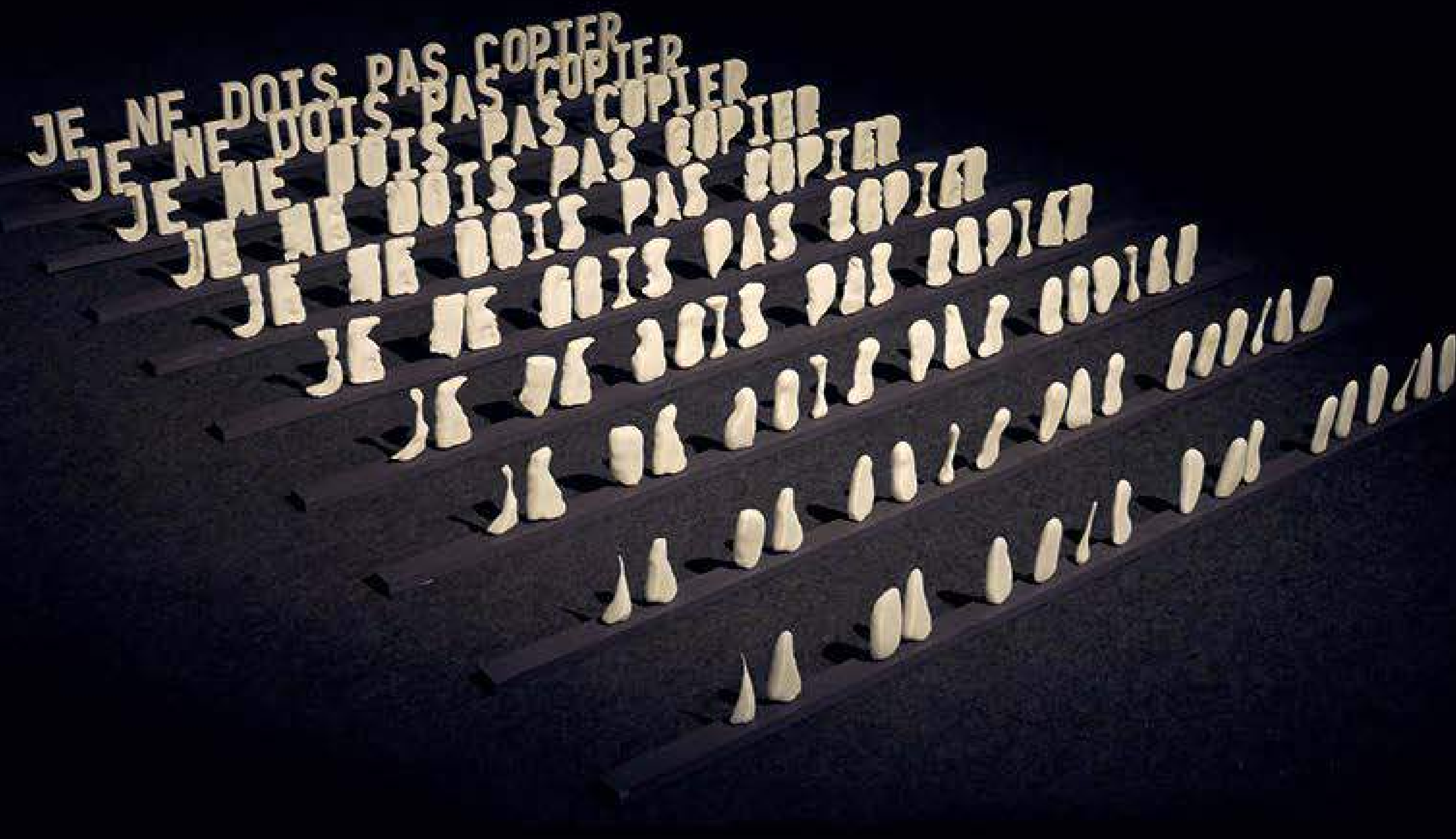
IS2M annual meetings

3D & 4D printing in Upper Rhine Valley

June 6-7, 2019

Faculté des Sciences et Techniques

Université de Haute-Alsace, Mulhouse - France



Registration and information

https://www.is2m.uha.fr/event/is2m-annual-meetings2019/

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IS2M annual meetings 2019
3D & 4D printing in Upper Rhine Valley

This year, the IS2M annual meetings will focus on 3D & 4D printing. During these two days, scientists from EUCOR - the European Campus, will present their latest findings in this field. This conference aims to provide a forum for EUCOR scientists, and more precisely, this year, for scientists concerned by 3D & 4D printing or any related research. The scientific committee of these meetings is thus composed by scientists from EUCOR. Besides EUCOR speakers, speakers from Germany, Switzerland and France are also specially invited this year to this event.

Keynote speakers

Prof. Dr. Rolf MÜLHAUPT
(Universität Freiburg, Freiburg Materials Research Center, FMF, and Freiburg 3D Printing Alliance, F3D)
Dr. Dr. Florian M. THIERINGER
(University Hospital Basel, Cranio-Maxillofacial Surgery and 3D Print Lab)
Prof. Jacques LALEVEE
(University of Haute-Alsace – Institute of Materials Science of Mulhouse, CNRS)

Scientific committee

Dr. Dr. Florian M. THIERINGER
(University Hospital Basel, Cranio-Maxillofacial Surgery and 3D Print Lab)
Prof. Dr. Rolf MÜLHAUPT
(University of Freiburg, Freiburg Materials Research Center, FMF, and Freiburg 3D Printing Alliance, F3D)
Prof. Dr.-Ing. Bastian E. RAPP
(University of Freiburg, Department of Microsystems Engineering, NeptunLab)
Prof. Dr. Matthias FRANZREB
(Karlsruhe Institute of Technology, Department of Bioengineering and Biosystems)
Prof. Dr. Juergen HUBBUCH
(Karlsruhe Institute of Technology, chair of Biomolecular Separation Engineering)
Prof. Pierre RENAUD
(INSA Strasbourg, ICube)
Prof. Jörg BASCHNAGEL
(University of Strasbourg, Institut Charles Sadron, CNRS)
Dr. Arnaud SPANGENBERG
(University of Haute-Alsace – Institute of Materials Science of Mulhouse, CNRS)
Dr. Laurent VONNA
(University of Haute-Alsace – Institute of Materials Science of Mulhouse, CNRS)

Local organizing committee

Arnaud SPANGENBERG
Laurent VONNA
Nathalie CASTELEIN
Mehdi BELQAT

Cécile Babiole is a french artist based in Paris. Her creations combine visual and audio arts through installations and performances that investigate digital medias with irony. The installation *Copies Non Conformes* (*Certified Inaccurate*) proposed by Cécile Babiole during these two days explores the erosion and mutations that take place in the reproduction of 3D printed letters in the sentence: "JE NE DOIS PAS COPIER" ("I must not copy").
For more information about this installation http://babiole.net/en/copies-non-conformes/

