Hybrid Craft: Showcase of Physical and Digital Integration of Design and Craft Skills

Amit Zoran
Artist, researcher, educator
Department of Visualization
Texas A&M University
zoran@cs.huji.ac.il

Amit Zoran

This article introduces the Hybrid Craft exhibition, positioning 15 hybrid projects in the context of today's Maker culture. Each project demonstrates a unique integration of contemporary making practice with traditional craft. The presenters in the show represent a wide range of professional backgrounds: independent makers, students and teachers, designers associated with research institutes, and commercial organizations. The background of Hybrid Craft, the makers and their works, including tool-making, jewelry, bowl-making and interactive design, are presented. The discussion focuses on integrating human skill and design to introduce a diverse portfolio of technologies used in this hybrid making process.

Introduction

Human skills are diverse, but many of today's design and fabrication processes rely on automation rather than manual practice. Modern technology often reduces the need for manual labor, rather than extending it. As a result, traditional crafts are disappearing. The machine has replaced the craftsperson. Plastic has replaced wood. Programmable synthesizers have replaced acoustic instruments. Similarly, traditional design has arrived at an evolutionary impasse, as the reduction in techniques that instill personal values results in artifacts that seem less natural and less human. Yet digital technology contributes an entirely new set of design tools, while contemporary researchers pave the way for computational creativity that can overcome the limitations of the digital terrain, integrating rich and personal design capabilities into contemporary making practices.

The SIGGRAPH 2015 Hybrid Craft exhibition showcases craft techniques and values in contemporary digital design. We show 15 works from skilled makers who rely on computational design tools in their craft, integrating computer-numeric control (CNC) milling capabilities into their processes; using 3D printing technologies to make jewelry, models or artworks; or embedding computational and electronic interaction capabilities into their designs. This demonstrates the multi-directional exchange of knowledge between the new and the traditional. The show emphasizes the importance of craft heritage in contemporary digital design, where beautiful and meaningful artifacts are produced by a machine and craftsperson working together, not by a machine or craftsperson alone. Thus, the show's portfolio is a condensed yet diverse summary of contemporary hybrid making practice.

Background: Digital Making

Digital design and fabrication technologies are no longer a theoretical promise. 3D printing has evolved into a widespread creative discipline that attracts attention not only from skilled makers, but also from investors, entrepreneurs and activists outside the design terrain [1]. Researchers and reporters have suggested that we are experiencing the third industrial revolution, linking digital bits with material atoms to create a programmable physical world [2,3]. Leading media venues discuss the digital making revolution and its potential to empower independent and novice makers with new making capabilities, allowing for personalization of consumer goods.

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In this environment, two different perspectives inform the modern making discourse. On one hand, the democratization of code and growing accessibility to technical knowledge, open source software and hardware groups, and communities of independent makers who share their work online all contribute to the contemporary DIY (Do-It-Yourself) movement [4]. Meanwhile, 3D printing technologies are attracting corporate attention: the digital fabrication revolution is a powerful engine of market growth [5], producing new industrial icons of innovation, such as the promise of getting anything, anywhere and anytime. Public economic and technological discussion of both models centers on electronically empowered making, focusing on either technology or what the technology enables.

Yet people designed and crafted artifacts long before the digital age. Design requires much more than the skills needed to use technical devices as part of the creative process. It integrates diverse sets of tools to fulfill technical needs or constraints while embodying meaningful symbolic and aesthetic values. Many designers, though, cannot explain or define their processes. Dedication and investment are the keys to mastering creative skills, whether they are the skills of a computer programmer, a wood carver or a potter.

Nevertheless, in the last 20 years, researchers from the computer graphic and human-computer interaction communities have been studying ways to shorten the learning curve of manual creative tasks, by developing tools that allow novices to draw with computer assistance [6], or automating part of the creative process. These approaches assume that aesthetic appeal can be reduced to a finite set of quantitative criteria [7] or that the primary purpose of design is to satisfy technical needs [8]. Within the SIGGRAPH 2015 Hybrid Craft exhibition, we wish to focus on a holistic addition to contemporary making, showcasing skilled makers who use digital creative technologies. Rather than highlighting the machine, the algorithm or the economic narrative, we present unique makers who use digital design, fabrication or interaction technologies as part of their creative palettes, integrating them with other tools, techniques and making traditions: these are the makers of Hybrid Craft.

