder jet 3D printing, the "green part" obtained right after the manufacturing process can have enough strength to withstand the debinding step during which the polymer binder material will be removed before going on to a sintering process that will form a stronger and dense part. The only thing is that, given the fact that the manufacturing process requires a powder spreading step, the ***flowability*** is critical to the success of the printing operation.

Other additive manufacturing processes have been explored to process WC-Co hardmetals as well. They include SLM, Electron Beam Melting, 3D gel printing and FFF. While each of them presents its share of advantages and disadvantages, one thing we will keep in mind is that **there are still a wide range of mechanical properties issues** to address to deliver viable WC-Co 3D printed parts.

Indeed, in an AM production that involves WC-Co, **density** is a primary indicator for quality. Other indicators are related to the aforementioned main properties of hardmetals: **hardness, fracture toughness and bending strength.**

"The almost unavoidable defects, such as micro-cracks and porosities, and lack of dimensional accuracy, prevent AM processes from being widely used for producing WC-Co parts in the industry. Post-processing, such as heat treatment, hot isostatic pressing (HIP), infiltration, and machining, are often required, resulting in additional time and cost", a research on "*Additive manufacturing of WC-Co hardmetals*" reads.

Currently, several material producers & OEMs have developed proprietary solutions that addressed these mechanical issues. Material producer Sandvik is one of them. The expert in hard materials has recently introduced **3D printed cemented carbide** developed with a patented process. On the other hand, the company is also involved in GE Additive's Binder Jet Beta program to advance the manufacturer's beta H2 system into pilot lines. In the same vein, the latest company that joined this program is industrial technology provider **Kennametal** that will further advance the **Binder Jet printing capabilities in cemented tungsten carbide**.

While waiting for these announcements to lead to fruitful results, we can already share the various advantages and disadvantages we might deal with, when processing WC-Co hardmetals with other AM processes.

AM Process	Advantages	Disadvantages
Selective Laser Melting (SLM), also known as Laser Powder Bed Fusion (L-PBF)	High dimensional Accuracy High geometric freedom Less steps High hardness	High residual stress Uneven microstructure Carbon loss and evaporation of Co.
Selective Electron Beam Melting (SEBM) also known as Electron Beam Powder Bed Fusion (E-PBF)	High dimensional accuracy High geometric freedom Less steps High hardness High scan speed	High residual stress Uneven microstructure Needs vacuum
Binder Jet 3D Printing	Uniform microstructure High toughness Low cost Low residual stress No raw material loss	High shrinkage Low hardness
3D gel-printing	Low residual stress Uniform microstructure Low powder requirements No raw material loss	Large shrinkage Low hardness
Fused Filament Fabrication	Low residual stress Uniform microstructure Low powder requirements No raw material loss	Large shrinkage Rough surface

Table shows the additive manufacturing techniques that can be explored to print WC-Co hardmetals

"In summary, the above five additive manufacturing processes can be divided into two types: selective melting process and shaping-debonding-sintering (SDS) process. Selective melting processes include SLM and SEBM, which make parts by melting powder with a heat source. This type of process is very simple and enables one-step molding. But sometimes post-processing is needed to eliminate stress and defects. The SDS process includes Binder Jet 3D printing, 3DGP, and FFF. The SDS type processes are characterized by forming a green part with organic compounds as binder and then sintering. Compared with the selective melting process, the SDS process is more complicated. Because SLM, SEBM, and BJT all contain a powder spreading step, all three processes require the powder to have good flowability. While 3DGP and FFF prepare powders as slurry and filament for printing, there is no need for powder flowability. The application of SEBM is limited by its very high equipment cost. SLM suffers from uneven microstructure, carbon loss, and evaporation of Co", the research lays emphasis on.

What about applications?

"There are currently no commercial applications made possible via AM and hardmetals. Most projects are being conducted right now for prototyping or research purpose. One notable advancement is that sinter-based AM processes are ahead of the curve since they can meet the stringent requirements of hardmetals [assuming that the operators know how to deal with concerns raised by material composition, production speed, accuracy and desired part size]", Pötschke told 3D ADEPT Media.

That being said, the current lack of applications is indicative of the long route ahead to make tungsten carbide-cobalt a viable commercial application with AM. This is all the more important given the fact that when used with conventional manufacturing processes, hardmetals are pivotal to various sectors such as agricultural, textile, metallurgical, mechanical, mining, aeronautical and aerospace and medical. They are often the best choice for fabricating valves, rollers, cylinders, plates, pins, blades, nozzles, or gears, etc.

Most importantly, in the medical and healthcare industries,

Cemented carbide components. Image: Sandvik

Pötschke told us that hardmetals are mostly used with conventional manufacturing processes:

"Given the fact that they deliver the ideal [compromise between toughness and hardness], hardmetals are ideal for the fabrication of cutting tools. In the medical industry, they can serve applications in dentistry and bone tissue machining."

Jan Philippe Grage

This might not be **tungsten carbide-cobalt (WC-Co)** but a few number of companies are using pure tungsten for medical 3D printing applications. **DUNLEE** is one of them.

If you are a regular reader of 3D ADEPT Media, you may have already discovered the company through our *Opinion of the Week segment*. In this exclusive feature, we have asked **Jan Philippe Grage**, Product & Business Development Manager 3D Printing at DUNLEE to answer a short list of questions that may help us understand how (fast/slow) this niche market evolves.

3DA: Has Dunlee only explored the use of tungsten for anti-scatter grids (ASGs)? (Are there any other applications?)

Our core business is anti-scatter grids and that is also what will be a driving force of our developments in the future. However, Dunlee is also actively providing components for other medical applications such as shielding windows or collimators for X-ray tubes. Going further we are also working on new applications outside of medicine, such as nuclear fusion, aerospace, automotive or even the mining industry. This is due to tungsten:

i. high melting point making it ideal for extreme temperature environments

ii. High density making it ideal for radiation absorption or as a counterweight in small or complex geometries

iii. Long lifetime and resistance to corrosion

3DA: While there are many advantages to additive manufacturing with tungsten, there are obstacles to scaling the technology for mass production. In most cases it takes longer and is more expensive to make parts. How can we address this issue?

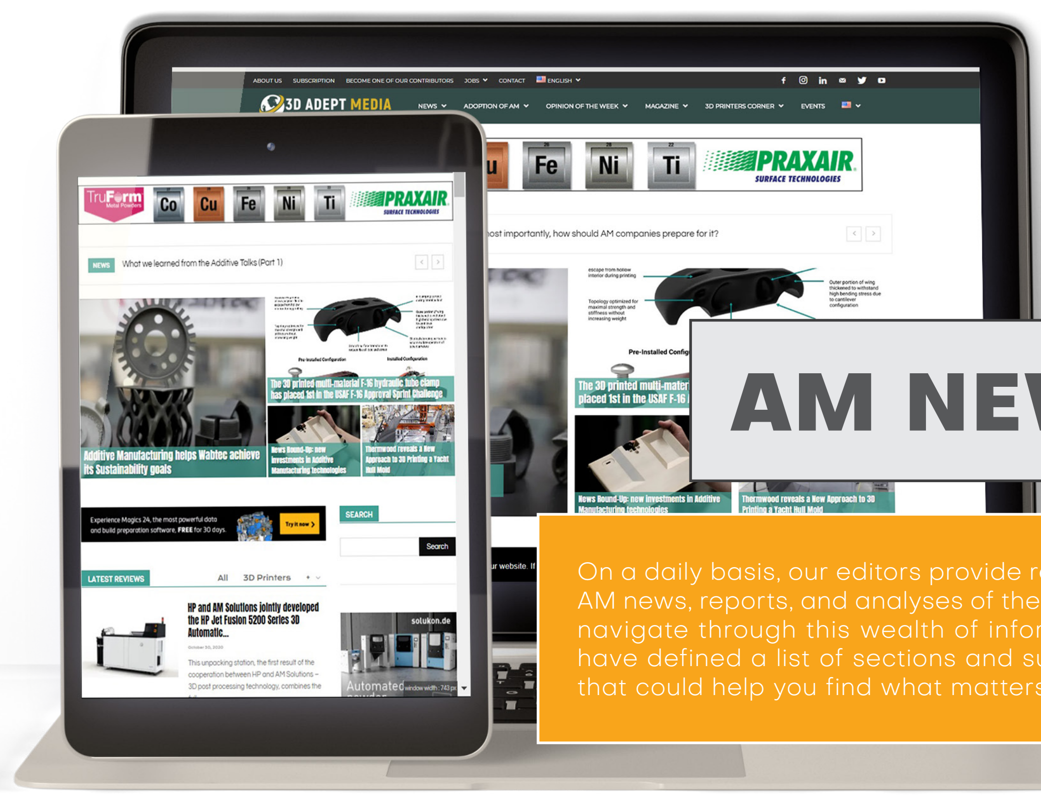
Indeed, there are cases where additive manufacturing is just not a fit in terms of price, scalability or even performance. Yet, there are still so many untapped opportunities where additive manufacturing can support production of components at volume, the right mix starting with part evaluation and design all the way to post processing need to be found. This takes time and effort but as can be seen with our major application, ASGs, is worth the development. Therefore, for companies entering these kinds of developments, they need to set the right expectations and understand that delays or even an unsuccessful investigation could be the result. When it comes to scaling, I believe a big element is finding the right partners. Partnering up within the AM field is key as many developments and potentials have not been unlocked yet, therefore you need partners across your value chain that constantly look to develop and invest the time required in order to continuously improve.