Thursday 6th of June

9h30 - 10h00	Welcome	
10h00 - 10h40	**Prof. Dr. Rolf Mülhaupt** University of Freiburg Freiburg Materials Research Center, FMF, and Freiburg 3D Printing Alliance, F3D	*Tailoring material systems for 3D and 4D printing*
10h40 - 11h00	**Dr. David Eglin** AO Research Institute Davos	*High-fidelity orbital floor repair using patient specific osteoinductive implant made by stereolithography*
11h00 - 11h20	Coffee Break	
11h20 - 11h40	**Lukas Wenger** Karlsruhe Institute of Technology Institute of Functional Interfaces	*Emulsion-based bioinks for 3D extrusion-printing of ensymatically active materials*
11h40 - 12h00	**Prof. Pierre Renaud** Icube - Université de Strasbourg Institut National des Sciences Appliquées de Strasbourg (INSA)	*Multi-material Additive Manufacturing for Robotic Applications*
12h00 - 12h20	**Prof. Dr. Matthias Franzreb** Karlsruhe Institute of Technology Department of Bioengineering and Biosystems	*3D printing of bioanalytical assays and devices*
12h20 - 12h40	**Dr. Thierry Engel** Icube - Université de Strasbourg Institut National des Sciences Appliquées de Strasbourg (INSA)	*Simulation thermomécanique du procédé LMD-CLAD® optimisation du temps de calcul des pièces de grandes dimensions*
12h40 - 14h00	Lunch	
14h00 - 14h40	**Prof. Jacques Lalevée** University of Haute-Alsace Institute of Materials Science of Mulhouse	*Towards New High Performance Radical and Cationic PhotoSensitive Resins For PhotoPolymerization Processes and Examples in 3D printing Resins*
14h40 - 15h00	**Prof. Dr.-Ing Bastian Rapp** University of Freiburg Department of Microsystems Engineering (IMTEK)	*Next generation 3D Printing: The emergence of enabling materials*
15h00 - 15h20	**Dr. Charles Baur** École Polytechnique Fédérale de Lausanne (EPFL) Instant-Lab	*SPOT: a Femto laser-printed tool made of fused silica for safe retinal vein cannulation*
15h20 - 15h40	**Dr. Jean-Pierre Malval** University of Haute-Alsace Institute of Materials Science of Mulhouse	*Two-Photon Active Chevron-Shaped Type I Photoinitiator Designed for 3D Stereolithography*
15h40 - 16h00	Coffee Break	
16h00 - 16h20	**Dr. Bruno Colicchio** University of Haute-Alsace Institut de Recherche en Informatique, Mathématiques, Automatique et Signal (IRIMAS)	*Observation of 3D microprinted polymeric materials by tomographic diffractive microscopy*
16h20 - 16h40	**Dr. Frederik Kotz** University of Freiburg Department of Microsystems Engineering (IMTEK)	*Glassomer- 3D printing of transparent fused silica glass*
16h40- 17h00	**Cécile Babiole** Artist	About *Copies Non Conformes* (*Certified Inaccurate*)
17h00 - 19h30	Poster Session	
19h30 - 21h30	Friendly evening	

Friday 7th of June

9h30 - 10h10	**Dr. med. Dr. med. dent. Florian Thieringer** University Hospital Basel Oral & Maxillofacial Surgery, 3D Print Lab	*Medical 3D Printing in hospitals – current and future applications*
10h10 - 10h30	**Dr. Peter Koltay** University of Freiburg, Department of Microsystems Engineering – IMTEK Laboratory for MEMS Applications	*Towards a generic 3D-Bioprinting Platform*
10h30 - 10h50	**Daniel Seiler** Hochschule für Life Sciences FHNW Institut für Medizinal- und Analysetechnologien	*3D printing in medicine with focus on titanium and nitinol alloys*
10h50 - 11h20	Coffee Break	
11h20 - 11h40	**Dr. Thierry Roland** Institut National des Sciences Appliquées de Strasbourg (INSA)	*In-Situ X-ray tomography analysis of 3D printed open-cell structures during mechanical loading*
11h40 - 12h00	**Dr. Sylvain Lefebvre** National Institute for computer science and applied mathematics (Inria)	*Synthesizing stochastic elastic structures*
12h00 - 12h20	**Prof. Dr. Chris Eberl** Fraunhofer-Institut für Werkstoffmechanik, IWM, Freiburg	*Small Scale Mechanical Characterization for Coating and Thin Film Application*
12h20 - 12h40	**Didier Boisselier** IREPA LASER	*To make parts with functionally graded materials: a real industrial opportunity thanks to additive manufacturing with DED-CLAD®*
12h40 - 13h40	Lunch	

Session posters

	Name	Surname	Laboratory	poster title
n°1	Bonardi	Aude-Héloïse	IS2M	NEW PHOTOSENSITIVE RESINS @405 nm: APPLICATIONS TO 3D PRINTING
n°2	Kavalli	Tuba	IS2M	Advanced photopolymers materials and photoinitiating systems for 3D printings
n°3	Belqat	Mehdi	IS2M	Investigation of the nanomechanical properties of 3D printed microstructures
n°4	Tkachenko	Vitalii	IS2M	Polymerization-Induced Self-Assembly (PISA) via Photo-mediated RAFT Polymerization in Dispersion
n°5	Le	Cuong	IS2M	Thiol-Ene Emulsion Photopolymerization
n°6	Wu	Xingyu	IS2M	Molecular engineering of one/two photon-sensitive photoacid generators
n°7	Spangenberg	Arnaud	IS2M	Direct laser writing of crystallized TiO2 and TiO2/carbon microstructures with tunable conductive properties
n°8	Mzoughi	Jihane	IS2M	Design of gelatin based films for drug delivery application
n°9	Risch	Patrick	IMTEK Freiburg	3D printing of highly fluorinated methacrylates for the fabrication of transparent and chemically-resistant microfluidic devices
n°10	Milster	Sebastian	Uni Freiburg	Multiscale Simulations of Polymers: Network Permeability and Radical Polymerization.
n°11	Cao	Shuaishuai	Uni Basel	Accuracy Comparison of Two Rapid Prototyping Technologies
n°12	Neha	Sharma	Uni Basel	Applications of fused filament fabrication (FFF) 3D printed patient-specific PEEK implants in Cranio-maxillofacial surgery
n°13	Hohmann	Siegfried	Karlsruher institut für technologie	Development of a parallelizable high content QCM-D biosensor array with flexible sample routing
n°14	Tran	Huyen-Tram	Karlsruher institut für technologie	3D printed analysis device for diagnostic applications
n°15	Diehm	Juliane	Karlsruher institut für technologie	Development of 3D printed rotatory microfluidic valves for application of an analytical micro SMB device
n°16	Haas	Sandra	Karlsruher institut für technologie	3D-Printing using photoinduced cross-linking of unmodified proteins (PICUP)
n°17	Pfeil	Antoine	ICube, Strasbourg	Hydraulically-Actuated Compliant Revolute Joint for Medical Robotic Systems Based on Multimaterial Additive Manufacturing
n°18	Begey	Jérémy	ICube, Strasbourg	A Novel Force Sensor with Zero Stiffness at Contact Transition Based on Optical Line Generation
n°19	Arnoux	Caroline	ENS Lyon	Improved Photoresists for High-Throughput, Low-Threshold Two-Photon Polymerization

Tailoring material systems for 3D and 4D printing

Rolf Mülhaupt

Freiburg Materials Research Center, FMF, Institute for Macromolecular Chemistry, and the Freiburg 3D Printing Alliance, F3D, of the Albert-Ludwigs-University Freiburg, Germany.

Institut für Makromolekulare Chemie, Albert-Ludwigs-Universität, Stefan-Meier-Straße 31, D-79104 Freiburg, Germany; Email: rolfmuelhaupt@web.de

At the beginning of the 21st century, Additive Manufacturing (AM) alias 3D printing is making rapid progress going well beyond the scope rapid prototyping. Today, AM applications span from aerospace and automotive industries to architecture, consumer goods, medicine and food. Although most 3D printing processes are much slower with respect to injection molding, this free-form fabrication shortens the pathway from idea to product by digitalized manufacturing. The emerging 3D printing technologies offer new opportunities for both design and fabrication of complex, multifunctional material systems meeting the demands of specific applications and even of individuals. Personalized manufacturing and the integration of different materials and functions in a single printing step are unfeasible in most state-of-the-art processes which frequently require multi-step processing. Moreover, additive manufacturing enables decentralized manufacturing. By exploiting the internet of things, logistics are simplified. The close interplay of chemistry, mechanical engineering and information technology represents the recipe for success of 3D printing. Today, the spectrum of material systems tailored to 3D printing is rapidly expanding and includes metals, ceramics, glass, cement, plastics, rubber, functional materials, pastes, powders, solutions, dispersions, polymer blends, composites, and even biological systems. While most 3D-printed objects retain the same shapes and properties throughout their entire product life, the emerging 4D printing technology introduces time as the fourth dimension to create programmable, smart and even life-inspired material systems. Such 3D/4D-printed materials are interactive, adapt and respond to environmental stimuli. They change their shapes and functions in a programmed fashion. This presentation provides an overview of trends and challenges in the development of materials systems, illustrated by selected examples of additive manufacturing technologies based on photopolymerization, powder fusion and extrusion.

