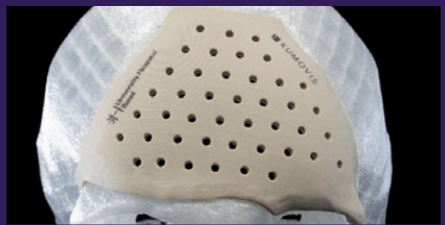
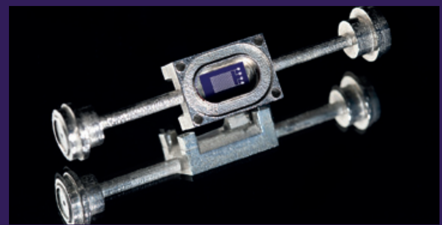
Swiss AM Guide 2023

Exploring new applications in additive manufacturing

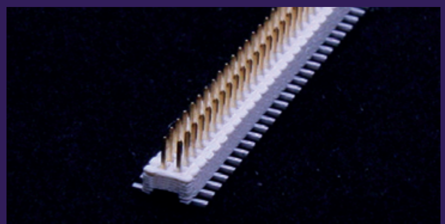


Showcase 1
Patient-specific cranial implants



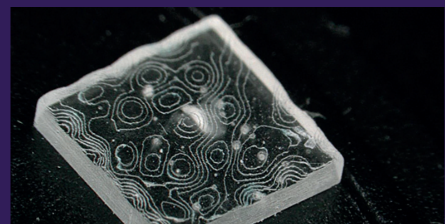
Showcase 2
Highly integrated thermal control system

Showcase 3
Personalized prosthetic gripper



Showcase 4
Individualized electronic connectors

Showcase 5
Patient-specific neurostimulator



Showcase 6
Glass additive manufacturing of optical devices

Showcase 7
Hybrid additive manufactured impeller

Editorial

Dear readers

The recent history of Additive Manufacturing (AM) has been characterized by waves, alternating between phases of hype and consolidation. Since our last report in 2020, AM was again brought to the public eye through the context of multiple crises. When the global manufacturing industry halted due to the Covid-19 pandemic, AM stepped in to produce dearly needed personal protection equipment and other critical healthcare products. The continuing climate crisis requires a sustainable economy. AM plays an important role in reducing the carbon footprint of the entire product life cycle. With ongoing disruptions in global supply chains, manufacturing leaders are growing increasingly curious about AM's capabilities and how they can be leveraged to make their production systems more flexible, resilient, and shock-proof.

With the Swiss AM Guide 2023, we want to provide you with the most up-to-date developments in the AM industry. This report presents seven highly advanced showcases of AM and covers the main fields of application as well as major AM technologies and materials. The showcases are based on interviews conducted by experts from the IWK Institute for Materials Technology and Plastics Processing and Inspire. The case studies show the successful outcomes and discuss the challenges and stories behind.

We hope this report gives you the impulse and inspiration to excel at your own AM projects in your organization.

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Patient-specific cranial implants manufactured at the point-of-care

The University Hospital Basel developed a workflow for point-of-care manufacturing of patient-specific cranial implants.

With recent developments in AM materials and machines, healthcare institutions are increasingly deploying AM at the point-of-care (POC). Having AM in proximity to the theater of operation opens a wide range of potential use cases, including anatomical models, personalized surgical guides, prostheses, and even customized or patient-specific implants (PSI). Especially when it comes to PSI, POC manufacturing can lead to substantial benefits, such as shorter turnover times, cost savings, and improved treatment routines. The Swiss Medical Additive Manufacturing research group (Swiss MAM) of the University Hospital Basel (USB) is currently working on a POC manufacturing workflow for custom cranial implants that could revolutionize the field.

The Swiss MAM research group at USB, led by Prof. Dr. mult. Florian M. Thieringer (Group Head) and Dr. Neha Sharma (Deputy Head), have been actively investigating the application of AM for reconstructive purposes, including the use of both metal and polymer AM. For the creation of customized cranial implants, the USB is using a polymer material-extrusion 3D printer from Kumovis, a German-based machine manufacturer specializing in medical industry systems that was recently acquired by 3D Systems. Thanks to its temperature management system based on laminar flow, the 3D printer can manufacture parts using high-temperature thermoplastic polymers like polyetheretherketone (PEEK) or polyetherketoneketone (PEKK). Furthermore, its integrated filter system allows it to be operated under clean room conditions, which is of paramount importance for medical applications.

The customized implant creation process at the USB starts with medical imaging data using computed tomography scans that are then processed in-house by biomedical engineers. The resulting 3D anatomies are used for surgical planning and implant design. The cranial implants are designed to ideally fit the patient's anatomy and are then manufactured on the material-extrusion 3D printer at the POC—next door to the operation room. After production, the implants go through post processing, i.e. the removal of support structures and sterilization—all of which is done in-house at the USB. The implants are then ready for implantation. With all production process steps taking place in-house and nearby, it is possible to reduce the time it takes to complete the entire process, from implant design to post-processing, to less than a week. This is made possible by the streamlined and efficient workflow that the Swiss MAM research group at the USB has developed for the POC manufacturing of customized PEEK cranial implants using AM technology.

Up next, the USB is planning to fully roll out the process for AM cranial implants soon. The validated workflow could also be translated to other applications, such as orbital and jawline implants. Other fields of future research lie in integrating an intra-operation workflow. With the emergence of a fast and robust implant design and production process chain, implants could be created during the operation process, thereby vastly improving treatment conditions for patients. The current developed workflow, therefore, represents an essential building block for the design and production of future medical implants.

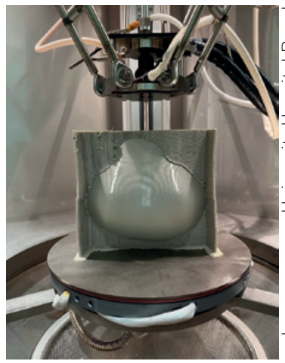


Image source: University Hospital Basel

1


Image source: University Hospital Basel

2

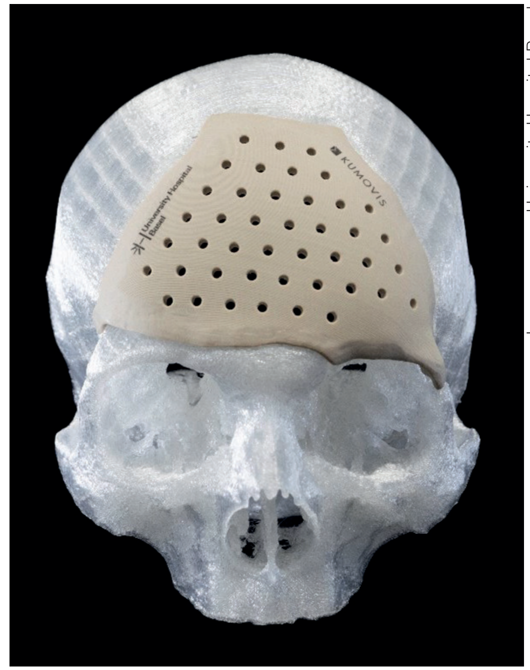


Image source: University Hospital Basel

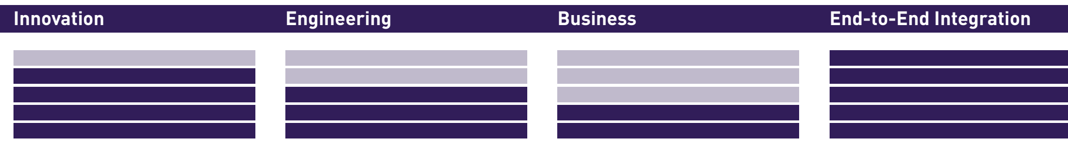
3

Customer	**University Hospital Basel**
Manufacturer	**University Hospital Basel**
Technology	**Polymer material extrusion**
Material	**PEEK**
Machine	**Kumovis R1**
Produced quantity	**›30**
Part bounding box	**Not applicable**