Hybrid Craft Exhibition

In the last several years, researchers, designers and artists have explored approaches toward merging digital making technologies with traditional ones. For example, in my own work, I have looked at different ways to hybridize traditional artifacts with 3D printing [9] and proposed an entirely different approach to combining craft and computers in a line of smart handheld devices [10]. Yet, even as a hybrid maker myself, I am occasionally surprised by the range of creative approaches makers utilize to integrate tools, techniques and materials from a wide spectrum. Sometimes the results I find most exciting are entirely opposite to what I expected, as I discuss in describing the project that opens our walkthrough of the exhibited works.

The Other Way Around: From Virtual to Physical. At SIGGRAPH 2008, I presented a futuristic concept for designing guitars with 3D printing. The reAcoustic eGuitar allowed guitar players to customize it by digitally modifying six separate acoustic chambers (one chamber per string), then printing and assembling these chambers on a modular platform [11]. Over the last seven years, however, I learned that the concept couldn't be accomplished as planned, due to acoustic constraints. I gave up on the idea, but the illustration stayed viral, appearing in several guitar design blogs. Finally, a luthier decided to challenge himself by building a replica based on this concept.

Seppo O. Valjakka, from the Dominican Republic, owns a small guitar design studio. He has been playing, modifying and building guitars for more than 53 years. In 2013, after reading

Figure 1. [A] The original SIGGRAPH posters of reAcoustics eGuitar from 2008. Photos © 2007 Amit Zoran. [B] The process of making the instrument. Photos © 2014 Seppo O. Valjakka. [C] The physical wooden (acoustic-electric) instrument by Seppo O. Valjakka. Photo © 2015 Amit Zoran.

about the reAcoustic eGuitar online, he decided to craft a wooden instrument based on this 3D-printed guitar concept (Figure 1). His craft realization of my virtual rendering shows that ideas and narratives do not always flow from what we naively consider as the old to the modern; sometimes, the virtual contributes to the traditional, rather than the other way around.

Guitar design, like the design of many other instruments, is challenging due to the long process of evolution that has contributed to high standardization. With such devices, ergonomic constraints, functionality, and cultural context have shaped both their performance and the skills needed to master them. This standardization motivates researchers to evaluate how digital making technologies can alter their design [12].

Brian Chan is an origami master, artist and designer who teaches at the MIT Hobby Shop. Chan works with both modern and traditional techniques to create structures that articulate, fold and transform. He also uses digital design and fabrication to alter the traditional design of stringed instruments:

> I try to create works that bring together the spirit of traditional arts, natural structures, and science fiction/fantasy by using both high-tech tools and hand-crafting techniques. Modern technologies like 3D printing and waterjet cutting make it possible to create designs that would otherwise be deemed too complex to realize.
> —Brian Chan

In his *Folding Musical Instruments*, Chan designed instruments so that a musician can travel with them while continuing to practice and perform. These instruments are designed so that

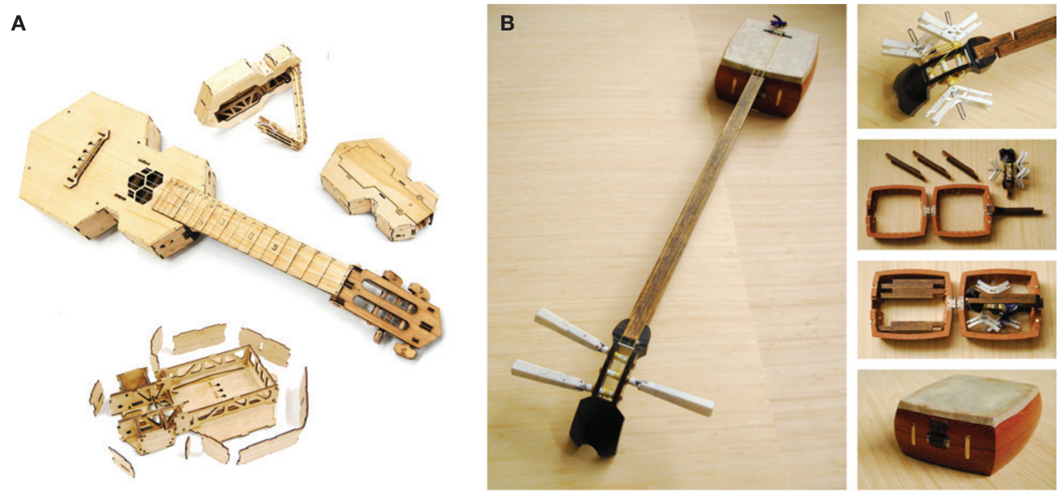


Figure 2. [A] Laser cut folding ukulele and [B] the CNC-milled shamisen by Brian Chan. Photos © Brian Chan.

most of the components can be produced with digital fabrication tools, such as the laser cut folding ukulele or the CNC-milled ultra-compact shamisen (Figure 2).