Ligon, S.C.; Liska, R.; Stampfl, J.; Gurr, M.; Mülhaupt, R.; Chem. Rev. **2017**, 117 (15), 10212-10290; Polymers for 3D printing and customized Additive Manufacturing (free download)

High-fidelity orbital floor repair using patient specific osteoinductive implant made by stereolithography

David Eglin

AO Research Institute Davos, Clavadelerstrasse 8, 7270 Davos Plat, Switzerland.

The orbital floor (OF) is an anatomical location in the craniomaxillofacial (CMF) region known to be highly variable in shape and size. As alternative to titanium mesh implants dedicated to OF repair, we propose a flexible patient-specific implant (PSI) made by stereolithography (SLA), offering a high degree of control over its geometry and architecture. The PSI is made of biodegradable poly(trimethylene carbonate) (PTMC) loaded with 40 wt. % of hydroxyapatite (called Osteo-PTMC). We developed a complete work-flow for the additive manufacturing of PSIs to be used to repair the fractured OF, which is a clinically-relevant individualized medicine approach. This work-flow consists of (i) the surgical planning, (ii) the design of virtual PSIs and (iii) their fabrication by SLA, (iv) the monitoring and (v) the biological evaluation in a preclinical large-animal model. We have found that once implanted, titanium meshes resulted in fibrous tissue encapsulation, whereas Osteo-PMTC resulted in rapid neovascularization and bone morphogenesis, both ectopically and in the OF region, and without the need of additional biotherapeutics such as bone morphogenic proteins. Our study supports the hypothesis that the composite osteoinductive Osteo-PTMC brings advantages compared to a standard titanium mesh, by stimulating bone neoformation in the restored OF defects. PSIs made of Osteo-PTMC represent a significant advancement for patients whereby the anatomical characteristics of the OF defect restrict the utilization of traditional hand-shaped titanium mesh.

Emulsion-based bioinks for 3D extrusion-printing of enzymatically active materials

Wenger Lukas[1], Radtke Carsten[2], Göpper Jacqueline[2], Wörner Michael[2], Hubbuch Jürgen[1,2]

[1] *Institute of Functional Interfaces, Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany*

[2] *Institute of Process Engineering in Life Sciences, Section IV: Biomolecular Separation Engineering, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*

The immobilization of enzymes is a commonly used method to increase the reusability of enzymes in biocatalytic applications and has been used in 3D-printed flow-through bioreactors where enzymes were immobilized on a 3D-printed synthetic surface [1]. In order to avoid the additional immobilization step, enzyme-loaded hydrogel grids have been produced using an extrusion-based 3D printing approach [2]. The disadvantage of the incorporation of enzymes into hydrogels is the limited diffusion of substrate through the hydrogel which massively reduces reaction speed and hence the efficiency of the process. Printing finer grids of hydrogel with thinner strands is a way to reduce the diffusion path length and thereby increase efficiency. In order to enable the printing of thinner strands with simple extrusion-based methods, the rheological properties of the bioink need to be optimized for good printability. Emulsions offer a way to formulate hydrogel precursor solutions with excellent rheological properties for 3D extrusion printing.

High internal phase emulsions (HIPEs) are emulsions containing at least 74 % (v/v) of internal phase. Polymerizing the external oil phase of w/o HIPEs creates an interconnected porous scaffold (polyHIPE). By adding polymerizable monomers to the internal aqueous phase, hybrid materials with hydrogel embedded in a porous scaffold can be created. In this work, the model enzyme β-galactosidase was incorporated into 3D-printed hydrogel-filled polyHIPEs to evaluate the biocompatibility of HIPE-based inks. Hollow cylinders containing β-galactosidase were printed using a customized cure-on-dispense setup and activity assays were performed in a high-throughput approach. Rheological properties of the bioinks were determined and the polymerized structures analyzed using scanning electron microscopy.

[1] Kazenwadel, F., Biegert, E., Wohlgemuth, J., Wagner, H. and Franzreb, M. *Engineering in Life Sciences*, ***2016****,* 16: 560-567.

[2] Schmieg, B., Schimek, A. and Franzreb, M. *Engineering in Life Sciences*, **2018**,18: 659-667.

Multi-material Additive Manufacturing for Robotic Applications

Pierre Renaud

AVR - ICube, CNRS – University of Strasbourg – INSA Strasbourg, France.

Robotics is considered in an increasing number of contexts. Robotic systems are being developed for instance for exploration tasks, domestic use, assistance in medicine and surgery, in addition to the well-known industrial tasks. It is however still very difficult to design robotic systems that offer at the same time contradictory requirements such as dynamic performance and limited weight, or large motions and high level of compactness. In medical and surgical robotics, our main focus at ICube, the designer has to face additional constraints such as the need for compatibility with medical imaging modalities, which cannot be ensured with conventional sensing and actuation technologies.

Multi-material additive manufacturing (MMAM) provides the opportunity to combine within a single part materials with different mechanical properties. Soft and rigid materials can then be combined to obtain so-called compliant architectures at the base of some robotic systems. MMAM of polymer parts can in addition solve the issue of compatibility with imaging modalities in the medical context. We have therefore developed solutions for robot design based on Polyjet process, a commercial MMAM process. Using MMAM is not straightforward, as it is needed to reconsider all design solutions to ensure motion generation, sensing and actuation, which are the basic robotic functions. In this presentation, we will describe how characterization of the process, elaboration of new robotic components and systems are interrelated. Design of compliant joint, soft actuator and a 3D-printed system for medical use (Figure 1) will be detailed.

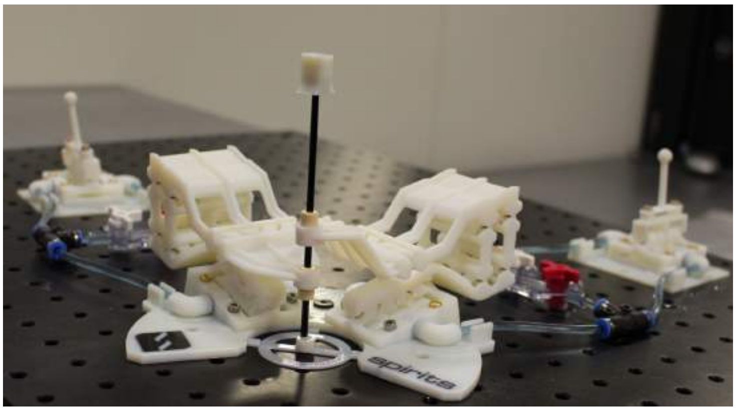

Figure 1 : Proof of concept of SPIRITS device for interventional radiology

3D printing of bioanalytical assays and devices

Matthias Franzreb, Sandra Roth, Jonas Wohlgemuth

Institute of Functional Interfaces, Karlsruhe Institute of Technology, Hermann- von- Helmholtz-Platz 1,76344 Eggenstein- Leopoldshafen, Germany

Point-of-Care Testing (POCT) is indispensable in medical diagnostics today. These tests, which also include lateral flow immunoassay (LFA), are sensitive, fast and easy to use - without prior knowledge, laboratory personnel or laboratory accessories. An LFA in its simplest form consists of a test strip with sample pad, conjugate release pad, reaction membrane, test and control line, and suction pad (see Figure 1A). The components are glued onto a backing card, where adjacent components overlap. This test strip is inserted into a plastic housing which exerts a certain contact pressure on the overlapping areas to ensure ideal liquid migration. The handling of these tests is very user-friendly, the detection reaction is selective, the tests are comparatively inexpensive and they are available in various configurations. A disadvantage, however, is that the tests can only be produced cost-effectively in large batch sizes and that production still often requires manual steps. Complete automation is only suitable for very large quantities and can only be realized at great technical and financial expense.