1
Material extrusion 3D printed PEEK cranial implant with support structures (in situ)

2
In-house 3D designing process for customized cranial implants

3
Customized PEEK cranial implant



Highly integrated thermal control system with embedded sensors and energy harvester

Together with its partners, CSEM is working on a new generation of AM thermal control systems.

Thermal control systems represent critical components of high-performance devices, such as satellites and particle detectors. Important fluid parameters like pressure, temperature and flow rates must be accurately monitored to control those systems. When made conventionally, the integration of multiple sensors makes these devices heavy, bulky, and laden with many connectors and cables.

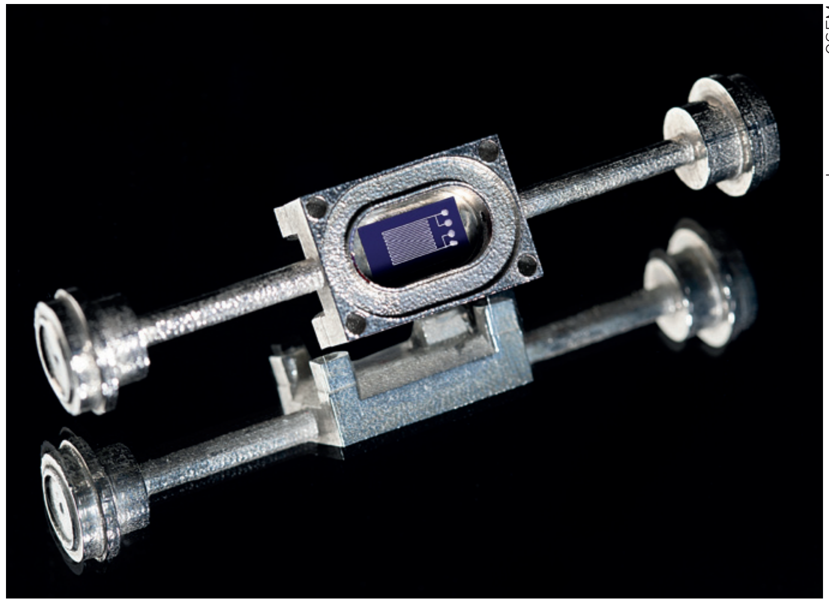


Image source: CSEM

1

To overcome the current constraints related to weight and size, CSEM is working on a new generation of AM thermal control systems. Within an EU-funded project led by CSEM, the six partners are developing an AM pipe segment that integrates printed temperature sensors, heaters and an energy harvester.

The smart pipe segment is produced through a series of multiple AM and conventional manufacturing steps. The workflow starts with the laser powder bed fusion (PBF-LB/M) of the pipe segment using stainless steel 316L. To integrate the temperature sensor and heater inside the pipe, the process is then stopped at a specific height, followed by a process of de-powdering and cleaning. Aerosol jet printing (AJP) is used to build the sensor and heating element onto the PBF-LB/M segment. The basic principle of the AJP process is the highly precise deposition of conductive and insulating inks, followed by thermal and photochemical processing. The sensor of the thermal control system consists of electrically conductive tracks encapsulated within two layers of insulation. The heater is manufactured in a similar way. The smart pipe segment also includes an electrical feedthrough for data and power transmission. The physical connector and electrical wires are directly manufactured using PBF-LB/M based on the CSEM patent EP3740382. To hold the wires in place, support structures are needed, which are removed at a later stage. To insulate the electrical feedthrough, the structure is filled with insulating resin.

CSEM is also working on integrating a mechanical energy harvesting system—developed by the startup InanoEnergy—into the smart AM pipe. The realization of this feature would provide electrical energy to the AJP sensor, enabling a standalone operation that is highly desired in many application scenarios. The energy harvesting principle is, in this case, based on the oscillation of a membrane to transduce the mechanical motion of the fluid into electrical energy.

Currently, CSEM is investigating the implementation of sensor-equipped pipes in two fields of application. The first area is related to silicon detectors used at CERN. Furthermore, CSEM is working on research with Thales Alenia Space (TAS) on the application of a novel system in telecommunication satellites. The reduced weight and size, in combination with the improved precision in temperature control, presents significant benefits when compared to conventional systems.

This project coordinated by CSEM has received funding from ATTRACT, a European Union's Horizon 2020 research and innovation project under grant agreement No. 101004462. Apart from those cited in the text, further project partners include LISI Aerospace Additive Manufacturing (responsible for PBF-LB/M) and the Norwegian University of Science & Technology (NTNU), which oversees the validation tests on an industrial refrigeration system.

Customer
Thales Alenia Space, CERN, NTNU

Manufacturer
CSEM, LISI Aerospace Additive Manufacturing, InanoEnergy

Technology
PBF-LB/M, Aerosol jet printing

Material
Stainless steel

Machine
EOS M400

Produced quantity
About 10 prototypes foreseen

Part bounding box
120 x 25 x 25 mm^3

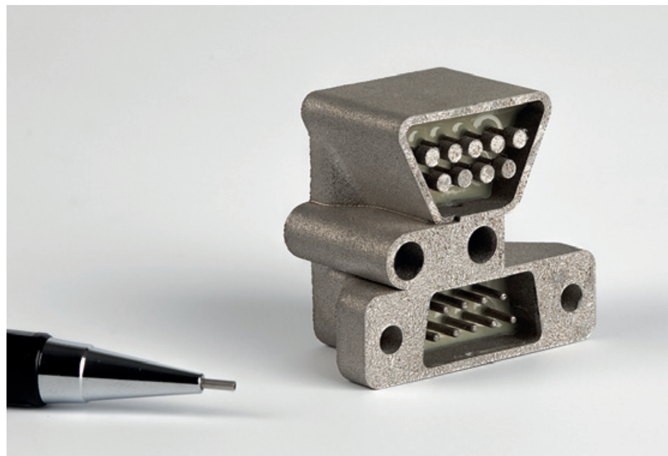


Image source: CSEM

2

Image source: CSEM

3

1
Smart pipe element with fluidic and electrical interfaces and embedded sensing capabilities

2
Electrical feedthrough casted with epoxy

3
Conductive ink tracks manufactured with the aerosol jet printing process

Highly integrated prosthetic gripper based on a compliant mechanism

macu4 has developed a highly integrated prosthetic gripper, which is manufactured with laser powder bed fusion and is actuated by a compliant mechanism.

