Computational Design and Fabrication

Bedrich Benes ■ *Purdue University*

David J. Kasik

Wilmot Li ■ *Adobe Research*

Hao Zhang ■ *Simon Fraser University*

Computer graphics research is increasingly interested in the high-level analysis and processing of geometric objects. The focus is more on the objects' structure, semantics, and even functionalities than their geometric details. By acquiring a structural or functional understanding of 3D shapes, researchers are able to tackle mid- to high-level design problems for which machine computations can replace or at least relieve human efforts. In parallel, with the rapid advances in 3D printing technologies, many design solutions explored by researchers and practitioners are focusing on the needs and constraints arising from physical fabrication. Methods that combine interactive design and digital fabrication have also been developed to enable novice users to use these tools without advanced domain knowledge. The intricate connections between design and fabrication, along with strong interests from both graphics researchers and industry in developing computational approaches to both problems, provide the motivation for this special issue of *CG&A*.

This special issue received contributions from both academia and industrial research labs. All four accepted articles are cross-disciplinary, connecting physical fabrication with design and processing tasks in new domains including circuit design, geospatial visualization, and 3D scanning, leading to never-before-seen 3D printing applications. Another common theme shared by the articles is that they all contain an interaction component, allowing human users to remain in the design and manufacturing loop to improve the efficiency of the overall workflow.

Special Issue Articles

The article "FabSquare: Fabricating Photopolymer Objects by Mold 3D Printing and UV Curing" by Vahid Babaei, Javier Ramos, Yongquan Lu, Guillermo Webster, and Wojciech Matusik from the Computational Fabrication Group at the Massachusetts Institute of Technology promotes personal fabrication and rapid prototyping by combining 3D printing and injection molding. Such a combination is drawing attention in the 3D printing community, as well as application domains, because contemporary 3D printers do not yet allow fabrication with all kinds of materials. Using the proposed method, 3D objects are fabricated with photopolymer material via 3D printed molds, while the molds themselves are fabricated with UV-transparent materials that allow for UV curing (the polymerization and solidification of the fluid content). The printed molds can be reused many times, which allows for the fabrication of identical objects as well as those with different materials or components. The proposed process is accessible to any user with a 3D printer, and the required hardware is both simple and inexpensive. The authors also developed a software platform to help users design the molds.

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"Differential 3D Scanning," an article contributed by Ammar Hattab, Ian Gonsher, Daniel Moreno, and Gabriel Taubin from Brown University, is an innovative attempt to combine physical and digital modeling. Although the merits of virtual design have become clear, from a designer's perspective, physically holding and manipulating an object offers a completely different and more intimate experience. The proposed method allows designers to save and update 3D models (fabricated via 3D printing) as part of an iterative design process. The authors leverage 3D scanning to automatically detect changes in the physical model, which are then translated to the virtual model. This work takes a first step toward the ultimate goal of providing a fluent transition from the virtual to the physical and from the physical to the virtual during the design process.

In "SurfCuit: Surface-Mounted Circuits on 3D Prints" by Nobuyuki Umetani and Ryan Schmidt from Autodesk Research, a novel approach to combining 3D printed objects with electrical circuits is proposed. With SurfCuit, a user can design durable electric circuits and embed them into the surface of a 3D printed object using an interactive tool that accounts for the object's arbitrary 3D geometry. Because SurfCuit does not require tedious circuit casing design or expensive setups, it accelerates circuit construction design for 3D models. The article demonstrates how a user can construct complex circuits for consumer-level desktop fused decomposition modeling (FDM) 3D printers, where FDM plastic forms a strong bond with metal when it is melted. This latter observation enables the construction of robust circuit traces using copper tape and soldering.

Finally, "Physical Visualization of Geospatial Datasets," by Hessam Djavaherpour, Ali Mahdavi-Amiri, and Faramarz F. Samavati from the University of Calgary, explores yet another innovative application of 3D printing. The authors describe an approach that leverages digital fabrication to create physical visualizations of geospatial data. Their work extends the capabilities of traditional geospatial models (such as globes and 2D maps) using modular 3D printable components that can be attached and removed to create tangible visualizations of multimodal, multiresolution data. This article demonstrates several example visualizations and interaction techniques on different globe models using various materials.

Future Perspectives

We believe that *CG&A* offers a suitable platform for contributors to present innovative, even futuristic, but perhaps not yet fully tested ideas, to the computer graphics community. Articles accepted to this special issue attest to this assessment. The articles explore how 3D printing can be best integrated into classical design and manufacturing processes (such as molding) as well as innovative applications such as circuit design and geospatial visualization. The development of seamless and efficient means of integration and emerging applications of 3D printing will play central roles in bringing computational fabrication to prominence and realizing its full potential.

At the same time, we should not overlook the limitations associated with contemporary fabrication technologies: long printing time, small print volume, and limited material adaptation and combination. Graphics researchers and practitioners must continue to invest in efforts address these challenges.

Due to the interdisciplinary nature of research in computational design and fabrication, the key to success will be the accumulation and integration of efforts from multiple disciplines including computational science, engineering, CAD/CAM, hardware design, and material research.

Bedrich Benes *is a professor in the Department of Computer Graphics Technology and director of the High Performance Computer Graphics Laboratory at Purdue University. Benes has a PhD in computer science from the Czech Technical University. He is an associate editor of* Computer Graphics Forum *and* Computers & Graphics. *Contact him at bbenes@purdue.edu.*

David J. Kasik *was a senior technical fellow at Boeing until he retired in June 2016. Kasik has an MS in computer science from the University of Colorado. He is a recipient of the ACM Siggaph Outstanding Service Award and is a fellow of the ACM and a senior member of IEEE. Contact him at dave.kasik@comcast.net.*

Wilmot Li *is a principal scientist at Adobe Research. Li has a PhD in computer science from the University of Washington. Contact him at wilmotli@adobe.com.*

Hao Zhang *is a professor in the School of Computing Science at Simon Fraser University, where he directs the graphics (GrUVi) lab. Zhang has a PhD from the Dynamic Graphics Project at the University of Toronto. He is a recipient of the NSERC Discovery Accelerator Supplement Award, a Faculty of Applied Sciences Research Excellence Award, and a National Science Foundation of China Overseas and Macau Scholar Collaborative Research Award. He is a senior member of IEEE. Contact him at haoz@cs.sfu.ca.*