Therefore, within the framework of the project DiagPrint3D supported by the German AiF, an alternative manufacturing method was developed for the production of an LFA, in which the test strips are produced by means of 3D printing in only one pass. At the same time, the end product, which is a disposable product, should be environmentally friendly and biodegradable. Cellulose was therefore chosen as the starting material because it is cheap and can be easily modified chemically. The project also aimed to replace the plastic housing with a paper housing. Such production using 3D printing is only suitable for small to medium batch sizes and is limited to certain applications, but at the same time there is the possibility of parallelization (multiplexing) or individualization. In the framework of the project KIT and the company axiss GmbH developed a multi-material 3D-Bioprinting system with up to six print heads using different printing technologies. By the use of this system a fully 3D-printed LFA analyzing the clinically relevant protein cystatin C was printed and tested regarding sensitivity and reproducibility.

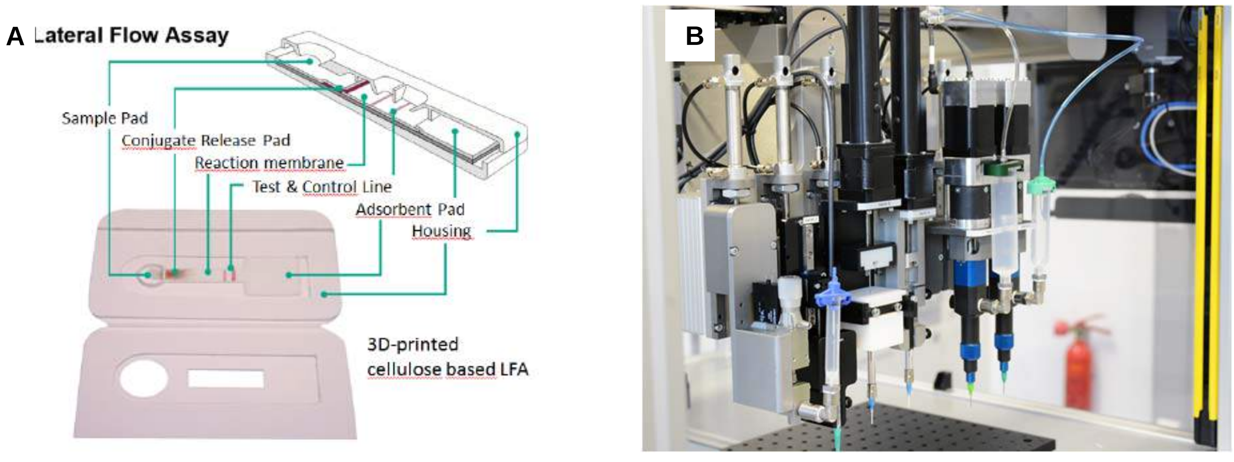

Figure 1: A: Structure of a lateral flow assay printed in a paper package; B: Multi-material 3D-Bioprinter using up to six print heads

Time efficient simulation of the LMD-CLAD™ process in order to predict distorsion and residual stress in large workpieces

Thierry Engel[1,2], Ludovic Koundé[2], Vaibhav Nain[2], Christophe Cordier[1], Didier Boisselier[2]

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[2]*IREPA-LASER, Parc d'Activités d'Illkirch, 67400 Illkirch*

Additive Manufacturing (AM), Direct Metal Deposition (DMD) or additive layer manufacturing such as LMD-CLAD® has gained a lot of interest in industrial applications, notably in aeronautics, taking advantage of the ability to build complex geometries and big scale parts. However, because of building duration (up to 155 hours), because of the big scale workpieces (up to Ø600mm x 500mm in volume or 70kg in mass), because of the nature of the deposited metal (Titanium) and the associated costs, workpieces must be successfully manufactured at the first try. For that reason, local residual stresses, strains, cracks and mismatches induced by the process in manufactured workpieces need to be calculated before construction, in order to correct eventually the building strategy.
In this work, thermal and distortion measurements on Titanium'TA6V' material were conducted in order to appreciate the effects of the deposition strategies on the time cycle. Analysis show that the time cycle has a great influence on the microstructure, the residual stresses and the distortions. A numerical model based on thermal measurements called 'micro-MESO' is designed to model the LMD-CLAD ® process.
Analyzing the time cycle helped us to improve the model first and appreciate the influences of the construction strategies on small samples. Thermal and distortion comparisons were done between numerical results and manufactured sample measurements. Micro-MESO model was inserted then in a 'Macro model' which corresponds to the real scale workpiece. This simulation method helped us to drastically reduce computation time of large workpieces that could not be done otherwise. Finally, the distortions trends were located and corrected before the scale part construction. Distortion trends of LMD-CLAD® process could be studied with the Micro-MESO-Macro approach on an ordinary PC (core i5 8Gbytes RAM) in 48h computing time, shorter than the construction itself. This is an encouragement point in simulation.
In this presentation, we demonstrate that numerical tool helps to optimize construction strategy and jigs. This tool is also used to reduce process setup, to calculate and analyze distortion and to modify eventually the part design according to estimated trends.

Figure 1 : A example of a big scale workpiece

Towards New High Performance Radical and Cationic PhotoSensitive Resins For PhotoPolymerization Processes and Examples in 3D printing Resins

Jacques lalevée[1], Tuba Kavalli[1], Fabrice Morlet-Savary[1], Bernadette Graff[1], Céline Dietlin[1]
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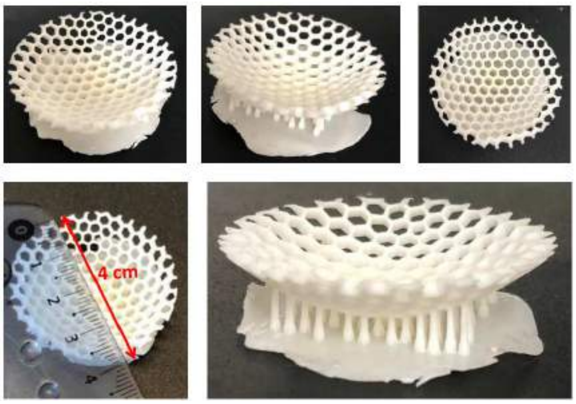
The field of 3D printing is a hot area and is actually claimed as a “revolution”. The key point in the photopolymerization area is the transformation of multifunctional monomers (*e.g.* acrylates or epoxides) or prepolymers into highly crosslinked networks using a photochemical route where photoinitiating systems PISs generating radical, cation or radical cation initiating species play an important role. This process is widely used in different 3D printing approaches. In particular, the use of light emitting diodes (LEDs) to industry processes (such as 3D printing) offers tremendous potential to stimulate industrial renewal.

The state of the art for photopolymerization upon near-UV or visible light will be given. And, new photosensitive formulations (photoinitiating systems and monomers/oligomers) well adapted for 3D (LED) printing and requiring specific conditions (irradiation wavelengths, light intensity, viscosity, writing speed ...) will be presented. All the active component of the photosensitive resins must be developed for this specific application: both the initiating systems and the monomers/oligomers must be taken into account.

Figure 1. Example of biosourced 3D printing resin developed @IS2M.



[1] Assi Al Mousawi, Frederic Dumur, Patxi Garra, Joumana Toufaily, Tayssir Hamieh, Bernadette Graff, Didier Gigmes, Jean Pierre Fouassier and Jacques Lalevée, *Carbazole Scaffold Based Photoinitiator/Photoredox Catalysts: Toward New High Performance Photoinitiating Systems and Application in LED Projector 3D Printing Resins*, Macromolecules, 2017, Articles ASAP, DOI: 10.1021/acs.macromol.7b00210.
[2] Assi Al Mousawi, Cyril Poriel, Frédéric Dumur, Joumana Toufaily, Tayssir Hamieh, Jean Pierre Fouassier, Jacques Lalevée *Zinc Tetraphenylporphyrin as High Performance Visible Light Photoinitiator of Cationic Photosensitive Resins for LED Projector 3D Printing Applications*, Macromolecules, 2017, 50 (3), 746–753.

Next generation 3D Printing: The emergence of enabling materials

Frederik Kotz[1], Dorothea Helmer[1], Bastian E. Rapp[1]

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Department of Microsystems Engineering (IMTEK)
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3D printing is the manufacturing revolution of the 21st century. The invention of printing by Johannes Gutenberg over 500 years ago, the ability to generate, replicate and disseminate artifacts has changed human history significantly. Recent decades have seen printing moving from two-dimensional to three-dimensional. Just as the printing press enabled individuals to share, distribute and archive information, printing in 3D will enable to share, improve and generate objects from digital designs via the internet. This technology has the potential to eventually resolve the boundaries between classical industries specialized on manufacturing and the end user which classically only used objects generated by someone else.