When it comes to prostheses, patients can choose between standardized, off-the-shelf products, or individualized, handcrafted aids that are associated with high costs and long lead times. The Zurich-based startup macu4 aims to improve patient care by offering individualized forearm prostheses made with AM. Their core product is a modular prosthesis system that does not rely on active actuation, thereby avoiding heavy and costly electronics. As a result, macu4's products are more affordable and lightweight than existing solutions.

The key component of their modular system is an individualized socket that can be extended with various functional modules. These extensions include, for instance, modules for cycling, swimming, or ball handling. The socket is personalized to ensure a comfortable and firm fit. The measurements required for personalization can be taken with the assistance of a prosthetist or by the user themselves via a photography-based approach. Users can download and print out a reference sheet, which is placed underneath the arm together with a credit card or similar-sized object. With the help of multiple photos, the 3D geometry of the arm can then be approximated.

To streamline the design generation of the complexly shaped socket, macu4 developed a web-based configurator. Based on the measurement inputs, the tool automatically creates the 3D geometry of the shaft, greatly reducing both development time and cost. The 3D design is then forwarded to a select, certified production partner. Due to the digital nature of their process chain, macu4's business model is highly scalable.

The newest module of the startup is a flexible gripper that is actuated by a fully mechanical, compliant mechanism. The module is functional for a wide range of gripping applications, such as holding a pencil or playing cards. The system consists of two main components. The flexible TPU gripper integrates the compliant mechanism. The gripper closes automatically when the force acting on the hinge exceeds a certain threshold. This part also incorporates two slits for holding cylindrical objects, like a pencil for example. The threshold of the compliant mechanism can be tuned with the rigid bottom made from PA12. Depending on the screw tension in the lamella arc, the actuation and holding force of the gripper can be adjusted. Moreover, the bottom incorporates a ball joint and a quick fastening lever. The joint enables a 180° rotation of the gripper in every direction. A rubber coating on the ball joint ensures the right level of friction. Due to its highly integrated design, the module requires minimal assembly effort, thereby once again minimizing cost.

To summarize, the showcase by macu4 reaffirms the importance of proper design for AM. By exploiting the design freedom of AM, highly integrated systems can be realized with advantages in terms of cost and performance. With increasingly more complex part geometries, the need for novel design tools becomes more and more important. As shown in this showcase, automated design configurators represent a promising approach to overcoming the restrictions of the time-consuming and costly design process.

Customer	Prosthetists, end-users
Manufacturer	macu4 together with production partners
Technology	PBF-LB/P
Material	PA 12, TPU
Machine	Various
Produced quantity	100 per year
Part bounding box	104 x 111 x 37mm

Image source: macu4

1

Image source: macu4

2

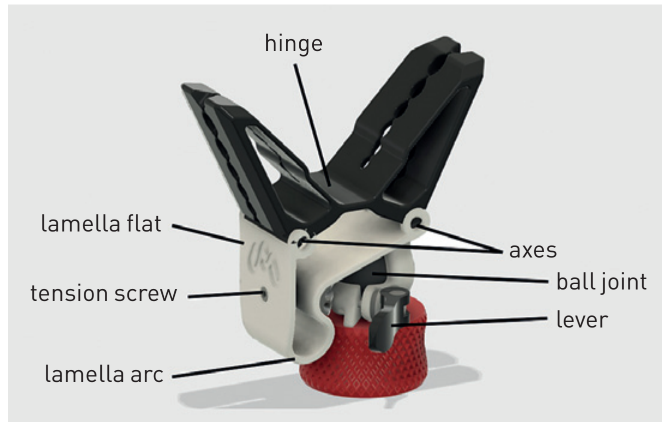


Image source: macu4

3

Innovation **Engineering** **Business** **End-to-End Integration**

1
Highly integrated prosthetic gripper actuated by a compliant mechanism.

2
Gripper manufactured with PBF-LB/P

3
Structure of the adjustable compliant mechanism

High-mix low-volume production of individualized electronic connectors with liquid crystal polymers

Together with their customers, NematX is producing individualized electronic connectors using liquid crystal polymers.

Electronic connectors represent essential components in many industrial applications, including for instance, the automotive, robotics, and mechanical engineering industry. Such connectors are typically mass manufactured with injection molding. Yet, many advanced applications increasingly require customized solutions in small quantities. Due to the need for molds and other tooling, the customization of electronic connectors is oftentimes not economically viable through means of conventional manufacturing techniques.

Until now, it has been difficult to realize electronic connectors using AM for high-end applications, mainly due to limitations in material properties. Such parts need to withstand high temperatures (up to 250 °C) due to subsequent processing in a soldering oven. In addition, a high flammability rating and very good mechanical properties are typically required. Furthermore, a high geometrical resolution is needed to reproduce thin-walled structures for miniaturized electronic and semiconductor components.

The Zurich-based ETH spin-off NematX has developed an AM material that can satisfy such demanding material properties. Together with their electronic connector supplier customers, NematX has implemented their technology for a series production of electronic connectors. NematX is offering filaments based on liquid crystal polymers (LCP), which belong to a group of high-performance thermoplastics. In contrast to materials such as PEEK or PEI, LCP molecules are relatively short and stiff. During printing, the chains can be aligned by the material extrusion process, resulting in exceptional mechanical properties. To be precise, a stiffness rating of up to 25 GPa (Young's modulus) can be reached with an ultimate tensile strength ranging up to 650 MPa.

The main challenge of the project came from properly aligning the novel AM material with the connector design and printing process to fulfill the strict functional requirements. The fine geometrical details require adaptations to the slicing strategy and software to prevent stringing or the unwanted rounding of contours. To satisfy the need for productivity and the low melt viscosity of LCP material, a dedicated printer from NematX was required for this application. The NEX 01 is an industrial production machine equipped with a high-speed, precision motion system that allows for the accurate control of extrusion volume, and it can be equipped with up to four print heads. After printing, post-processing may only be required for support removal, which is a key advantage compared to vat photopolymerization AM processes, for instance.

In terms of costs, an analysis revealed that the break-even point for electronic connectors produced with NematX's AM material and its printer is well in the four-digit range (→ 3000–6000 pieces depending on part size, complexity, and the number of print heads mounted onto the NEX 01 platform). In addition, the process is highly relevant to bridge manufacturing, where firms can adapt to mass manufacturing technologies at a later stage without changing the material class. Furthermore, the NematX printers can be stationed close to their point of use, allowing for on-location production scenarios.