3DA: Are there any other hard metals the company has explored for medical 3D printing applications?

Till today, our strategy is to focus on pure tungsten and develop this niche metal industry. Of course, we receive requests for other refractory metals but we either managed to develop the application with tungsten or deemed the relation between that application and our capabilities a no match. We do however have it on our agenda to assess every new material opportunity that comes our way to see if there is a match.

3DA: Is there anything else you would like to share regarding the use of tungsten with AM?

For those looking into AM tungsten parts for the first time, do understand it is still not an easy task. We may be producing hundreds of thousands of parts a year but every new application has its challenges and for those new developments may be required. So do not shy away at hearing what needs to be developed first, the potential for tungsten in AM can save you costs, increase system performance or even a combination of both. What is increasingly being seen as well in the market is the opportunity to become more sustainable than with traditional manufacturing. With AM it's possible to have much smaller supply chains and can close the loop on material usage/wastage. Especially in these times, where supply chain pressure is high and everyone is facing material shortages, recycling and circular economies are becoming that more important.



AM NEWS

On a daily basis, our editors provide readers with AM news, reports, and analyses of the industry. To navigate through this wealth of information, we have defined a list of sections and sub-sections that could help you find what matters to you.

Do you have any current information related to 3D printing or a press release that needs to be published ?

Send an email to contact@3dadept.com

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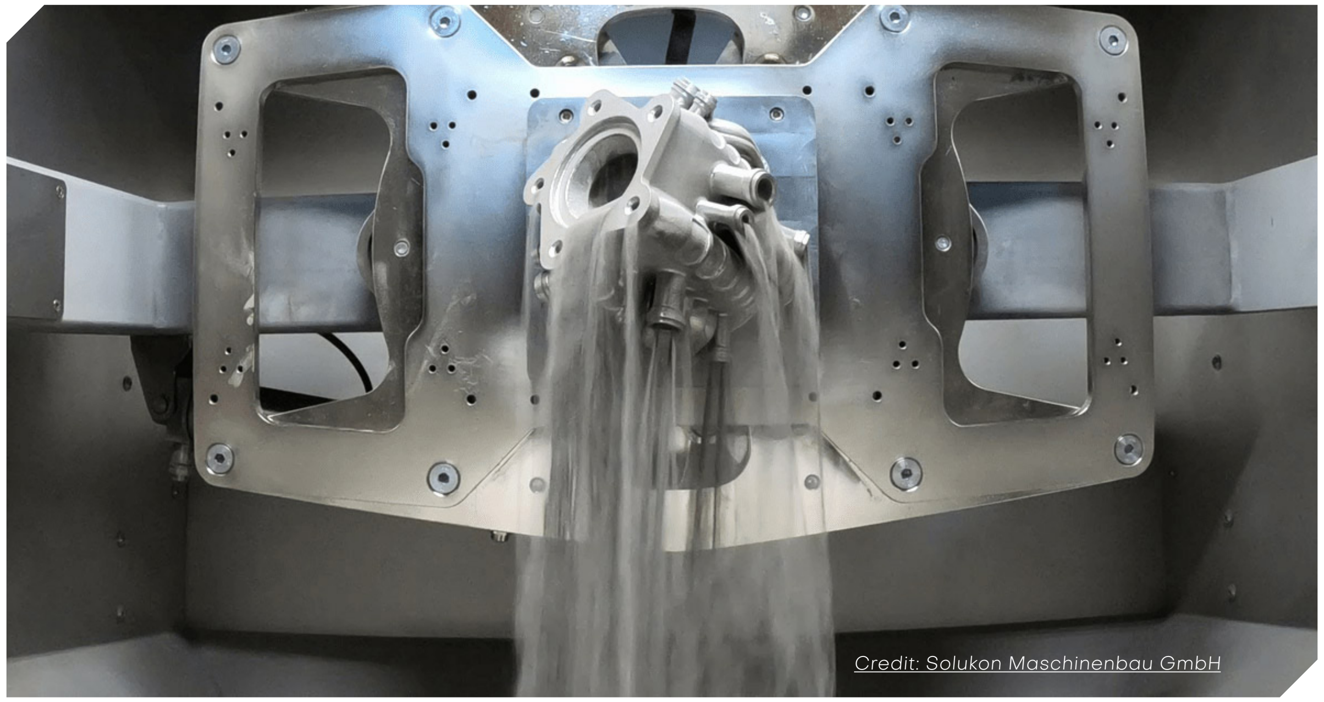

Credit: Solukon Maschinenbau GmbH

POST-PROCESSING

THE MUST-HAVE TECHNICAL FEATURES IN AN AUTOMATED POWDER REMOVAL SYSTEM

With key examples on medical 3D printing.

Most of the time when we talk to an additive manufacturing user, one of the challenges that keeps coming back when using additive manufacturing is the post-processing stage – powder removal in particular. Whether they are in the aerospace, consumer goods or medical industry, users want to be able to perform powder removal easily and perfectly. The irony here is that when additive manufacturing was not mature enough, users complained about the fact that they performed this task manually – which in the end took too much time and was expensive – but with the current maturity of the technology, users have understood the need for a machine that can do it for them, yet continue to complain. Does the current challenge lie in the lack of the right technical features within these machines? Let's put it like this: what are the technical features that will enable a powder removal machine to do the job well?

Powder removal is probably the most critical first step in the post-process chain of a finished part, especially for metals. This is because metal AM parts will frequently have heat treatment, and any residual powder will either be sintered to the outside, or worst still inside the part itself. Once that happens it's virtually impossible to remedy the part and it would be scrapped. For medical parts especially, and other critical use parts, the very last thing anyone wants, is residual sintered powder anywhere on the parts.

As you may guess, this stage of the manufacturing has raised a number of challenges that OEMs have done (and are doing) their best to overcome. Interestingly, as these are increasingly being addressed, the solutions found contribute to position AM as a serious manufacturing process for industrialization, and regulators, quality assurance managers and legal units are more eager to pay attention to other risks that may arise.

These challenges are mostly highlighted in laser powder bed fusion machines which are also the most widely used metal AM processes across industries. Let's remember that, although they are often mentioned across other manufacturing steps of the AM production, safety and health issues cause the greatest concerns during the "depowdering" process where operators might be in direct contact with the powders. Risks of explosion, costs, powder recovery, cleaning quality and process repeatability complete this list and explain the shift towards regulation and standardization. That being said, we have to recognize that human exposure to metal powders is a risk that most organizations cannot handle yet. Standards currently available do not always address all safety concerns. Most of the time, it is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to the use of a powder removal machine.