Additive manufacturing and 3D printing have seen significant improvements in terms of processing and instrumentation with the aim of increasing the complexity of the objects constructible, increasing resolution and lateral dimensions as well as speed of manufacturing. Interestingly, the choice of materials has not been increasing significantly. Most 3D printing techniques still use polymers or composites (e.g., with ceramic particles). Selective Laser Sintering (SLS) is the only process which has been extended to include metals. One of the oldest materials mankind has used was missing: Glass. Account of man-made objects in glass date back to 5000 BC. Glass has numerous advantageous properties including unmatched optical properties, mechanical, thermal as well as chemical stability to name but a few.

In 2016 we have contributed a prototyping process in glass which uses a glass nanocomposite which can cured by light and sequentially thermally annealed to result in highly-transparent fused silica glass [1]. With a recent contribution in *Nature*, this process was finally successfully transferred to 3D printing [2]. This closes an important gap in the material palette of modern 3D printing processes enabling, for the very first time, the free-form generation of highly transparent fused silica glass by a state-of-the-art 3D printing process. This has major implications for many applications ranging from 3D printing of complex lenses for smartphone cameras, next-generation microprocessors, all the way to ornaments or intricate glass panels used in buildings.

[1] F. Kotz, K. Plewa, W. Bauer, N. Schneider, N. Keller, T. Nargang, D. Helmer, K. Sachsenheimer, M. Schäfer, M. Worgull, C. Greiner, C. Richter, B. E. Rapp: “Liquid Glass: A Facile Soft Replication Method for Structuring Glass”, Advanced Materials, 28, 23, 4646, 2016.

[2] F. Kotz, K. Arnold, W. Bauer, D. Schild, N. Keller, K. Sachsenheimer, T. M. Nargang, C. Richter, D. Helmer, B. E. Rapp: "Three-dimensional Printing of Transparent Fused Silica Glass", Nature, 544, 337-339, 2017

SPOT: a Femto laser-printed tool made of fused silica for safe retinal vein cannulation

Charles Baur[1], Hubert Schneegans[1], Lisa Bonnefoy[1] , Thomas Fussinger[1], Yves Bellouard[2], Andrea Lovera[3], Thomas J. Wolfensberger[4]

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[2]Galatea Lab, EPFL (École Polytechnique Fédérale de Lausanne) STI- IMT, Rue de la Maladière 71b, 2002, Neuchâtel, Suisse.

[3]Femtoprint, Via Industria 3, 6933, Muzzano, Suisse.

[4]Hopital Ophtalmique Jules Gonin, Avenue de France 15, 1002, Lausanne, Suisse.

We present a novel medical device for safe surgical puncturing, particularly for use as a cannula in treatment of retinal vein occlusion. The passive mechanical device has adjustable stroke as an innovative feature and exerts a puncture force independent of operator-applied displacement: indeed, the puncture stroke is decoupled from operator input, thereby minimizing the possibility of over-puncturing. We achieve this using the concept of stability programming, where the user modifies the mechanism's strain energy as opposed to imposing direct displacement, as in standard bi-stable mechanisms. We manufactured the surgical tool using Femto-laser 3D printing from fused silica (glass), (Figure 1) and integrated a microfluidic channel into the tool for drug injections after cannulation. We validated the mechanical stability behavior of the puncture mechanism using numerical simulations and experimental measurements and characterized its puncturing stroke and force. Together with our medical partner, Prof. T.-J. Wolfensberger from the Jules Gonin Hospital, we performed several successful in vivo vein cannulations using the SPOT tool (for example in pig eye retinal veins, chicken embryo veins).

During the talk, we will highlight the advantages of the SPOT mechanism and their contribution to new surgical-device design.

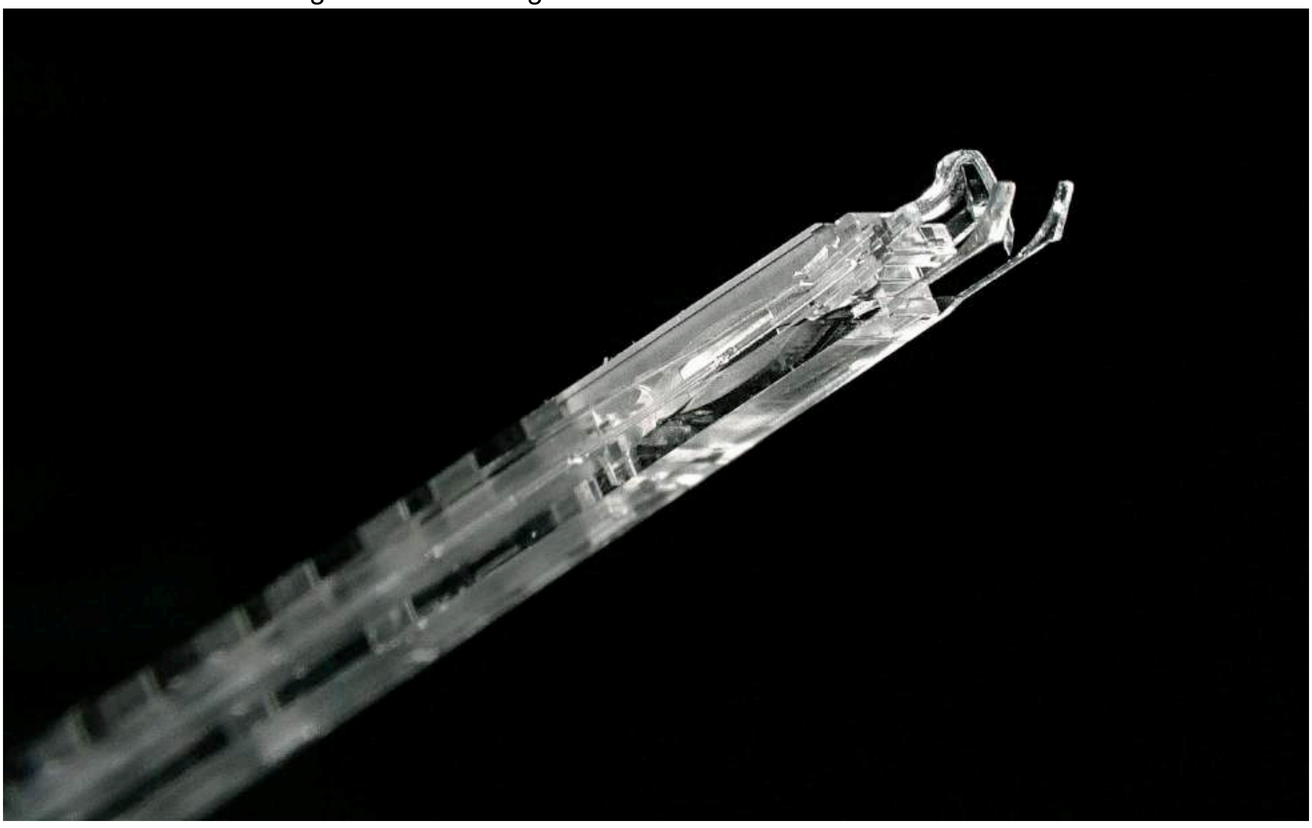

Figure 1 : SPOT femto laser-printed safe puncture tool for vitro-retinal vein cannulation

Two-Photon Active Chevron-Shaped Type I Photoinitiator Designed for 3D Stereolithography.