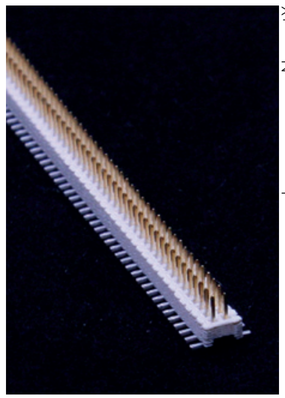


Image source: NematX

1


Image source: NematX

2

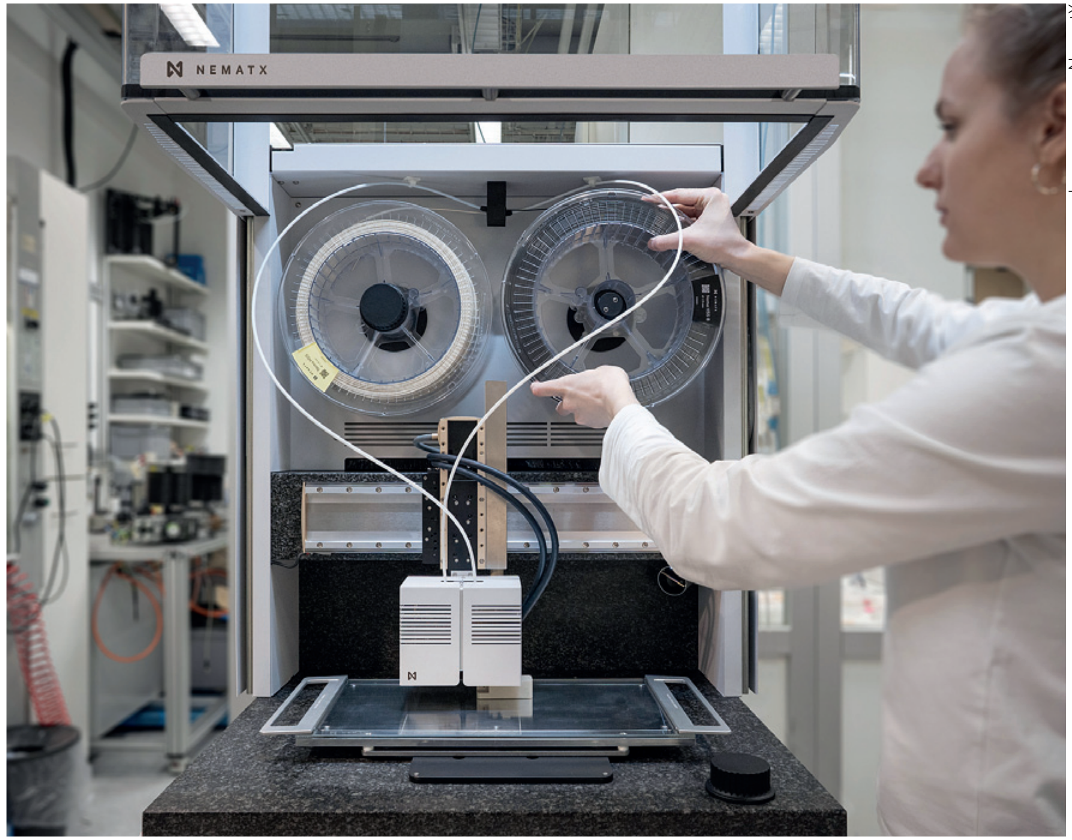


Image source: NematX

3

Customer
Electronic connector supplier

Manufacturer
NematX

Technology
Polymer material extrusion

Material
Liquid crystal polymers (LCP)

Machine
NematX NEX 01

Produced quantity
40 pcs

Part bounding box
50.6 x 3.0 x 1.5 mm

Innovation **Engineering** **Business** **End-to-End Integration**

1
High-performance electronic connectors manufactured with liquid crystal polymers

2
Printing of liquid crystal polymers with filament offered by NematX

3
High precision NEX 01 printer by NematX

Patient-specific neurostimulator for Alzheimer's disease patients

Bottneuro AG is a MedTech start-up in Basel that improves the diagnosis and treatment of Alzheimer's disease.

Alzheimer's disease affects about 150 thousand people in Switzerland and more than 50 million people worldwide. Neurostimulation, specifically transcranial alternating current stimulation, is a promising treatment for Alzheimer's disease by stimulating the patient's brain with weak alternating currents. However, existing neurostimulation devices have several drawbacks, including accurate positioning of the electrodes, fit discomfort, and a complicated setup process applying wires on the patient's head. To address these challenges, Bottneuro AG is developing a high-resolution, personalized, additively manufactured wearable headset device for daily home use.

Bottneuro AG was founded in 2021 as an offshoot of the University of Basel. It has quantitatively validated the positive effects of alternating microcurrents on glial cells. Bottneuro AG is now translating this basic research into a product.

The neurostimulator consists of three components: the patient-specific head cap, the neck piece, and a commercially available tablet. The head cap and neck piece are manufactured additively using multi jet fusion technology (PBF-IR/P). The material used is PA12 for biocompatibility and mechanical behavior.

Based on the magnetic resonance imaging (MRI) scan of the patient's brain, electrodes are individually placed on the headset for optimal treatment. The idea is to build a fully automated digital process chain, including design and manufacturing based on the patient's personalized brain images. The main function of the head cap is to position the electrodes on the individual's head, apply a defined pressure via a spring, and fix the cable. At present, 34 electrodes are placed on the head cap. The headgear increases the overall comfort of the neurostimulation treatment by fixing the cables in place and consolidating them within the neckpiece. The neckpiece is a medical-grade electronic enclosure that connects the cables, electronic hardware, and USB-c connection to the tablets. The app allows for an intuitive user interface from which to monitor the treatment.

Current R&D topics focus on further performance improvements and cost reduction. An Innosuisse collaboration is in progress with ETH Zurich, inspire AG, and prodartis. The main goal of the Innosuisse project is to increase the number of electrodes from 34 to 500, which will significantly improve patient treatment. In addition, the repetitive design process will be fully automated within an end-to-end digital process chain. Assembly will also be automated and reduced by integrating the cables into the AM part. The Innosuisse project consortium is working closely with HP's R&D department and PBF-IR/P technology. Bottneuro's patient-specific neurostimulator demonstrates how the use of an MRI, a digital process chain, and additive manufacturing improves the treatment of Alzheimer's patients.