So, what are the technical features that will enable a powder removal machine to do the job well ?

Image via SMS Group

The first thing that one should understand here is that powder removal can be a very meticulous task, and when carried out manually, it can involve multiple steps to continuously check and inspect the part.

Automating powder removal can provide many advantages in this respect. As a matter of fact, an automated process is a very good support towards the possibility to validate a depowdering process. It provides consistency and greater control.

This is especially a need for regulated industries such as the medical device sector. By having a supply chain step allowing an operational reproducibility, you will get a good base to assess your powder removal performance accurately.

At the end of the day, once a process has been defined for a particular part this can be reliably repeated over and over again with a high level of confidence that the result will be the same.

As far as features are concerned, it's interesting to assess the powder removal machine's ability to not only remove residues in an effective way, but to also apply different strategies if and when required. A **clear depowering parametrization** should allow to get optimal results in the long term.

We can never stress this enough: powder removal systems must be able to adhere to strict health and safety guidelines associated with handling fine powders. In this regard, they should be equipped with an **enclosed working chamber.** The addition of **using inert gases for atmosphere control** is also an important feature.

In terms of the actual operation, a very simple technique that has been used to great effect during manual powder removal involves simply weighing the part. So the ability to monitor the weight of the part by comparing the calculated weight with that in the equipment would be a key function.

However, any automated equipment must have **a flexible configuration** since they will be required to work with many different part geometries. The **ability to add tools to end of arm robotics**, and the **ability to program the movement of the part** inside the chamber are also essential.

With the possibility of trapped powder inside parts, it is very important to study the optimized path inside the movement space of the equipment that will enable that powder to flow freely and find an exit point. For this, systems that are able to interact with 3D CAD models and interpret the optimum path would provide excellent solutions. Sometimes, extra effort is required and the use of fine point tools, gas injectors and other implements that attach to robotic arms would be very desirable, especially when dealing with medical parts that may have bone ingrowth enhancing mesh structures on their surfaces.

With only a handful of companies offering automated powder removal machines, we came to realize that some functions are increasingly demanded by operators.

The most-sought after features in a powder removal system	Description/remarks
Table size	Varies from one system to another
Vibration of the build plate	Adjustable and/or programmable vibration frequency
Access to large parts (optional)	Easy crane loading from the top of the machine/back entry for robot-loading system integration
Rotation of the build plate	Freedom of rotation allows for reaching and cleaning stuck powder inside support structures or internal channels;
Inert gas capability	Prevents explosion risks
Programmability & automation	Allows for predictable & repeatable cleaning results
Compressed air or gas | ventilator system	This helps avoid ejecting particulate matter into the atmosphere. Prevents windows from getting dusty
Glove access/ blow off gun	
Ionization unit	Reduces static electricity
Cyclone	Blasts media cleaning
Sealed dust bin	Collects dust from the filter

Needless to say that each application is unique, and may therefore have its own requirements; which is why we recommend to look at the ins- and outs of your project: the environment, the appropriate equipment and even the final purpose after the removal of powders.

What about savings?

The question of savings increasingly becomes of paramount importance in a context of sustainability. This raises several other considerations regarding production, purchase, and the viability of the powder that we have addressed in a previous feature.

As of today, it's difficult to put an actual value on savings because it depends on whether one is considering the reduced time to process a set number of parts, in a consistent and reliable way, compared to the equivalent manual operation, or whether one also wants to factor in the reduced likelihood of having any reject parts further down the process chain. A single scrap part due to unseen trapped powders could have associated costs that run into the tens of thousands of pounds/euros/dollars. Furthermore, an automated system would actually introduce cost to any operations from the capital investment, running costs, and overheads including maintenance, and these need to be factored into any cost saving analysis.

When we look at medical 3D printed parts for example, we might quickly observe that a performant depowdering will avoid issues along the subsequent supply chain steps such as heat treatment, post machining or surface treatment. This will also decrease risks related to powder contamination on final devices. Moreover, quantifying the savings of a patient infection due to powder residues on implants is not an easy task. It is however clear that we should do everything we can to reduce this risk.

Concluding thoughts

Powder removal solutions remain relatively new hence the small number of OEMs that currently deliver solutions in this regard. (You may have a look at the 2022 International Catalogue of AM Solutions to discover some of the latest solutions available on the market for this task). Anyway, one thing we can easily agree on is that there is not yet a defined guideline to the use of depowdering. The reason for that is that holistic experiences are often the way the industry learns the most about this stage of manufacturing. This means, every project should be assessed separately to get an optimal result.

The most important consideration has to be whether it makes sense or not to employ these solutions, since using automation for some parts may just be overkill, and may end up providing no real benefit to the business.

As for specifications, the AM world is a fast moving sector right now and there are an ever growing list of draft and approved specifications to govern everything from selection of powders, qualification of equipment, and certification of final parts. In the medical industry especially, the ASTM F 3335-20 standard gives a good guidance for residue removal. Lastly, all aspects of biocompatibility should be assessed according to the ISO 10993 standards.

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SOFTWARE

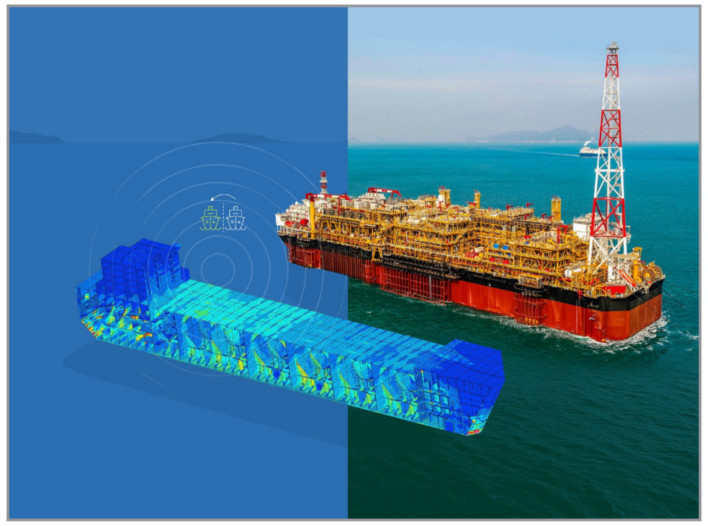
Digital Twins in (additive) manufacturing environments : what are the major challenges to overcome ?

Despite the capabilities of additive manufacturing, producing parts with only a trial-and-error approach remains time consuming and expensive. Indeed, you will never know the number of batch productions you are going to launch before obtaining the desired parts. Furthermore, there are so many reasons why an error may occur, errors that go beyond the simple design and manufacturing of the parts, that it has become crucial to ensure optimal process conditions within machines, processes and more. A Digital Twin (DT) technology might be a potential solution that can be leveraged to overcome many issues in additive manufacturing but the lack of thorough understanding of the DT concept, framework, and development methods constitute key factors that slow down the development and integration of such technology across AM production environments.

The lack of understanding of DT may often come from the assimilation to simulation technologies. The fact is, it is more than just "simulation". A simulation process replicates what could happen to a product during the manufacturing process whereas a digital twin duplicates what is happening to an actual specific product in the real world. Interestingly, the DT concept goes beyond what may happen to a physical **product**, to encompass the prediction of **production** and **performance** within specific environments. DT therefore refers to a virtual representation of a physical product or process based on a computer program. The latter uses real world data to create simulations that can predict how a product or process will perform.

In manufacturing, a DT is a virtual copy of a real-world component in the manufacturing process. This means that it uses inputs from a real-world component to mirror the real part's status, functionality, and/or interaction with other devices.