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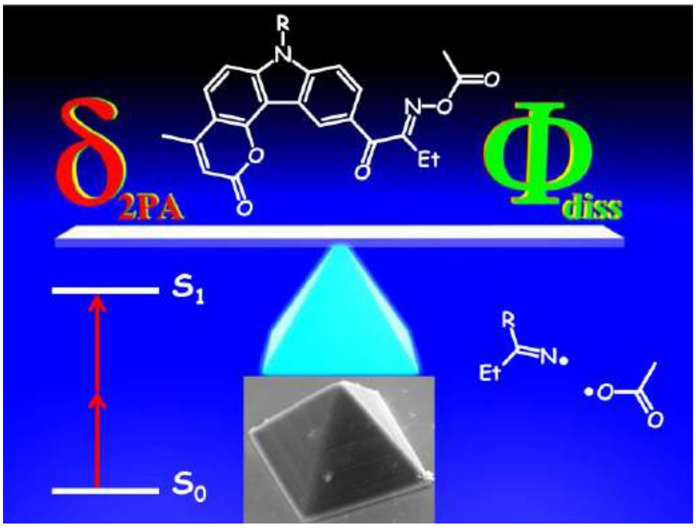
Since a decade, the field of multiphoton fabrication has developed rapidly so that it is no longer a prototyping technology but a real manufacturing technique that is commercially available[1]. Two-photon induced polymerization constitutes the spearhead of such a technology. In this context, a very large variety of two-photon active initiators have been developed. However, most of them correspond to bi-component devices with their inherent sequential mechanisms leading to severe losses in the polymerization efficiency and subsequent impacts on the fabrication writing time.

Alternatively, the 'integrated molecular strategy' offers the possibility to design direct two-photon cleavable initiators (Type I) which associates into the same architecture the initiating and two-photon absorption (2PA) functionalities. This approach clearly appears more attractive but also more risky in the sense that the distinctive primary processes promoting 2PA and homolytic bond dissociation are incompatible. This certainly explains why very few examples of free radical 2PA initiators have been reported in literature.

In this lecture, we propose a relevant molecular design approach which circumvents such an apparent incompatibility. A carbazole-based 2PA module with a chevron-shaped structure is judiciously associated with an *O*-acyl-α-oxooxime function that integrates a photocleavable N-O bond. This chevron-shaped π-conjugated structure presents an interesting geometry, which not only allows long-range electronic delocalization with a specific directionality but also actively maintains the photodissociative character of the N-O bond. From the application point of view, we demonstrate that the two-photon polymerization performances of this new type of photocleavable system are amplified by more than two orders of magnitude compared with those of a commercially available Type I photoinitiator (Lucirin TPO-L), which is extensively used for multiphoton 3D stereolithography[2].



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Observation of 3D microprinted polymeric materials by tomographic diffractive microscopy

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The micro-fabrication of objects using 3D direct laser writing (3D DLW) by multi-photon polymerization makes possible to achieve manufacturing sub-micron structures. This technique has already proven its usefulness for the manufacture of sensors and tissue engineering structures [1][2]. Optical elements such as micro-lenses can also be printed, as well as complex optical elements such as gradient-index optical elements (GRIN).
However, in order to control the quality of the printed objects, it may be interesting to observe theirs optical properties. Optical properties provide us information about the target object quality, but also about the quality of the manufacturing process itself, and then optimization could be based on the observations.
IRIMAS has designed a tomographic diffractive microscope (TDM) for local measurement of the complex optical index, and thus to optically characterize microscopic specimens. A first collaboration between IRIMAS and IS2M, allowed the use of photopolymerized tips on an optical fiber's end to physically attach samples like microcrystals, or pollens, to control rotation of the sample under the TDM (see Fig. 1 Left), and improve the 3-D resolution of TDM images by merging several acquisitions [3].
We now propose to use TDM to improve the manufacturing process of 3D micro-printing by observing the local optical indices of printed objects under different printing conditions (laser tuning and polymer type), to observe the consequences and importance of phenomena related to chemical interactions such as diffusion, or optical phenomena such as the spreading profile of the laser beam or its power. First tests (see Fig. 2 Right) were carried out using a commercial TDM system (Nanolive).
In order to achieve higher resolutions of 3D optical mapping, our own TDM system will be used and complemented by an improvement in image reconstruction based on the inverse approach, in order to exceed the present resolution limits imposed by the optical system.

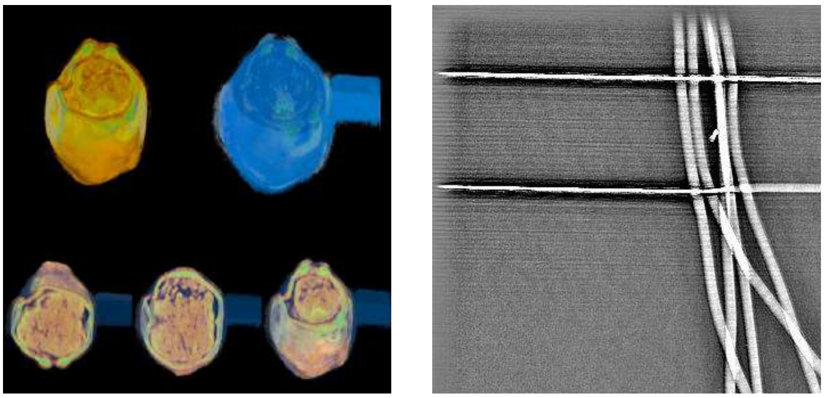

Figure 1. Left: TDM images of a pollen attached to an optical fiber by a photopolymerized bridge. Yellow coded: absorption image. Blue coded: index of refraction image. Left: observation of microprinted polymeric materials by tomographic diffractive microscopy. Gray level variation indicates optical index variation.

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[2] Chia Gomez L.P.*et al*, Rapid Prototyping of Chemical Microsensors Based on Molecularly Imprinted Polymers Synthesized by Two-Photon Stereolithography, *Adv. Mater. 2016, 28, 5931–5937*
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Glassomer – 3D printing of transparent fused silica glass

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Fused silica glass is an important material due to their high chemical and thermal stability their outstanding optical transparency, hardness and well known surface properties. Due to these properties fused silica glass is an interesting material for future applications in chemical synthesis or optics and photonics. However structuring of glasses is difficult, especially when high-resolutions are needed structuring is usually done using wet chemical or dry etching using hazardous chemicals.[1]

We have previously described a new technology to fabricate and structure fused silica glass. We have therefore developed nanocomposites (called Glassomer) which can be processed like a polymer e.g. by UV casting, 3D printing or high-throughput polymer replication.[2-4] After the structuring process the nanocomposites are turned into fused silica glass via thermal debinding and sintering (see Figure 1). We have demonstrated that the sintered fused silica glass is chemically and physically identical to commercial fused silica glass. It shows the same high transparency in the UV, visible and infrared combined with the same mechanical strength, hardness and chemical and thermal resistance.[2-4] Glassomer will enable many applications from optics and photonics and chemistry to life sciences and biotechnology.

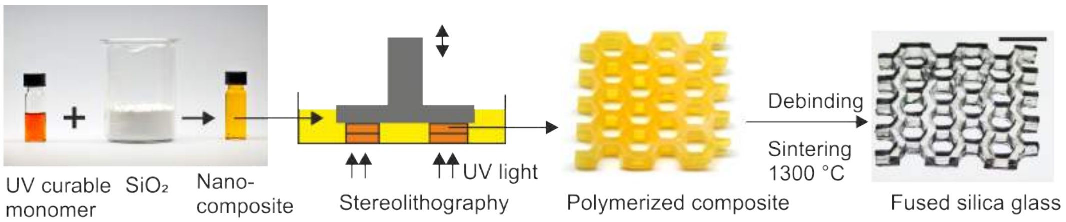

Figure 1 : The Glassomer process: Liquid nanocomposite are consisting of silica nanopowders in a photocurable binder matrix, are printed using stereolithography printers. The polymerized nanocomposites are subsequently turned into high purity fused silica glass via thermal debinding at 600 °C and sintering at 1300 °C.[3]

Literature

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About Copies Non Conformes (Certified Inaccurate)

Cécile Babiole

Independant artist

The installation *Copies Non Conformes* (*Certified Inaccurate*) (Figure 1) explores the erosion and mutations that take place in the reproduction of small sculptures of the 17 letters in the sentence : “JE NE DOIS PAS COPIER” (“I must not copy”). This line is inspired by the punishment commonly meted out to schoolchildren, who are ordered to copy a hundred times by hand prescriptions and proscriptions like “I must not talk in class”. In this case, the prohibition is not copied by hand, but by a digital duplication process : each letter is modelized and printed in 3D, then the resulting object is digitized by a 3D scanner. This new model is reprinted, and so on and so forth, a certain number of times in a row. Because each subsequent generation accentuates the previous morphological alterations, the last reproductions become unrecognizable.