While Chan uses digital tools to revise instruments' design while keeping their traditional appeal, and Valjakka presents a steampunk-like demonstration of traditional process inspired by sci-fi illustration, for many other makers, digital tools enable the democratization of the design process and making practice. One example of this trend includes DIY bamboo bicycles.

Atar Brosh is a designer specializing in 3D desktop-printer technologies and the implementation of domestic DIY manufacturing scenarios. As a bicycle hobbyist, he says, "Building your own bicycle frame is an independence declaration, it's about regaining control over our abilities, making a clear and bold statement about who you are in a post industrial era, or simply enjoying your creation and the way it rolls and sounds on pavement." Brosh aims to reinvent the way bicycle frames are fabricated by using 3D printing to enable new construction solutions. In addition to using 3D printed parts, he employs a diverse collection of materials, such as aluminum, bamboo, and recycled fibers to reinforce connectors (Figure 3).

Bicycle Frame Domestic Fabrication is a retail project—a comprehensive bicycle frame-building kit. By using 3D printed parts and aluminum tubes, Brosh empowers novice makers to construct their own frames, and reduces the shipping costs of a full-scale bicycle.

The last tool or instrument maker in the exhibition is Rab Gordon. Gordon is a full-time knifemaker from Scotland who works in an old mill overlooking Loch Ness. He specializes in crafting bespoke "Sgian Dubhs" (traditional Scottish knives) and custom-made jewelry. His project *The Celtic Knife Design Using CNC Techniques* shows examples of the creative use of CAD, Computer-Aided Manufacturing (CAM) and CNC in the non-industrial setting of bespoke knifemaking (Figure 4), incorporating traditional Celtic craft values with digital technology through specialized software (CNC Toolkit), machines, and methods developed by the knifemaker.

> In order to craft my knives and jewelry exactly as I wished… I felt that I had to develop my own software, machinery and skills to enable me to use CNC technology as a creative tool in much the same way that I would use a hand held cutter to remove material.… I found that working around the trajectory of the tool via its toolpath … helped bring me closer to the interaction between the tool and material. —Rab Gordon