In additive manufacturing in particular, the greatest adoption of 'digital twins' would be tied to the design and manufacturing phase – according to **Duann Scott**, Consultant & Founder of Bits to Atoms. *"I have only seen performance in testing during the design iteration phase, less so in the performance of a manufactured part over time"*, he states.



While any industry that fabricates products is likely to use digital twin technology at a certain point, our focus in this feature will be to understand how the concept is applied within an AM production environment. To do so, the first step consists in understanding the potential of this technology and its framework.

What framework applies to the use of DT in manufacturing?

No matter what manufacturing process is utilized, the first step required to integrate a DT technology is to create or provide access to virtual representations of the products, machines, and environments that organizations design, manufacture or operate.

This integration therefore relies on the incorporation of CAD or 3D Modeling Tools, IoT/Connected Devices, Game Engines, version control, multi-physics simulation, data analytics, and machine learning capabilities to demonstrate the impact of design changes, usage scenarios, environmental conditions, and other variables; **the ultimate goal being to remove the need for physical prototypes, decreasing development time, and enhancing the quality of the finalized product or process.**

"To ensure accurate modelling over the entire lifetime of a product or its production, digital twins use data from sensors installed on physical objects to determine the objects' real-time performance, operating conditions, and changes over time. Using this data, the digital twin evolves and continuously updates to reflect any change to the physical counterpart throughout the product lifecycle, creating a closed-loop of feedback in a virtual environment that enables companies to continuously optimize their products, production, and performance at minimal cost", experts from **Siemens Digital Industries Software** said.

Furthermore, the convergence of these technologies indicate the **various ways DT can be used in manufacturing environments**:

- As explained at the beginning, to avoid going through a trial-and-error process, to test a new product, digital twins can be leveraged to test out updated configurations while reducing the risk of costly miscalculations. **Ingersoll Machine Tools** explored the DT concept this way to achieve better ROI targets.

- By planning out and testing new production lines using DT, operators can easily find potential issues and areas to optimize before they create the physical production line. In this case, DT helps to enhance a system design. That' exactly what Shell did for its Singapore-based Pulau Bukom Manufacturing Site.

- Innogy Ventures and Shell Ventures Back Predictive Digital Twin Pioneer with $10 Million Investment

This use of DT is gradually seen in fields such as maintenance, repair, overhauls, etc. Decision Lab Ltd and Siemens have developed a digital twin, **ATOM**, which emulates the global maintenance repair and overhaul (MRO) operations of Siemens' aero-derivative gas turbine division. The Agent-based Turbine Operations & Maintenance (ATOM) model is driven by live data already available within the supply chain. It can visualize fleet and maintenance facility operations, capture and predict key performance indicators (KPIs) of the system, and even quickly run a virtual and detailed scenery to help make decision of investment.

- Given the amount of vital information operators often collect from their machinery – information related to humidity, motion, vibration, etc.- the combined used of IoT connected devices and digital twins can facilitate their incorporation into a comprehensive view of a system, complete with real-time data. This way, if a component begins to develop an unexpected behaviour, the manufacturing team will be aware of it before it has the chance to halt production or become a hazard. At this stage, given the specifications of each manufacturing machine that can be used in a production environment, it's often easier for each OEM to develop digital twin solutions that may meet the specific needs of their technology. That's what machine manufacturer **Solukon** did with the development of its Digital Factory Tool – that it is upgrading following a partnership with Authentise.

- According to software company **Perforce**, with digital twin technology, manufacturers can provide augmented reality (AR) programs to maintenance technicians. Through AR glasses, technicians can view the most up-to-date models of the machine laid over the one in front of them. This ensures they always have the right specs as they need them.

Several projects – that ambition to demonstrate how the DT concept can serve the AM industry – are currently in progress. Furthermore, the incorporation of the aforementioned technologies (CAD or 3D Modeling Tools, IoT/Connected Devices, Game Engines, version control, multi-physics simulation, data analytics, and machine learning capabilities) definitely has a role to play in the construction of a digital twin of AM hardware, software, and related technologies, but there is no consensus yet on the right technologies to leverage for each manufacturing device. On the other hand, most of these technologies raise their share of challenges that must be overcome.

Major challenges to overcome to create a DT of AM led by dynamic data-driven application systems

The concept of DT is challenging at different levels and since it mostly makes sense to deploy it at scale, the first barrier AM teams often face is **data**.

According to Scott, *"the most challenging aspect of implementing and deploying a digital twin, is that the data typically needs to flow through different software and hardware vendors, so becomes less of a digital twin, and more of a digital quintuplet unless there is a unified file format that meets the needs of every software. Having sometimes competing companies collaborate on behalf of the customer to ensure the data is communicated without loss or fragility due to software or firmware updates can be very challenging and time consuming."*

Interestingly, other major issues often navigate around this problem of data. They include a **real-time digital representation of the physical domain in additive manufacturing, database and models, IoT and machine Learning.**

To realize the real-time digital twin of AM, it's crucial to obtain the heat transfer and thermal distribution, melt-pool solidification, residual stress and distortion, structures and properties of the 3D printed parts as well as the operation conditions of the machines. Normally, the appropriate sensors could obtain some data such as the temperature distribution.

"A lot of information needs to be computed and simulated, which is very time consuming based on the current available computing capabilities. Currently, the prediction of temperature distribution inside an AM part that is being printed with non-proprietary mesh-based finite element models will take at least several hours, if not days", a research reads.

Furthermore, the digital twin of AM needs plenty of data to train the model to improve the accuracy of the model. The data could come from experiments, sensors and numerical simulation. However, to collect and classify a sufficiently large volume of useful data is intractable, and usually the concepts of the Internet of Thing (IoT) and cloud computation may be necessary. To date, in actual production, the big data obtained from a product's lifecycle is still isolated, fragmented, and stagnant because the convergence between the product's physical and virtual space is lacking, which made it difficult to utilize the data, the same research explains.

Nevertheless, a nuance is brought for additive environments that involve modeling. Such an environment requires a lot of models, therefore too much data to verify them. However, to reduce the "computational burden", there is a great need for a temperature-dependent thermophysical properties database for commonly used engineering alloys.

On another note, to adopt a DT in AM, an effective Internet of Things system is of paramount importance for each part of the system to be linked. As seen with the Solukon Digital Factory, a smart connection for the sensors, equipment and system should be effectively achieved. Massive amounts of data in the additive process will also play a key role in the creation of a digital twin that interacts with the cyber domain by means of the Internet of Things. For this operation to run smoothly, OEMs need to ensure there is a link between existing brownfield systems and their data.

As for machine learning, this technology is important as the DT depends on the concept of data driving.

Through learning based on data gathered from various resources such as simulation, experiments, literature, machine learning could make reliable predictions on microstructure, properties and defects. This technology could extract helpful information and relationships from data instead of phenomenological guidance or explicit programming; and the solution of complex equations from physical and math problems based on phenomenological understanding could be avoided. Thus, the calculations are rapid. The quality and volume of data will decide the accuracy of the predictions, the research lays emphasis on. The good news is, it is not difficult to build machine-learning programs once we have well-tested, user-friendly, and reliable algorithms.

So, how do we foster the adoption of DT across AM production floors?

It's really weird to say, but the DT technology can be both complex and simple at the same time. Its complexity lies in the challenges to overcome – most of them revolving around data –, while its simplicity lies in the range of possibilities it allows for the prediction of products, production and performance.

Amid the **short list of software companies/collaborations** that currently develop and commercialize DT solutions for the AM industry, one notes Siemens NX, Autodesk (the Additive Simulation Extension available in Netfabb and Fusion 360), Authentise and Nebumind, Intellegens & Ansys as well as Vertex.

Moving forward, *"the quickest way to adopt digitization of the manufacturing process is to empower those working on the factory floor to implement connectivity and analyze the results. We are seeing new waves of digital tools that make this possible to implement, with less reliance on IT departments and information officers which may slow things down in getting buy-in. It is often said that every time a decision has to go 'up the chain' you half the chance that it will be understood or approved. By enabling those closest to create and connect, the time and cost of adoption is lower, and the ability to tune the connectivity by enabling those closest to create and connect, the time and cost of adoption is lower, and the ability to tune the connectivity quickly [makes it possible to leverage data in the most efficient way within] the manufacturing process"*, Scott concludes.