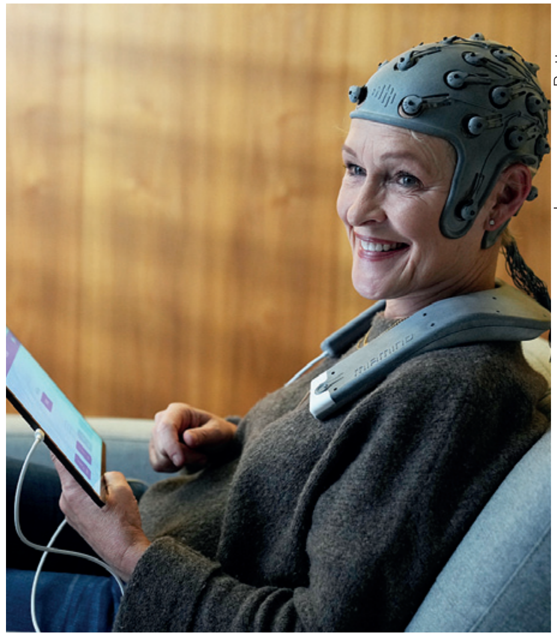


Image source: Bottneuro

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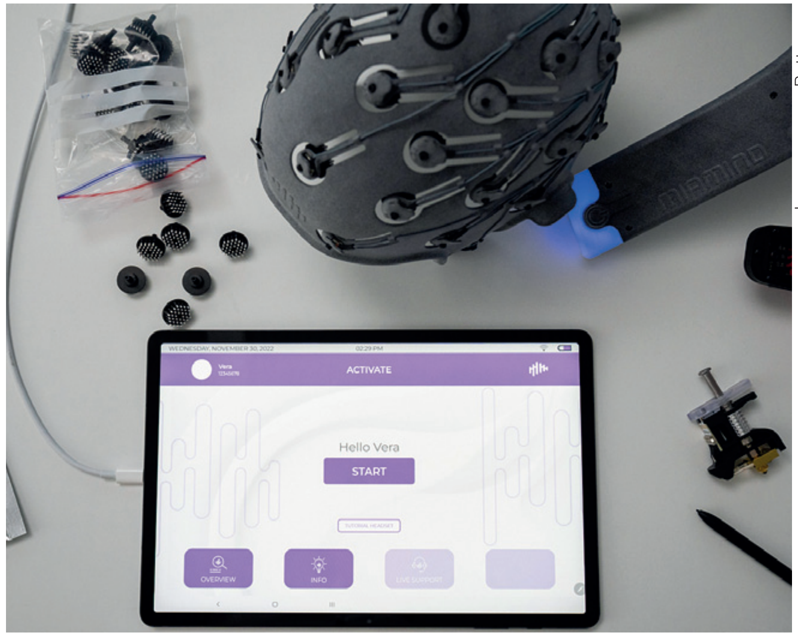


Image source: Bottneuro

2

Image source: Bottneuro

3

1
Patient-specific headset for neurostimulation

2
Electrodes, head cap, back piece, and neurostimulation tablet

3
Increased comfort for Alzheimer's patients by AM neurostimulator

Customer
Patients and hospitals

Manufacturer
Bottneuro, Prodartis

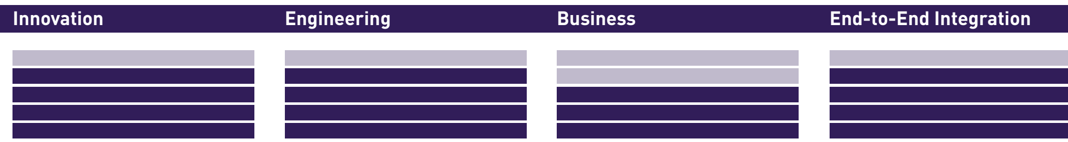
Technology
PBF-IR/P

Material
PA 12

Machine
HP Multi Jet Fusion

Produced quantity
20

Part bounding box
Not applicable



Glass additive manufacturing of micro-optical devices

The Institute of Materials and Process Engineering at ZHAW has developed a glass additive manufacturing method that has been validated by producing randomized engineered diffusers.

For most industries, additive manufacturing of polymers and metals still represents the most widespread process. Nevertheless, additional material groups are increasingly emerging for AM, including for instance technical ceramics and glass. Specifically for optical glass, AM provides significant benefits. The possibility of producing small, individualized lot sizes along with AM's freedom of design enable unprecedented potentials that have been unfeasible through traditional glass processing until now.

The Institute of Materials and Process Engineering (IMPE) at ZHAW has been investigating glass AM for an extended period. Within their research, Prof. Dr. Dirk Penner and Michal Gorbar have developed a manufacturing method to produce highly customized, micro-optical devices. The process is comprised of two main phases: the layer-by-layer manufacturing of a green body using digital light processing (DLP) and the subsequent thermal treatment. Within the first phase, a slurry of glass powder and UV-sensitive resin is selectively cured using a modified Admatec DLP printer. Compared to traditional vat photopolymerization processes (VPP), the method utilizes a continuous transparent film, which is evenly coated with the glass slurry. Due to the projection's good optical resolution, highly precise structures can be manufactured within this step, enabling the realization of micro-optical devices. The utilized material has been specifically developed by the IMPE for this AM method. The green body manufactured with the DLP process is not yet transparent and therefore needs to be post-processed via several thermal treatments. During debinding, the UV-cured polymer matrix is burned away, a process that is then followed by sintering to fuse the remaining glass particles. The thermal treatments can be performed within a few hours. Throughout these processing steps, proper thermal management is crucial; this ensures consistent reproducibility of the shapes across the substrate and high optical transmittance of both the surface and the bulk material.

To validate the novel manufacturing method, the IMPE has performed a feasibility study together with SUSS MicroOptics. The firm produces high-quality refractive and diffractive micro-optics for fiber coupling, collimation, and beam homogenizing. Within the feasibility study, randomized engineered diffusers were manufactured using the two-stage glass AM process. Optical diffusers are used in various applications to reduce glare, minimize unwanted reflections, and create uniform illumination. They are used in areas such as lighting technology, photography, display technology, optics, and many more. Traditionally, the parts are manufactured with casting processes. The glass AM diffuser in the feasibility study is equipped with a complex, randomized topography, measuring approximately 10 x 10 x 1 mm. The layer height amounted to 30 µm. As depicted in the figures, the part was successfully manufactured with small angular spectra (±0.3° to ±3°) and structure sizes ranging from 50 to 100 µm, thus validating the technical feasibility of this novel AM method. Apart from DLP, the newly developed material could also be used in material extrusion or casting processes. Overall, this showcase underlines the potential of sinter-based production for micro-optical devices.

Customer	**SUSS MicroOptics**
Manufacturer	**ZHAW IMPE**
Technology	**DLP with subsequent debinding & sintering**
Material	**Glass powder and UV-curable resin**
Machine	**Modified Admatec DLP printer**
Produced quantity	**Few prototypes**
Part bounding box	**102 x 64 x 246 mm**