Copies Non Conformes diverts the 3D printer and scanner from their usual functions, using them instead to generate shapes unobtainable in any other way. And thus, because of the iteration protocol chosen by the artist, this installation can be seen as the result of a 4D printing process.

Medical 3D Printing in hospitals – current and future applications

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Additive Manufacturing (AM) or 3D printing is a generative manufacturing process that has rapidly gained in importance, not only in industry but also in medicine, since its introduction about 35 years ago. Especially in the field of personalized medicine, 3D printing already plays an important role. Founded in 2016, at the 3D Print Lab at the University Hospital Basel [www.usb.ch/3dprintlab] realistic anatomical models and other 3D objects from patient image data are being fabricated daily. With the 3D Print Lab, the University Hospital of Basel and the Department of Biomedical Engineering of the University of Basel are responding to the increasing demand for 3D anatomical models on the one hand and creating a platform for research, development and training in this key technology on the other. By this, the lab has already gained an international reputation in the field of medical 3D printing.

The 3D Print Lab acts as a service provider and research platform for radiological imaging, data visualization and additive manufacturing processes. It consists of an interdisciplinary team of surgeons and radiologists with the aim of finding new forms of presentation and applications for three-dimensional image data. The starting point for this is the long-standing expertise of the Department of Oral and Maxillofacial Surgery, where 3D models, surgical 3D guides and implants made of various materials are already routinely used today. Radiological imaging methods such as computed tomography and magnetic resonance imaging, but also conebeam CT and 3D optical surface scanning methods are leading as source data modalities. [1] With almost 30 3D printers of different printing technologies that are now available at the 3D Print Lab and the tight collaboration with external AM partners almost all materials from high-performance polymers (eg PEEK) and metals (eg titanium, magnesium) to ceramics and bioprinting of living cells as printing technologies are being covered. [2,3]

The 3D models produced at the 3D Print Lab support other surgical (medical and dental) disciplines in treatment planning and are also used to educate patients. [4,5] In addition, 3D-printed image data are increasingly being used in teaching and training. In combination with modern imaging techniques, visualization technologies such as augmented reality and virtual reality
(AR/VR), as well as robotics and other innovative tools, medical 3D printing is a key technology that will play an even greater role in future medicine.

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Towards a generic 3D-Bioprinting Platform

Peter Koltay

University of Freiburg, Department of Microsystems Engineering – IMTEK, Laboratory for MEMS Applications

In this talk I will briefly introduce the emerging field of 3D-bioprinting [1] and review the most prominent 3D-bioprinting technologies [2-3] . Furthermore, I present our own activities in the framework of the 3D-Bio-Net project towards a generic 3D-bioprinting platform. The topic will be addressed from a technological perspective rather than focusing on a specific material or application. Pointing out the most important application requirements as well as recently emerging technological trends, it appears that the combination of various materials and printing technologies has gained increasing importance in the recent years. A future universal 3D-Bioprinting platform therefore will probably be required to support several established technologies like micro extrusion, drop-on-demand printing, fused deposition modelling and the like, as well as the combination of these technologies in a seamless software environment. Furthermore, the potential benefit of novel technologies such as for example for single cell printing or spheroid printing in the framework of a generic platform will be discussed and the specifications and the design of the 3D-bioprinter prototype currently being developed within the 3D-Bio-Net project will be presented.

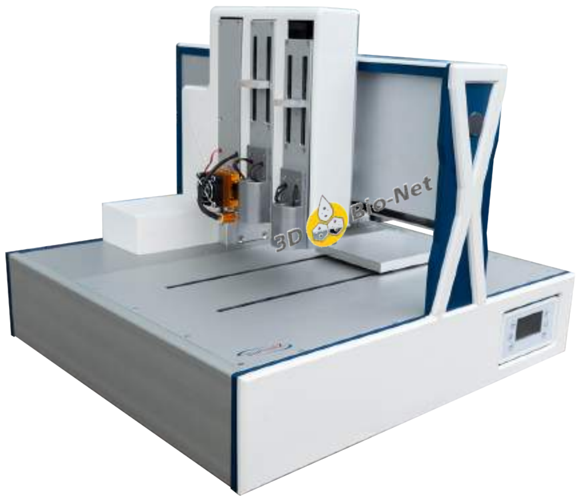

Figure 1 : A photograph of the 3D-bioprinter prototype developed within the 3D-Bio-Net project

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3D printing in medicine with focus on titanium and nitinol alloys

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The Institute for Medical Engineering and Medical Informatics IM^2 conducts research on diagnostics in living organisms and therapeutic systems. This work focuses on patient-specific solutions and on processing, analyzing and processing medical data. In cooperation with our partners, we address problems from the field of medicine and develop innovative solutions from the initial idea to the functional model. Our fields of research are implant development, surgical support systems and medical data sciences.

The implant development research group has access to outstanding infrastructure and has expertise in developing [1] and testing [2] medical implants, particularly bone replacement materials [3]. Its key competency is designing and producing functional complex-shaped components from polymers, ceramics, titanium and shape-memory alloys [4] in small batches by means of additive manufacturing. Patient specific implants [5] (Figure 1) as well as functional implant materials and surfaces [6], e.g. with antibacterial properties, are developed and studied.

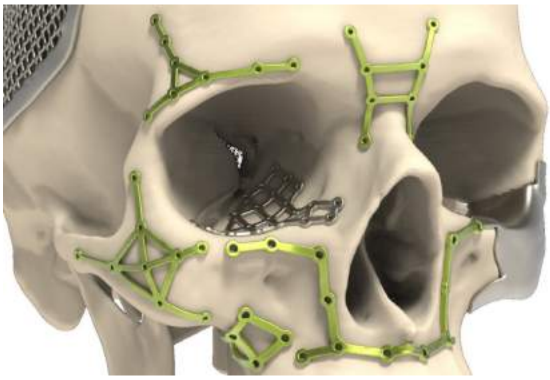

Figure 1 : Patient specific titanium CMF implants

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In-Situ X-ray tomography analysis of 3D printed open-cell structures during mechanical loading

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3D printing of polymeric materials is a layer-by-layer manufacturing method that has gained considerable interests, especially for producing open-cell porous structures for lightening purposes. Compared to traditional foaming process that lead to quasi-stochastic cells organization, 3D printing technology offers the opportunity to create 3D complex geometries with well controllable geometrical features. One can thus imagine creating specific cellular topology to achieve interesting mechanical responses including negative modulus[1], negative Poisson's ratio[2] or optimizing the weight to stiffness ratio[3]. However, the technic is not free from defects and printed parts may suffer from modest mechanical properties related to problem of internal unmelted or material flowing, irregular shape, internal porosities, corrugated or stepped edges. In this study rhombic dodecahedron structures and tetradecahedron (Kelvin's cell) structures of comparable porosity were prepared by 3D printing using two different natures of polymer. Their mechanical behaviors were subsequently analyzed with a particular attention on the influence of the inherent artifacts. To this purpose, *In-situ* X-ray computed tomography was used to image the cellular materials in 3D during uniaxial compression at quasi-static strain rate. Dimensional measurements as cell wall thickness analysis reveal clear deviations from the geometrical characteristics prescribed by the CAD model leading to a difference in the obtained porosity (fig. 1). This is a key point when we know that one of the first parameters determining the elasticity of foam is the porosity. Also, the build-up method layer-by-layer induces surface roughness or stepped edges on the cell strut which constitute one the main difference with that of the perfectly flat CAD geometry. To get a deeper understanding of their consequence on the mechanical response, a finite element model based on a micro-mechanical approach was developed incorporating roughly the same irregular edge shape. Since micro-scale X-ray tomography allowed us to capture the bending and buckling of materials during loading, a comparative study was performed with the F.E simulation. To see how the strut cross-section affects the ultimate mechanical performances of porous structures various cross-section types were implemented and a specific algorithm used to acquire the resulting stiffness and the post-yielding behavior.