Image: Norsk Titanium AS

AM SHAPERS SEGMENT : MEDICAL GOES ADDITIVE, A DIVISION OF MGA

The global healthcare additive manufacturing market size is expected to be valued at USD 6.4 billion by 2028 and is anticipated to grow at a CAGR of 21.8% from 2021 to 2028, according to a new report by Grand View Research, Inc. While AM continues to gain traction across various fields of the healthcare segment, we need to recognize that this segment is truly one of its kind. With its own rules, its share of opportunities and barriers, everything has been designed to ensure that new technologies serve the vital needs of patients (end users). However, unlike other vertical industries that often present similarities in terms of integration of these technologies, the healthcare industry has often strived to grow due to its niche nature, and lack of spaces where dedicated knowledge could be shared. A few years ago, Medical goes Additive, a sister organization of Mobility goes Additive, was created to enable organization members – technology providers & users – to drive new and innovative topics, to transfer know-how and to shape the future of applications in medical technology and point of care manufacturing with custom-made solutions.

To remain committed to this mission, the network has pioneered the launch of a medical AM-dedicated event – AM Medical Days - alongside Kumovis, a 3D Systems company, ottobock and University of Basel as other founding partners. Today, as part of this executive Q&A series, we asked Dr. Cora Lüders-Theuerkauf, Network Manager MGA Medical at MGA Mobility where the organization and the medical 3D printing market are headed.

3DA: The organization's activities seem to have gained a lot of traction since the Covid-19 pandemic. How far/well have they evolved?

The world was in a difficult situation in 2020 when the EU Commission called for the fabrication of breath machines: supply chains had collapsed, official organization was non-existent, hospitals were struggling – therefore quick local solutions were the only option.

During the first wave of the pandemic, we offered two virtual meetings per week for all players using medical equipment, e.g. hospitals, suppliers, industry and F&E institutes. During our online sessions, we informed more than 200 participants about needs and solutions, for example protection equipment like face shields, masks, door openers, spare parts and others. Within our network team we tested equipment and organized donations for aid organizations. With the situation now more under control, more and more companies have broadened their field from their former core competence (e.g. automotive) towards new medical fields and are interested in boosting AM with like-minded players from the industry that can help them overcome problems that one company alone might not be able to face.

3DA: According to you, what are the most important challenges that slow down the adoption of AM technologies in healthcare units?

The implementation of MDR (Medical Device Regulation) and standards are most challenging for healthcare units since they are also suppliers for patients and therefore have a special responsibility. For us as a network, it is important to point out that no one should be slowed down but should be able to operate safely in the manufacturing of medical devices from a regulatory perspective.

3DA: What are the ready-to-commercialize medical 3D printing applications that will foster the most the use of 3D printing in the healthcare industry?

The need for individual medical applications is huge and AM offers a lot of personalized solutions. Many medical applications produced with AM are not yet ready for the market in general but are custom-made or individually adapted to the patient. Dental applications are the most common, followed by orthotics and anatomical models for pre-operative planning and education.

3DA: Are there any limitations you would like to see improve in medical 3D printing technologies?

We would like to see more focus on biocompatible materials that are suitable for both, a medical device, and a 3D printing technology. More and more new materials are entering the market such as silicone, plastics, glass, new alloys, and others. New technologies capable of processing these materials are also slowly becoming more relevant. It is important that regulatory requirements are met with all these innovations, without slowing them down.

3DA: Moving forward, 3D printing will coexist with other technologies in the theatre room. What are they? And how important do you think they are for doctors?

AM, AI, AR and robotics are an interesting quartet, as they complement each other very well. Examples are the digital twin or an AR-driven OR-robot, which is being used in a growing number of hospitals. Manufacturing times and risks in surgeries are reduced, analysis of patient data and therapy models customized to the patient are accelerated. This ensures better patient care, shorter treatments in hospitals and therefore results in real cost savings.

3DA: Anything else you would like to share?

There is a lot of potential in AM for medicine and pharmaceuticals! We now need to implement it in accordance with regulatory requirements. This includes new materials, methods & technologies as well as further use cases, which must be advanced together. Therefore, in our MGA network you will find all players of the value chain who want to work together to advance AM-relevant topics in medicine and pharmacy. We are always open for further expertise, new ideas and use cases.

Startup AREA

HOW **METSHAPE** USES INDIRECT AM PROCESS LMM FOR MEDICAL 3D PRINTING AND MORE.

Founded in 2019, **MetShape** turned stealth mode off when it secured [seed financing from AM Ventures](). The fund raising received a lot of hype as it was the first public announcement made by AM Ventures since the latter had opened a [100-Million-Euro Venture Capital Fund]() to further support AM companies.

The story goes that MetShape's journey started at the Hochschule Pforzheim as part of a project that focused on the recycling of magnets. While the results were not what was expected, the project revealed the potential of LMM technology – the manufacturing process used within the project –for the production of high-precision metal components with very good surfaces.

Today, [MetShape]() operates as a 3D printing service provider within the industry, and amid the wide range of service providers the industry abounds with, MetShape is really one of its kind.

The company is so far one of the rare companies that has dedicated its core business to delivering services with only one manufacturing process: **lithography-based metal manufacturing** (LMM). [LMM has been developed by Incus GmbH, a spin-off of Lithoz]() while MetShape is a spin-off of the Institute for Precious and Technology Metals at Pforzheim University.

"We specialize in the production of 3D printed metal components using the LMM technology and have developed ourselves as an expert in sintering. In addition to the production of prototypes and small series, we offer full-service application development and develop new materials for sinter-based AM. This qualifies us as a specialist in the industrial production of high-precision small and micro metal components", **Mike Schimmelpfennig**, Business Developer at MetShape states from the outset.

This expertise in thermal post-processing is crucial here as the heat treatment process is very well-known across manufacturing processes, but its utilization in AM processes has not always been satisfying. To acknowledge the potential of this step of manufacturing for MetShape, it's crucial to understand why LMM is described as indirect AM process.

LMM, an indirect AM approach

Lithography based metal manufacturing (LMM) is a manufacturing process that enables the creation of advanced metal models, prototypes and production parts using the principle of photopolymerization, where metal powder is homogeneously dispersed in a light-sensitive resin and selectively polymerized by exposure with light.

"In the first step, the green part is printed from a photopolymeric binder system which is highly filled with metal powder. In a second step, the green part is debinded and sintered. This means the polymers, which are only needed as a temporary binder for printing purposes, are then removed either by solvent or heat and the resulting 'brown compact' is then sintered at high temperatures to fuse the powder particles together.

The precise printing of green parts is essential for the production of a fully functional component part, but it is the sintering process that determines whether this part is dimensionally accurate and of high quality. That's why we also place a huge focus on the sintering process and have developed ourselves as an expert in this area" **Schimmelpfennig** explains.

According to Incus GmbH, an industrial 3D printer relying on this approach turns 3D files into prototypes and small-scale production of components in MIM (metal injection moulding) quality, a manufacturing process that ensures that this quality includes superior feature resolution, surface aesthetics and mechanical properties for part sizes <200 g.

"We are convinced of the possibilities and numerous advantages the LMM technology offers and therefore we see great potential for many industrial applications. Moreover, we can offer extraordinary expertise as we were actively involved in the development process of the technology within our partner network.

In the future, our unique know-how in the debinding and sintering technology, which is the core know-how in all indirect additive manufacturing processes, offers the ideal foundation for us to expand our technology portfolio for the production of precise metal components", the company's representative adds.