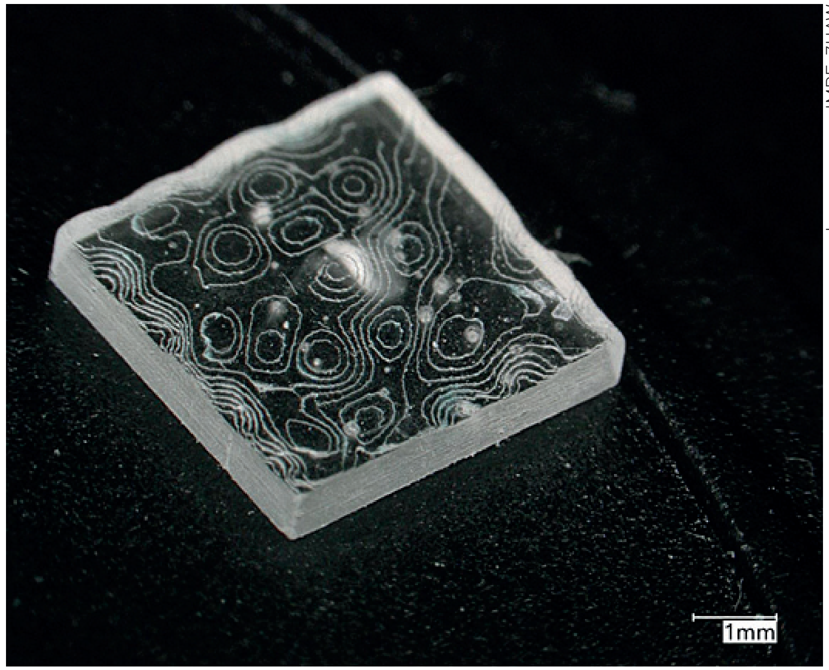


Image source: IMPE, ZHAW

1

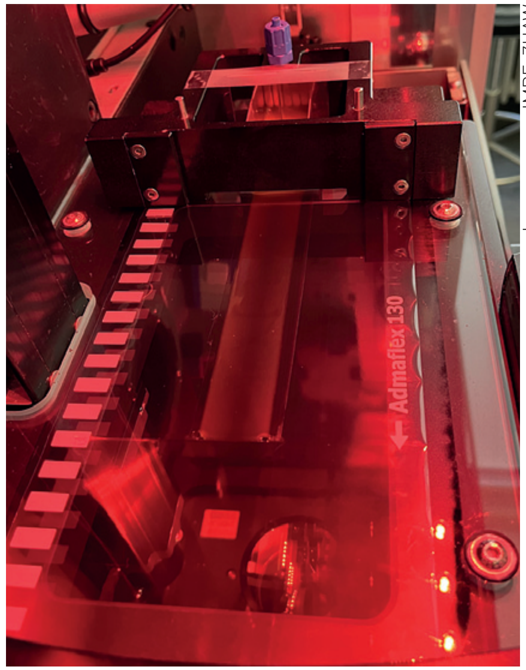


Image source: IMPE, ZHAW

2

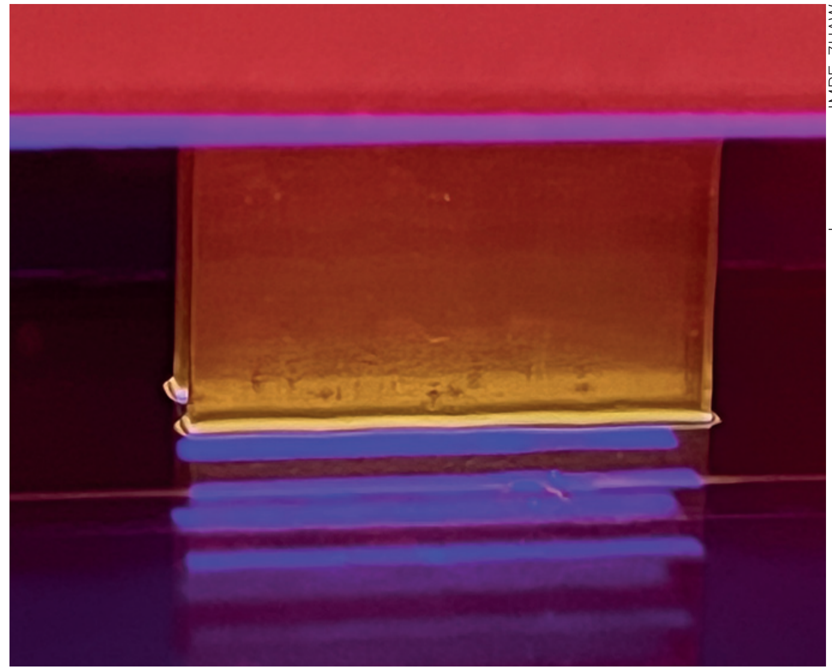


Image source: IMPE, ZHAW

3

1
Sintered glass diffusor

2
Modified DLP printer for green body production

3
DLP printing of the greenbody with UV light

Innovation **Engineering** **Business** **End-to-End Integration**

Hybrid additive manufacturing transforms impeller production

MAN Energy Solutions utilizes hybrid AM for the production of innovative impellers.

Impellers play a critical role in various applications that require gas compression. MAN Energy Solutions, a leading manufacturer of gas compressors, caters to industries focused on chemicals, oil and gas, and renewable energy. This includes the area of large-scale heat pumps for district heating networks. Each compressor is a customized product and thus comes with the challenge of long lead times. Especially critical is the production of the radial impeller. The impeller's complex design and multiple steps of production contribute to a lead time ranging from 4 to 6 months. To address these issues, MAN Energy Solutions has embraced hybrid additive manufacturing (AM) techniques, which have the potential to significantly reduce lead times and costs while also maintaining material properties.

Traditionally, the impeller production process involved several steps, starting with forging the raw material. Subsequently, vertical electrical discharge machining (EDM) and further finishing processes are employed. The production of EDM electrodes and the actual EDM process itself added several weeks to the lead time. Additionally, the complex fluid-optimized design of the impeller posed significant challenges to conventional manufacturing methods like EDM and milling.

MAN Energy Solutions has applied a hybrid approach that combines AM with a forged preform and sequential milling. The process begins with a small amount of forged raw material. This raw material is then subjected to a directed energy deposition (DED) process, which adds layers to create the intricate impeller design. To ensure the desired surface finish, sequential milling is employed. This double hybrid process eliminates the need for specialized tooling and significantly reduces the lead time to less than 2 months. Moreover, the DED process allows for the creation of highly complex designs on the forged raw material, leading to improved efficiency.

The impellers are manufactured by a DMG Mori - LASERTEC 65 DED hybrid machine through the use of corrosion-resistant 1.4313 steel. Material properties are of critical importance due to the impeller's operating conditions, which involve high dynamic loads due to rotations ranging from 5,000 to 30,000 rpm. The material must also exhibit a high resistance to corrosion—depending on the gas medium. The AM-produced impellers demonstrate similar material properties to conventionally manufactured components, ensuring reliable performance with increased efficiency.

The two involved companies share the DMG Mori - LASERTEC 65 DED hybrid machine, showcasing the potential for knowledge sharing and transfer across sectors. Sulzer AG uses the machine for pumps and MAN utilizes it for compressors. This collaboration exemplifies how technological know-how in AM can be effectively utilized.

MAN Energy Solutions' adoption of hybrid AM for impeller production presents a significant advancement. By leveraging this technology, they have successfully reduced lead times and costs, all while maintaining similar material properties to conventionally manufactured impellers. This innovation has wide-ranging benefits for the increased efficiency of energy solutions and contributes to a net zero future. Hybrid AM is paving the way for impeller production with increased efficiency, reduced costs, and improved lead times.

Customer
Chemical industry and energy sector

Manufacturer
MAN Energy Solution

Technology
Directed energy deposition (DED)