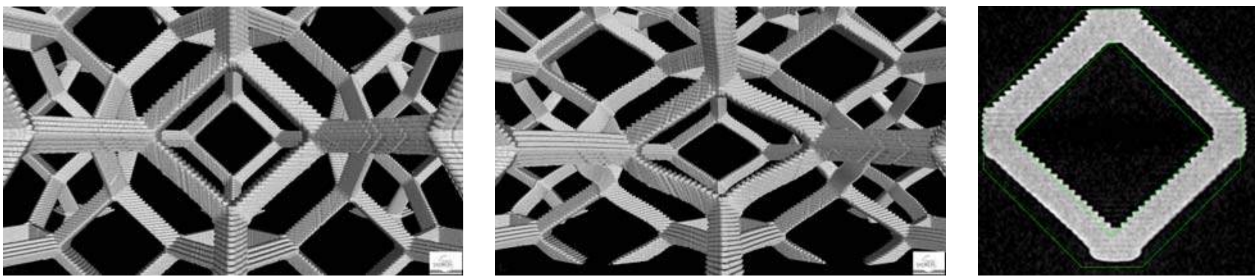

Figure 1. Buckling of the open-cell Kelvin structure deformed at 10% compression – "defects" of the cell edges and dimensional comparison with the CAD geometry (green line).

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Synthesizing stochastic elastic structures

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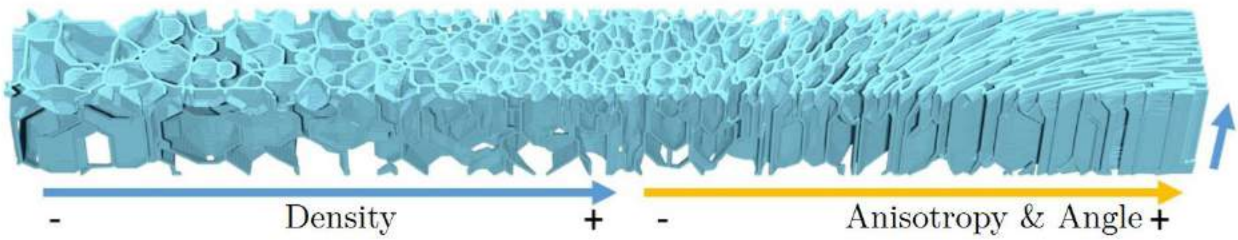
In this presentation I will describe the work done within the MFX team regarding the synthesis of stochastic structures for additive manufacturing. Our structures combine computational advantages with design freedom. In terms of computations, our algorithms synthesize structures during the manufacturing process, layer per layer, with bounded memory and compute resources. In terms of design freedom, our approaches afford for freely orientable and spatially graded orthotropic elastic behaviors within volumes.

We rely on stochastic processes to generate foam-like structures within volumes. By controlling the statistics of the generation process, we show that it is possible to control the final average elastic behavior, which we compute through numerical homogenization. Our techniques can be used in two-scale topology optimization problems, where a shape is globally optimized at a coarse scale, while the random process quickly generates a fine scale foam having the desired homogeneous behavior.

Our approaches take into account fabrication constraints, and we proposed techniques well suited for SLA/SLS [1,2] and FDM [3] additive manufacturing technologies. We develop these approaches within our software [4] for additive manufacturing, with a novel approach to allow for the programmability of infill patterns.



[1] Polyhedral Voronoi Diagrams for Additive Manufacturing
Jonàs Martínez, Samuel Hornus, Haichuan Song, Sylvain Lefebvre
ACM Transactions on Graphics (Proceedings of SIGGRAPH) 2018.

[2] Orthotropic k-nearest Foams for Additive Manufacturing
Jonàs Martínez, Haichuan Song, Jérémie Dumas, Sylvain Lefebvre
ACM Transactions on Graphics (Proceedings of SIGGRAPH) 2017.

[3] Procedural Voronoi Foams for Additive Manufacturing
Jonas Martínez, Jérémie Dumas, Sylvain Lefebvre
ACM Transactions on Graphics (Proceedings of SIGGRAPH) 2016

[4] IceSL : A modeler and slicer
https://icesl.loria.fr/
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From mechanical metamaterials to simple systems made from programmable materials

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AM is changing the processing world and the materials community has yet to tap its potential. The unprecedented lateral resolutions of stereolithographic methods can be used to give us a view into the future of AM, in that they allow the fabrication of artificial crystalline structures on the meso-scale with near complete control of each constituent unit cell's geometry. Furthermore, two-photon lithography enables to fabricate 3D and 4D metamaterials where elements of mechanical mechanisms have sub-µm resolution. Partial polymerization allows enclosing a monomer phase so that after development the metamaterial consists of a solid and liquid phase. This can be used e.g. to design mechanical metamaterials with hydraulic elements. Furthermore, small monomer reservoirs can be included into a 3D structure, which can be opened in a later stage. In combination with a UV-light-source, manufactured 3D micro structures can be manipulated and fixed into their final position. Also, small elements can be manufactured separately and joined later to form more complex structures or circumvent size and resolution limitations. This enables full tuning capabilities of local properties as well as their interaction with their surroundings. Combining different mechanisms in such elementary cells enables us to build IF..THE..ELSE-conditions into the material, actuate intrinsic or surface shape changes based on the decision, or even save deformations in metastable strain energy states. The possibilities are vast and enable fully programmable functional materials. Programmable Materials have the potential to initiate a paradigm shift by replacing technical systems of several components. Today's systems usually consist of a sensor, controller, actuator, mechanical components and power supply. Programmable Materials can replace all these systemic functions by the design of their internal structure and thus differ considerably from previous technical solutions.

A perspective for programmable will be presented for how materials will become stimuli responsive functional systems in the future and what is needed to achieve this goal.

To make parts with functionally graded materials: a real industrial opportunity thanks to additive manufacturing with DED-CLAD®

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In the family of additive manufacturing processes, the deposition of metallic material with laser, developed by IREPA LASER and named DED-CLAD® (Construction Laser Additive Direct), offers as main advantages not to be limited by the dimension of the part, to be able to work on an existing part by adding localized features and to use metal powders.

Metal powders are of great interest because they can be available in a wide range of materials and can be atomized on demand for specific composition. Moreover, since the precursor material is in the form of a metal powder, the materials can also be injected together in order to mix them so as to be able to provide new compositions and targeted properties according to the location into the part.

The objective of the presented development is to manufacture a defect-free functionally graded material (FGM) thin wall structure by the CLAD® process. FGMs are materials whose chemical composition, and thus mechanical and microstructure characteristics are gradually varied along one or more space directions. Interest of FGMs is to combine and concentrate the benefits of two or more materials into one part.

Along with the widely used titanium alloy Ti-6Al-4V, a refractory material, molybdenum, was chosen in this study for its betagene alloying effect on titanium structures. Ti-6Al-4V/Mo alloys can be found in aerospace application because of their high corrosion resistance, and their high melting point.

FGMs are manufactured by using two powder feeders, each one containing a different material. After injecting the powders with the good ratio to attain the desired chemical composition, they undergo to a mixing and homogenizing step, before being sent under the laser beam where they are melted and deposited. The chemical composition can be adjusted layer after layer to create a gradient of composition. The use of two powder feeders, each one containing a different material, also offers the possibility to create unique alloys and thus to make custom manufacturing. One of the main challenges associated to this study is the adaptation of the process considering the difference of physical properties between the metals such as melting point (1674°C for Ti-6Al-4V and 2617°C for Mo). Process parameters have to be adapted to melt both Ti-6Al-4V and Mo powders under the laser beam.

Different thin walls have been manufactured with simple and more complex chemical gradient variation. The study focused on the transition between layers with different chemical composition to understand microstructural evolution and evaluating mechanical properties.

Finally a FGM demonstrator (figure 1) has been manufactured in order to validate the results of the study. The combination of materials makes it possible to offer new solutions in the manufacturing and optimization of parts.

Figure 1 : Demonstrator with FGM section

Participants 2019 : annual meetings 3d 4d printing

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