Applications enabled by LMM

The medical & research fields have been the first vertical where we discovered MetShape's expertise. As a reminder, the company supported the research work of CIC nanoGUNE – the Basque Nanoscience Cooperative Research Center – [by 3D printing a high-precision virus model.]()

It should be noted that medical applications often involve the fabrication of small and micro metal components with high precision which can be achieved with sinter-based additive process – components which can be produced in small to medium annual production quantities (up to 10.000).

"The appropriate use of additive manufacturing technologies is linked to certain component characteristics and constraints which are fulfilled by a large number of medical technology products as they often have a need for complex geometries, high individualization and precision which is generally associated with low production volumes. Moreover, metal components that are used for medical technology are sometimes difficult to machine. This combination proposes a perfect field of application for the LMM technology and there are many applications that LMM is suitable for. Sinter-based AM with the LMM technology can be further used to manufacture complex and filigree tools and instruments, individual implants and even threads can be functionally printed. Additionally, I would like to state there are several applications that cannot be produced any other way with the same quality and precision. We also print a lot of prototypes for companies developing surgical instruments, tools or even implants. The great potential and uniqueness of our technology are confirmed by the fact we were approached by several partners for the same component part because they found no other supplier that was able to produce the requested part", Schimmelpfennig outlines.

Mike Schimmelpfennig

When asked if LMM presents more opportunities for the medical field than any other vertical industry, **Schimmelpfennig** recalls that the use of 3D printing naturally depends above all on how open companies are towards new technologies. Moreover, he adds that, apart from medical technology, LMM can also be a great fit for other industries such as jewellery, mobility and security as well as high-frequency technology.

What's the next step for the company?

LMM might be the only AM process used by MetShape right now. However, moving forward, we might expect the company to leverage other AM technologies which will be based on sintering technology. *"These technologies offer many possibilities and accomplish precise results that direct AM procedures aren't able to achieve due to for example the staircase-effect. What's great about sinter-based technologies is that they all follow the same pattern"*, the speaker concludes.

Image: MetShape

Industry News

Innovations across demanding industries can often steal the thunder to medical 3D printing innovations. In this news roundup, we shed light on news, product launches, collaborations, and applications you shouldn't have missed in this vertical since the beginning of the year.

Applications

Samaritan Surgeon uses a new 3D printed customized training model to perform two surgeries

Layron Long, MD, medical director of the Department of Urology and chair of robotic surgery at Good Samaritan Regional Medical Center, became the first surgeon in the Pacific Northwest to use a new 3D printed customized training model before performing two surgical cases.

The technology, **Pre-Sure®**, created by Oregon-based medical device company, Lazarus 3D, allows surgeons to rehearse complex surgeries on a soft, realistic silicone model created directly from scans of a patient's actual organ. The technology was recently approved by the FDA for use as a diagnostic device for pre-operative surgical rehearsals.

"Allowing surgeons to rehearse surgery on a realistic model could someday decrease the time for operations and reduce surgical complications," **Dr. Long** said.

As an experienced and skilled surgeon, Dr. Long said he would consider using this technology for complex surgeries, such as when there are lesions and blockages of the kidney, and it can be hard to see the transition points with traditional imaging including CTs and MRIs.

"If you're going to run in a race, you don't just do it. You practice," explained **Dr. Long**. *"It's the same concept with this technology."*

In the two cases performed since December 2021, Dr. Long set up a rehearsal with Pre-Sure® using the da Vinci® robotic platform at Good Samaritan Regional Medical Center. Since 2010, Samaritan's robotic-assisted surgery program has changed how doctors perform surgery, enhancing patient care and improving outcomes. The da Vinci surgical system gives doctors an alternative to both traditional open surgery and conventional laparoscopy.

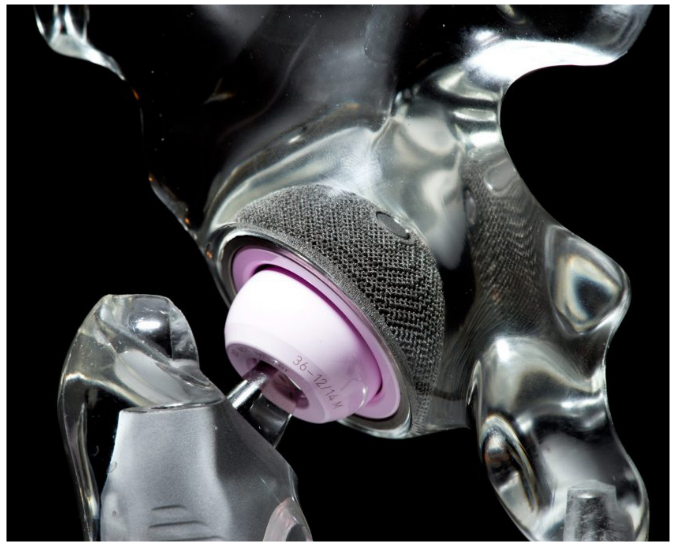
The surgeries Dr. Long rehearsed using the synthetic soft-tissue models, including the removal of a complex tumor from the kidney, were both successful.

"I went in before and practiced the surgery, performing the incision and the reconstruction," he said. *"It was a tough case. The technology helped me go in with more confidence."*

Dr. Long, who also serves as an assistant professor at Western University of Health Sciences College of Osteopathic Medicine of the Pacific-Northwest, said another application for this technology is to lessen the learning curve for new surgeons to become proficient.

He can envision a future where surgical residents could practice on lifelike 3D models to improve their skills.

"From an educational standpoint, these models could help bridge the learning gap and boost confidence," Dr. Long said.



First surgeries completed with Patient-Specific 3D printed Implants

Produced at the Limacorporate Promade point of care center at Hospital for Special Surgery

The collaboration between LimaCorporate S.p.A., a global orthopedics manufacturer, and Hospital for Special Surgery (HSS) reached a new milestone as both companies successfully conducted two complex joint reconstruction surgeries using patient-specific solutions designed and produced with 3D printing.

As a reminder, LimaCorporate's strength in medical 3D printing also comes from the acquisition of TechMah Medical it conducted four years ago in order to improve its offering of 3D printed Orthopaedic implants.

As part of this project, the LimaCorporate team worked in collaboration with expert surgeons, such as Dr. Robert L. Buly, MD and Dr. **Patrick Connor**, and the health care institution of HSS to perform two procedures: a hip procedure and a shoulder procedure.

The ProMade PoC Center offers the opportunity for enhanced collaboration between the design and manufacturing engineers and the surgeons to develop patient-specific solutions before being 3D printed in the onsite facility. It reduces by weeks the time to surgery and has become a resource available not only to HSS physicians, but to providers and hospitals throughout the U.S.

The center, established through a long-standing strategic relationship between HSS and LimaCorporate, is an FDA-regulated commercial facility located at the HSS main campus in New York City. The aim of this innovative, first of its kind project is to provide faster and more accessible care for U.S. patients requiring personalized and unique complex joint replacement solutions.

Collaborations

Colgate and Nourish3D to provide 3D Printed Supplements for Oral Health

"This limited-edition range of vitamins target better oral and body health and adds a whole new dimension to personalising your health care", Melissa Snover comments.

A poor oral hygiene can lead to a number of health problems including ulcers, pain, inflammation, loss of teeth, dryness of the mouth, swelling to name a few. Yet, amid the targets we set ourselves for improving our overall well-being; a lot of things can be mentioned (exercising, healthier foods, drinking more water) but not bettering one's oral health.

Nourish3D ambitions to make it a lifestyle goal as it partners with oral health care expert Colgate, to improve oral health care. As you may know, Nourished is an avid proponent of supplements created using 3D printing.

As part of this partnership, both companies have worked together to develop a '***Limited Edition Nutristacks***', a range of chewies that can help build stronger teeth and provide enamel protection.

Not only are they packed with high-impact, fast-absorbing nutrients, but each *"Nutristack is 3D printed fresh on demand to ensure optimum efficacy and absorption levels, and get to work as soon as you start chewing. In addition, they are sugar-free, plant-based and absolutely delicious"*, according to Nourished.