Material
1.4313 steel

Machine
DMG Mori - LASERTEC 65 DED hybrid

Produced quantity
10 per year

Part bounding box
30 x 30 cm x 20 cm

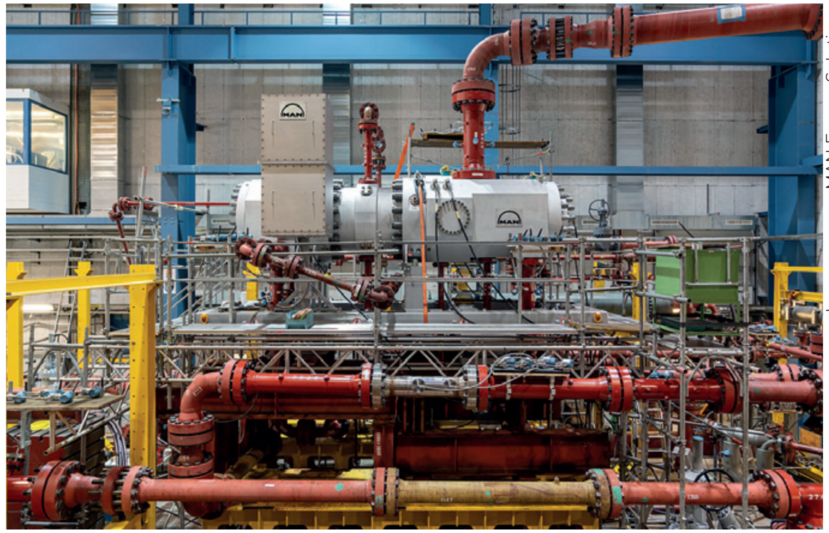


Image source: MAN Energy Solutions

1

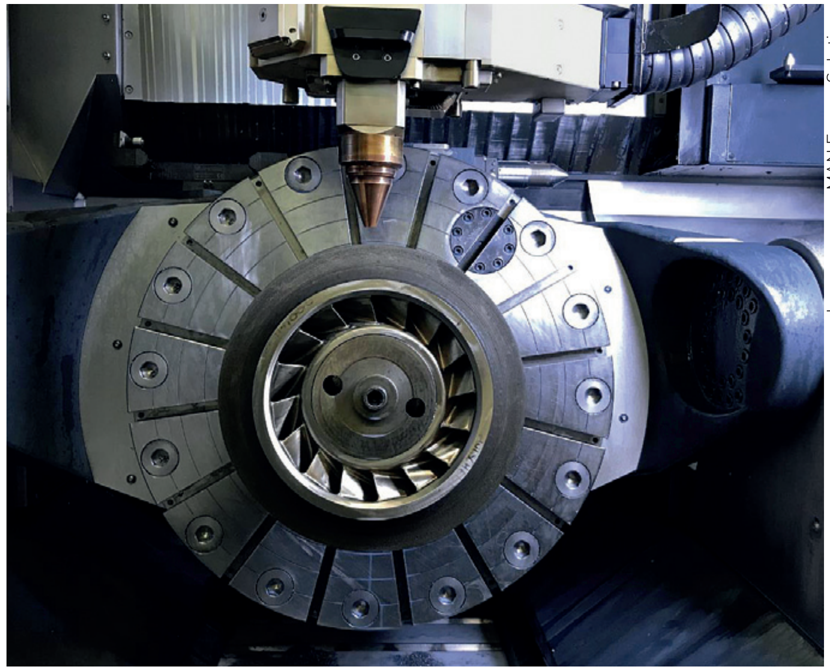


Image source: MAN Energy Solutions

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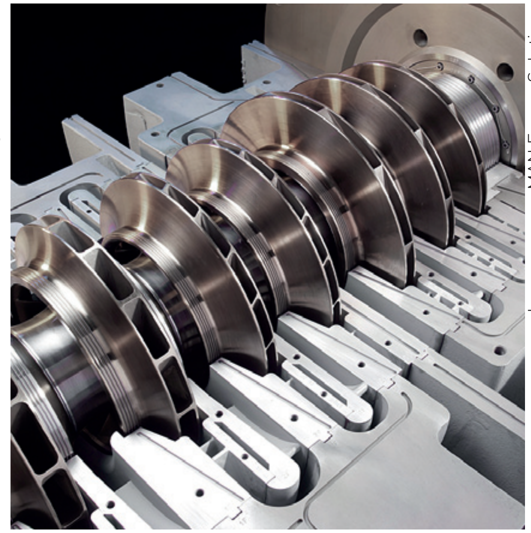

Image source: MAN Energy Solutions

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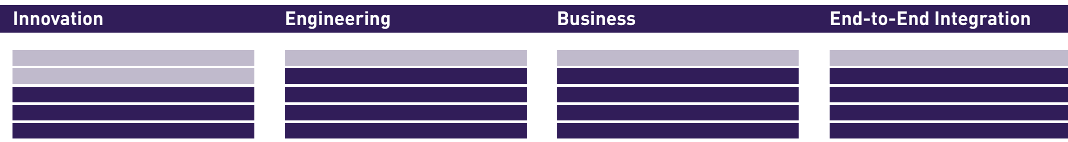
1
Hybrid AM impellers represent a key component of industrial heat pumps

2
AM impeller on the hybrid directed energy deposition machine

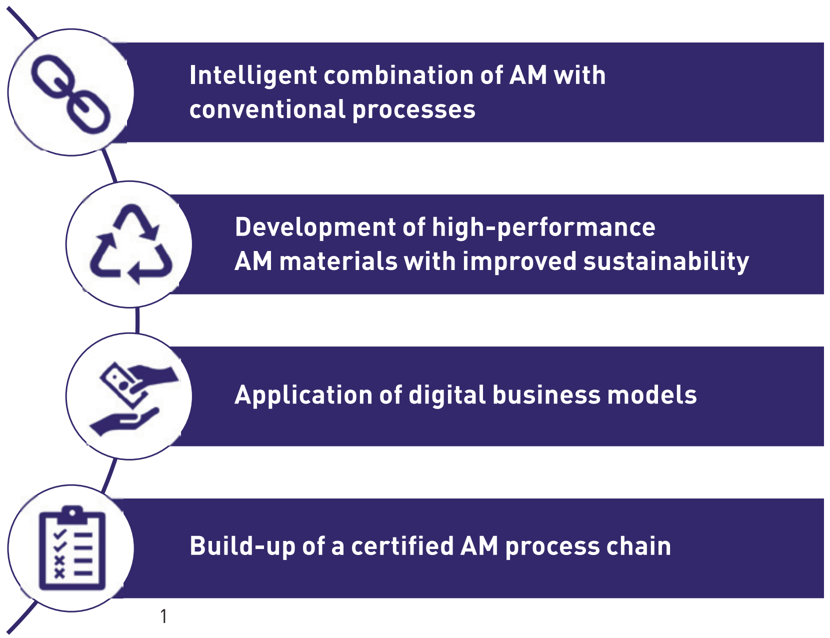
3
Multiple stages of hybrid AM impellers



Current innovation drivers of highly advanced AM applications

An analysis of the main takeaways from the showcases.

Within this section, we summarize the main takeaways from the showcases and provide further insights from our research at the IWK Institute for Materials Technology and Plastics Processing. For the selection of case studies, we conducted interviews with leading experts from the AM industry in Switzerland. The interviews revealed four main innovation drivers of highly advanced AM applications that are discussed in the following.



1

Intelligent combination of AM with conventional processes

As of the beginning of 2023, more than 40 different AM processes have been commercially released. Each one has its respective strengths and weaknesses. As demonstrated by the CSEM showcase, significant potential arises from the intelligent combination of AM and conventional processes. Highly integrated systems can be created by merging the strengths of individual technologies. This principle can also be applied to polymer parts, for instance, by functionalizing injection molded parts with conformal printed structures. Using additive material extrusion processes, structures for customization, stiffening, and sensor integration with directly printed electronics can be applied, thereby greatly improving the functionality and performance of the part.

Development of high-performance AM materials with improved sustainability

For a long time, the limited selection of AM materials represented one of the main hurdles against wider industrial implementation. In the recent past, there has been a major emphasis on AM materials development, both by established firms and start-up companies. With the introduction of dedicated AM materials, such as the liquid crystal polymer filament by NematX, AM can be increasingly used in cutting-edge applications that have thus far been unfeasible. Apart from increased performance, the sustainability of AM materials has become one of the key areas of development, especially for polymers. AM provides significant potential regarding circular economies, as demonstrated by the recycling of old ski boots into TPU filament for fused filament fabrication.

Application of digital business models

Due to its toolless production principle, AM can be characterized as a direct digital manufacturing process, enabling the application of novel business models that have been mostly restricted to the software industry up until now. Through the implementation of a fully digital process chain, firms can create and capture value in a more profitable and scalable way. As demonstrated in the showcase by macu4, an automation of the design process becomes one of the key building blocks in this digital process chain. By automating repetitive design tasks, the time and cost of product development can be significantly reduced, enabling the wider use of AM and greatly improving scalability.

Build-up of a certified AM process chain

For many industries, engineering parts and processes need to fulfill strict regulations. In contrast to traditional manufacturing technologies, standardization and certifications for AM are relatively scarce or novel. The showcase by the University Hospital Basel showed how such a validation scheme can be introduced. Through the standardization of utilized materials, machines, and processes, the deviations of part properties can be limited to a minimum, enabling the implementation of AM in even highly regulated markets like medical devices.

All in all, the showcases and analysis presented in the Swiss AM Guide 2023 create a promising picture for the future of AM. We hope this report provided you with interesting and inspiring inputs for your personal AM implementation journey!

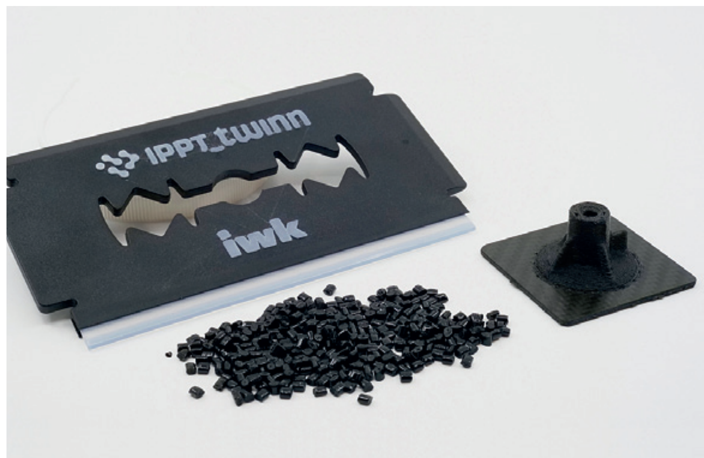


Image source: IWK

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Image source: Creamelt

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1
Four main innovation drivers of highly advanced AM applications identified in this study

2
Functionalizing polymer parts and composites with AM

3
Recycled TPU filament made from old ski boots

Table of research institutes in Switzerland

Research institute		Main research topics	Vat Photopolymerization VPP	Material Extrusion MEX	Material Jetting MJT	Binder Jetting BJT	Power Bed Fusion of Polymers PBF	Power Bed Fusion of Metals PBF	Directed Energy Deposition DED	AM post processing
CSEM	www.csem.ch	High Precision AM Integrated functions Enabling materials	x	x				x		x
EPFL Micromanufacturing Science & Engineering Center M2C	www.epfl.ch/research/domains/m2c/	AM by PBF-LB Multimaterial & multiprocess AM Free form laser material processing	x		x			x		
ETHZ Macromolecular Engineering Laboratory	https://macro.ethz.ch/	Advanced biomaterial design AM in medicine	x	x						x
FHNW Institute for Medical Engineering and Medical Informatics	www.fhnw.ch/lifesciences/im2	Medical devices AM Functional materials and surfaces Biofabrication and bioprinting	x	x	x	x	x	x		x
FHNW Institute of Production and Production Engineering	www.fhnw.ch/ippe	Process control Design and simulation for AM		x			x	x	x	x
HEPIA Institut inSTI	www.hesge.ch/hepia/rad/insti	Laser manufacturing Reverse engineering XRay tomography								x
HES-SO iPrint HEIA-FR	https://iprint.center/	Inkjet printing for manufacturing Material jetting Binder jetting		x	x	x				
HES-SO Powder Technology and Advanced Materials	www.hevs.ch/en/activites-instituts/powder-technology-advanced-materials-7266	Powder technology for metals & ceramics PBF-LB/M, P, BJ, SG-3DP Powder and materials characterization	x	x		x	x	x		
HSLU Institute of Mechanical Engineering and Energy Technology	www.hslu.ch/en/lucerne-school-of-engineering-architecture/about-us/organization/institute/engineering-and-technology/abteilungsseite-m/	Mechanical engineering Material sciences Product development		x			x	x		x

Research institute		Main research topics	Vat Photopolymerization VPP	Material Extrusion MEX	Material Jetting MJT	Binder Jetting BJT	Power Bed Fusion of Polymers PBF	Power Bed Fusion of Metals PBF	Directed Energy Deposition DED	AM post processing
inspire AG	www.inspire.ch/	Design for AM Powder Analysis, process monitoring Digital design and digital process chain		x	x		x	x	x	x
OST Institute of Microtechnology and Photonics	www.ost.ch/imp	Microtechnology Printing process development Materials formulation				x				
OST IWK Institute for Materials Technology and Plastics Processing	www.ost.ch/iwk	Materials development for AM Automated design for AM Simulation for AM	x	x			x		x	x
Paul Scherrer Institute	www.psi.ch	Microstructure evolution during LPBF Development of in situ LPBF and DED Post-processing characterization	x	x				x	x	
RhySearch	www.rhysearch.ch	Ultra-precision manufacturing Optical coating and characterization Digital innovations								x
SUPSI Institute of Systems and Technologies for Sustainable Production	www.supsi.ch/isteps_en.html	Laser-based AM process engineering AI-based closed-loop control systems Advanced Laser-based machine design						x	x	x
University of Basel BIROMED-Lab	https://biromed.dbe.unibas.ch	Medical robotics Human-machine interaction Real-time control	x	x	x		x			
ZHAW Institute of Materials and Process Engineering IMPE	www.zhaw.ch/impe	Materials development for AM AM Process development for materials Ceramics, metals, polymers, composites	x	x	x	x		x		x
ZHAW Institute of Product Development and Production Technologies IPP	www.zhaw.ch/ipp	Optimization of the AM production chain Sustainability for products production Development for pre- and post-processing	x	x						

SWISSMEM | Swiss Additive Manufacturing Group

SAMG – Swiss Additive Manufacturing Group

We strengthen the development of our members' business ties and information network, facilitate contact with universities and research institutions, maintain the industry's public reputation, provide services for members and partners, and promote collaboration with other organizations both in Switzerland and abroad.

Our areas of focus

Research and development
Overview of current and future research topics, link to research network.

Basic and further training
Overview of the training opportunities available. Developing and holding AM training courses.

National network
Regular exchanges between the division and external partners on current topics and projects.

International network
International exchange and overview of research and project partners, standardization bodies and legislation.

Materials
Clarification and overview of questions relating to plastic, metal and ceramic materials and special materials.

Industrialization
From AM research to the industry: Overview of the AM benchmark and strategic partnerships.

www.swissmem.ch/samg