This high-impact chewie is made with scientifically backed ingredients and 14 patented technologies. However, three ingredients included in this production currently stand out from the crowd:

Arginine: described as an ingredient that energises good bacteria in the mouth and that can strengthen your body's natural defence against cavities. This helps to protect the biofilm from a drastic drop in pH levels which can result in gum disease, dental decay and bad-smelling breath.

Xylitol which can enable to lower acid production by bacteria, protecting this way the strength of your enamel in the process. This anti-plaque agent enables oral microorganisms to produce fewer lipoteichoic acids and protect against gum disease.

And the well-known **Calcium**, which is needed for the maintenance of normal teeth, but also contributes to normal energy-yielding metabolism.

That being said, despite the excitement around this new vitamin, it's crucial to note that one cannot replace the daily teeth brushing by a Nutristack. And I believe the addition of Nutristack to your healthcare routing should be seen as a fun way to take care of your oral health, unlike other health measures we take.

In the long run, I may be still dubious regarding a lot of food products that are being 3D printed but I am not when it comes to personalized medicines. I see immediate value to leverage test scores and other crucial factors to create a custom 3D printed nutrient or food that can bring a myriad of benefits to those who suffer from a specific disease, athletes or simply those who are looking to improve their overall health.

Nvision Biomedical Technologies and Watershed Idea Foundry receive FDA Clearance for 3D Printed Anterior Cervical Plate

Nvision Biomedical Technologies, a medical device and implant manufacturer and Watershed Idea Foundry have been granted FDA Clearance for a 3D printed titanium anterior cervical plate, the **Quantum Titanium Cervical Plate System**. So far on the market, we witnessed the validation of several 3D printed titanium anterior cervical cages.

Nvision Biomedical Technologies explain that the Quantum system enables design freedoms which push clinical benefits to new levels and ultimately impact patient care. It offers multiple specialized features, including a nested assembly in which the screw-locking cover is 3D printed as a single unit inside the anterior cervical plate, and dual-plate finishes with a textured posterior surface and smooth, polished anterior surface. Enhanced screw holes accommodate 30 degrees of cephalad/caudal angulation, which allow the surgeon to use a shorter plate. Additionally, the Quantum system incorporates Structural Encoding® capabilities to address FDA Unique Device Identification (UDI) requirements. This adds up to a more elegant construct design with anatomically optimized placement and increased procedural options and flexibility, which potentially means less time in surgery to benefit both surgeons and patients.

"Combining multiple components into single nested 3D printed assemblies is one example of such an advancement, which can provide supply chain cost and timeline advantages while reducing patient risks of component disassembly. Nvision's willingness to champion additive manufacturing innovation into a commercial product made for an ideal technology transfer scenario", said **Nick Cordaro**, CEO of Watershed Idea Foundry.

Nvision's Senior Vice President of Product Development, **Tom Zink** added, *"By additive manufacturing the Quantum system, we leveraged design options that were not available with machined plates. The active* *locking system is integrally printed within the plates, and therefore never assembled, which means the locks cannot become unassembled in the surgical field. The posterior side of the Quantum plates present texture to allow for osteointegration and is designed to allow the plate to absorb load that with traditional plates is fully on the screws. With the hyper angulation of the screw holes design, the surgeon has the option to place the screws as far away from adjacent levels as possible."*

As sister organizations within the Fountainhead Investment Partners portfolio, Nvision and Watershed have previously collaborated on other innovative projects, such as Structural Encoding and 3D printed wedges and interference screws.

Usmih leverages Photocentric's LCD 3D printing to develop new manufacturing process for dental applications

Ukrainian aligner experts, **Usmih** has reimagined the manufacturing process of dental applications with a new aligner manufacturing process. Usmih brings here an expertise in 3D printing, materials science and automation. Photocentric's expertise in developing dedicated 3D printers and materials for this specific industry as well as its Engineering and Chemistry teams are the main reason why Usmih chose them for a partnership.

Based on Photocentric's solution, the new solution requires the use of **Photocentric LC Magna printers** and **Photocentric resins**, as well as a **conveyor belt solution** that enables rapid curing of aligner models.

So far, we may have seen Photocentric LC Magna printers in action in a consumer application but these 3D printers' consistency and speed of prints can also meet the needs of dental applications.

With the ability to manufacture products in hours, not days and months, the LC Magna 3D printers is convenient for dental aligner manufacture. It features a quad processor for enhanced performance, optimised platform coating for improved printing and cleaning, and upgrades to the control system for superior reliability and accuracy. Magna allows Photocentric partners to deliver accurate end-use parts consistently, at scale and also rapidly, with new printing materials capable of increasing print speeds to 16mm per hour and beyond.

Photocentric and Usmih are remaining tight lipped about how the improved aligner process will work, but both companies are very happy with the progress that has been made to date for the end-to-end solution. Usmih expects its process to be ready for full production by the start Q1 in 2022.

3D Systems & Saremco Dental AG join forces to enhance 3D Printing applications in Digital Dentistry

AM company 3D Systems and materials expert Saremco Dental AG joined forces to advance 3D printing applications in digital dentistry.

As part of this partnership, 3D Systems brings a NextDent® digital dentistry solution while Saremco will share its materials science expertise. They ambition to enable dental laboratories and clinics to address a variety of indications with unparalleled accuracy, repeatability, productivity, and lower total cost.

"Our goal is to enable dental professionals to become more efficient and by doing so, ultimately improve patient outcomes," said **Stef Vanneste**, vice president and general manager, dental, 3D Systems.

To facilitate these capabilities, the companies are also announcing the immediate availability of **CROWNTEC™** material to be used with 3D Systems' **NextDent 5100 dental 3D printer** and industry- software for the production of patient-specific permanent crowns.

CROWNTEC is a composite resin that can be used to additively manufacture biocompatible permanent restorations including crowns, inlays, onlays, veneers, and artificial teeth for dentures. This CE-marked Class IIa material, which also recently received 510(k) clearance is offered in a variety of shades to match the patient's teeth for a natural-looking aesthetic. It does not contain any volatile organic compounds thus contributing to CROWNTEC's excellent biocompatible properties. Employing CROWNTEC as part of the NextDent digital dentistry solution enables dental laboratories and clinics to produce these dental devices that are 30% stronger than those produced using previous generations of crown & bridge (C&B) materials while reducing material waste, a press release reports.

Trestle Biotherapeutics Licenses Innovations from Harvard University to Develop 3D Biofabricated Tissues to Treat Kidney Failure

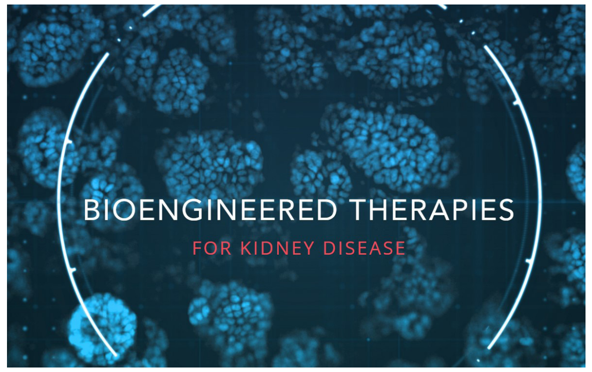
Trestle Biotherapeutics, a private company based in San Diego, today announced that it has entered into a license agreement with Harvard University. Under the agreement, Trestle will commercialize a suite of stem cell- and 3D biofabrication-based regenerative medicine technologies developed at Harvard's Wyss Institute for Biologically Inspired Engineering, Harvard John A. Paulson School of Engineering and Applied Sciences (SEAS), and Brigham and Women's Hospital.

The core of the technology being licensed to Trestle was developed by a multi-disciplinary research team in the laboratories of Jennifer Lewis, Sc.D. and Ryuji Morizane, M.D.

Trestle is developing functional kidney tissue to supplement and replace lost renal function in kidney failure patients. Trestle is building these novel tissue therapeutics through the integration of stem cell biology and 3D biofabrication technologies. As of 2021, there are more than 100,000 patients waiting for a kidney transplant and more than 550,000 patients who are dependent on dialysis for survival.

"Patients living with kidney failure have had the same two standard-of-care treatment options for more than 60 years. We are really excited to embark on the ambitious mission of changing that and building upon the work of the Lewis and Morizane labs towards making this a reality for those patients," said **Ben Shepherd**, Ph.D., Co-Founder and CEO of Trestle.

The technology to be commercialized by Trestle not only enables the rapid fabrication of vascularized kidney tissue at scale for regenerative medicine solutions, but also paves the way for increasing tissue maturation and vascular development within stem cell-derived organoids in response to fluid flow. These are essential components of building large, functional tissues which will one day be used to supplement, or even replace, renal function in kidney failure patients.



"Trestle was founded with the belief that recreating patterns and processes found in nature is key to building functional tissues. The next era of cell therapies and regenerative medicine, particularly for addressing diseases arising from complex organs such as the kidney, will rely on the integration of multiple advancing disciplines. Developmental biology, stem cell biology, and 3D biofabrication are core components of this approach. We look forward to integrating the innovative work from Drs. Lewis and Morizane into the platform we are building," said **Alice Chen, Ph.D.**, Co-Founder and CSO Trestle.

Product launches

Evonik unveils osteoconductive VESTAKEEP® Fusion PEEK filament for 3D printed implants

Any company that is operating in medical 3D printing is well aware of the potential of **PEEK** for applications in this field, when using FDM 3D printing solutions.

The material is a natural colored, high viscosity polyether ether ketone (PEEK) Filament, which is specially designed for long term implantable medical devices. One company that continuously invests extra miles to develop new forms of PEEK materials is **Evonik**. The materials producer has added a new osteoconductive PEEK filament to its **portfolio of 3D printable biomaterials**. The new material comes to strenghten the company's ambition to advance medical 3D printing applications. In addition to VESTAKEEP® i4 3DF and VESTAKEEP® Care M40 3DF, the portfolio includes the RESOMER® line of bioresorbable filaments, powders and granules for implantable medical devices.

Key specifications of Evonik's VESTAKEEP® Fusion product line

Named **VESTAKEEP® iC4800 3DF**, the biomaterial is part of Evonik's **VESTAKEEP® Fusion product line** launched in 2020 and is developed under strict quality management for biomaterials. With a diameter of 1.75 mm, it is available in natural color and is wound onto 250 gram or 500 gram spools. It can be processed in common extrusion-based 3D printing technologies such as fused filament fabrication (FFF) and is designed to improve fusion between bone and implants.

The new biomaterial would enhance quality of life due to faster bone healing and by delivering biocompatibility and biostability as well as improved osteoconductive properties.

The company explains in a press release that the osteoconductivity was achieved by using a functional special additive – **biphasic calcium phosphate** (BCP). The BCP additive allows bone cells to adhere to implants more quickly, thus positively influencing the boundary, so called osteointegration, between the bone and the implant. This, in turn, will accelerate bone fusion and thus patient recovery.

From a manufacturing standpoint, tests conducted so far reveal that the material can be easily processable. Furthermore, the functional additives are available directly on the surface of the 3D printed implant without further post-processing steps – a **novelty for osteointegrative PEEK biomaterials**, Evonik states in a press release.

"No other application field showcases more the classic advantages of 3D printing, such as individualization or design freedom, than medical technology," says

Marc Knebel, Head of Medical Systems at Evonik. *"Since the product launch of the first PEEK filament a good three years ago, we have been expanding the possibilities of modern medical technology in the individual treatment of patients using additive manufacturing by constantly developing new innovative biomaterials."*

Lastly, as far as applications are concerned, it should be noted that Evonik's 3D printable biomaterials can be used to manufacture medical device parts designed for temporary and permanent body contact.

Desktop Health Launches new series of Dental 3D Printers called Einstein – and new dental resin

Desktop Health, a healthcare business within Desktop Metal, has announced a new series of products for dental applications. Named after one of the greatest physicists of all time, the Einstein™ series reaffirms the company's commitment to develop 3D printing solutions for personalized medicine.

The new portfolio includes a high-precision family of 3D printers designed for dental professionals, and **Flexcera™ Smile Ultra+**, a strong dental resin that has already received FDA clearance for permanent use.

The 3D printers include the **Einstein**, designed for general dentists, enabling chairside printing; the **Einstein Pro**, designed for small dental labs and specialists; and the **Einstein Pro XL** designed for high production dental labs offering the largest build envelope within the series.

With speeds up to 50 percent faster than its predecessor, the Einstein 3D printer leverages a combination of powerful technologies to deliver the most *"accurate fit and natural-looking finish with stunning clarity"*. They include the Digital Light Processing (DLP) technology, the proprietary NanoFit 385 technology and the Hyperprint™ technology to ensure the print benefits from the power of heat and a closed-loop software upgrade.

"The Einstein 3D printer, coupled with our next-generation Flexcera Smile Ultra+ resin, is a major breakthrough for the dental community," said Michael Jafar, President & CEO of Desktop Health. "Combining advanced resin science with 3D printing technology delivers superior strength, aesthetics, and durability. A dentist can now print veneers, bridges, crowns, dentures, inlays, onlays and more in minutes. Beautiful, functional, same-day dental prosthetics with ceramic-like strength are now possible – with the added bonus of cutting patient waiting times from weeks to mere hours."

As for the resin, it was first introduced in 2020 as Flexcera™ Smile for temporary dental applications. The next-generation Flexcera Smile Ultra+ is described as an FDA 510(k) cleared Class 2 medical device for permanent, printable dental restorations. It has been formulated with the strength of ceramic coupled with long chain chemistry to ensure ideal properties. When used in tandem with the Einstein 3D printers, dental providers can now print same-day smiles, including crowns, bridges, veneers, full and partial dentures, the company says in a press release.

According to the company, the new resin delivers high fracture resistance, three times more resistant to fracture than select competitive resins; moisture resistance to prevent staining or discoloration, two times more resistant than a leading competitive formulation; and an overall natural aesthetic that offers lifelike tooth translucency and a natural-looking smile, providing a perfect blend of comfort, strength and flexibility.

Improving therapy modulation and patient comfort with 3D-printed, biocompatible patient-specific boluses

Approximately 50% of patients diagnosed with cancer will receive radiotherapy as part of their treatment. To help target the radiation during treatment, the provider (e.g., medical physicist, dosimetrist, radiation oncologist) will use a bolus—a flexible device that conforms to the patient's skin. Off-the-shelf boluses can often leave gaps between the device and the patient's anatomy, which can result in insufficient dosing and may also expose adjacent anatomy to undesired radiation.

To address this issue, 3D Systems has debuted on the radiation oncology market with FDA 510(k) clearance of **VSP® Bolus**, a solution designed to deliver patient-specific radiotherapy treatment accessories.

The new solution completes its VSP portfolio of personalized medical devices. When combined with additive manufacturing, it will enable the company to deliver 3D-printed, biocompatible patient-specific boluses that can improve therapy modulation as well as patient comfort.

The **VSP® Bolus** functions as a plug-and-play solution since it is a full design and production service based on the patient's treatment plan. This means, radiotherapy providers do not need specialized design software and expertise.

With VSP Bolus, 3D Systems can design and deliver boluses that conform to a wide range of anatomies. The process begins with the patient's imaging data and input from the radiotherapy professional. Using this information, VSP Bolus is designed at the requested material thickness to optimize the radiotherapy targeting. With these capabilities built into the solution, radiotherapy professionals are freed from the time-consuming task of creating the design and fabricating the accessory themselves. Once designed, 3D Systems' engineers employ the company's additive manufacturing solutions to produce a high-quality bolus from a soft material that contours to the patient's anatomy, enabling more efficacious treatment and a more comfortable experience, a press communication reads.