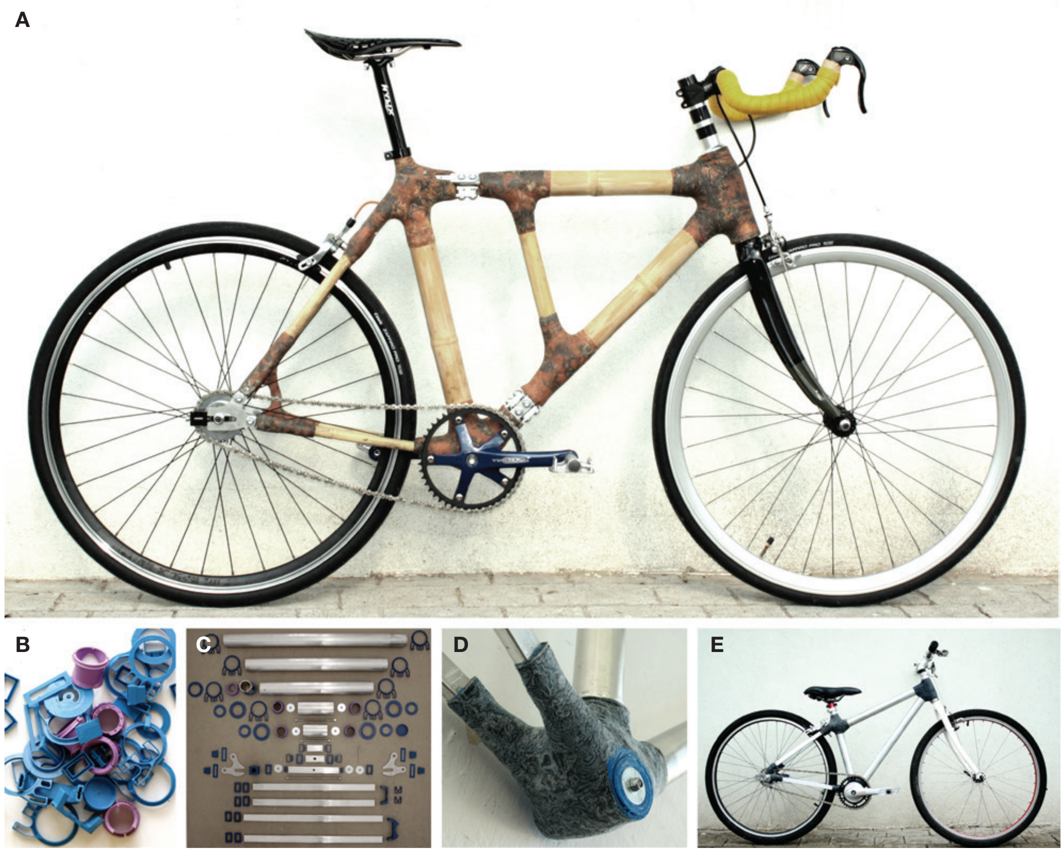


Figure 3. [A] Atar Brosh's bicycle project. [A] Bamboo frame with 3D-printed PLA and organic fiber/epoxy composite reinforcement; [B-C] The Bicycle Frame Domestic Fabrication kit of 3D printed connectors and aluminum tubes; [D] Denim/epoxy composite reinforcement; and [E] Aluminum frame with denim/epoxy composite reinforcement. Photos © 2015 Atar Brosh.

Because tools and instruments carry a symbolic meaning much deeper than the mere technical act of using the devices, they need to satisfy both the functional requirements of usability and the cultural heritage of the practice. While a similar duality between the value the artifact conveys and its performance exists in all design disciplines, jewelry-making presents a unique case, where functionality and aesthetics are relatively unified. Jewelry-making is one of the earliest territories in which digital tools proposed a computational aesthetic. Today, 3D printing processes such as wax prints for casting precious metals or Direct Metal Laser Sintering (DMLS) for steel or other hard metals are common, and digitally driven aesthetics can be found in the portfolios of many designers.

Figure 4. [A] Knife handle milling toolpath generated by Rab Gordon's CNC Toolkit and [B] his celtic knives and jewelry. Photos © 2015 Rab Gordon.

Figure 5. Nine of Yael Friedman's 3D-printed Puzzle-Rings. Photos © 2015 Nir Friedman.

Yael Friedman views jewelry as an interactive art form. For Friedman, it is an exploration of materials, shapes and colors, which all come together to become something new. In her project *3D Printing and Jewelry Making,* Friedman explores the world of toys. She uses Selective Laser Sintered (SLS) 3D-printed nylon or 3D-printed wax and casting in sterling silver or brass to combine 3D puzzles with wearable jewelry and create puzzle rings, pieces that are not only meant to be seen but also to be played with and touched (Figure 5):

> Each ring is constructed of a different number of pieces and assembled in a different manner; each ring is a puzzle. The precious jewelry becomes a toy and the wearer gets a role in the game. Puzzles are complex designs and their success depends on the design and the precision of manufacturing. Creating puzzle rings is more complicated due to the nature of the piece and its size. —Yael Friedman

The relationship between aesthetics and functionality in craft history cannot be discussed without a special focus on the craft of making containers. Some scholars position the mastery of container-making as the heart of craft [13]. Pottery, glassblowing, woodturning and basket weaving are particular examples of practices that evolved to fulfill functional needs, but which have gained and are still gaining a unique place in the history of making, although today their practical aspects cannot be fully explained in economic terms. Bowl- and vase-making, for instance, stand in the center of so many practices that no discussion on craft and technology is complete without a proper survey of contemporary works in that terrain.

The next three projects were created by makers associated with Autonomatic, a 3D digital design research group, which investigates the relationships between digital technologies and craft practices at Falmouth University, Falmouth, Cornwall, UK. This research has resulted in unique artifacts and innovative methods of production disseminated through live projects, workshops, seminars, exhibitions and conferences.

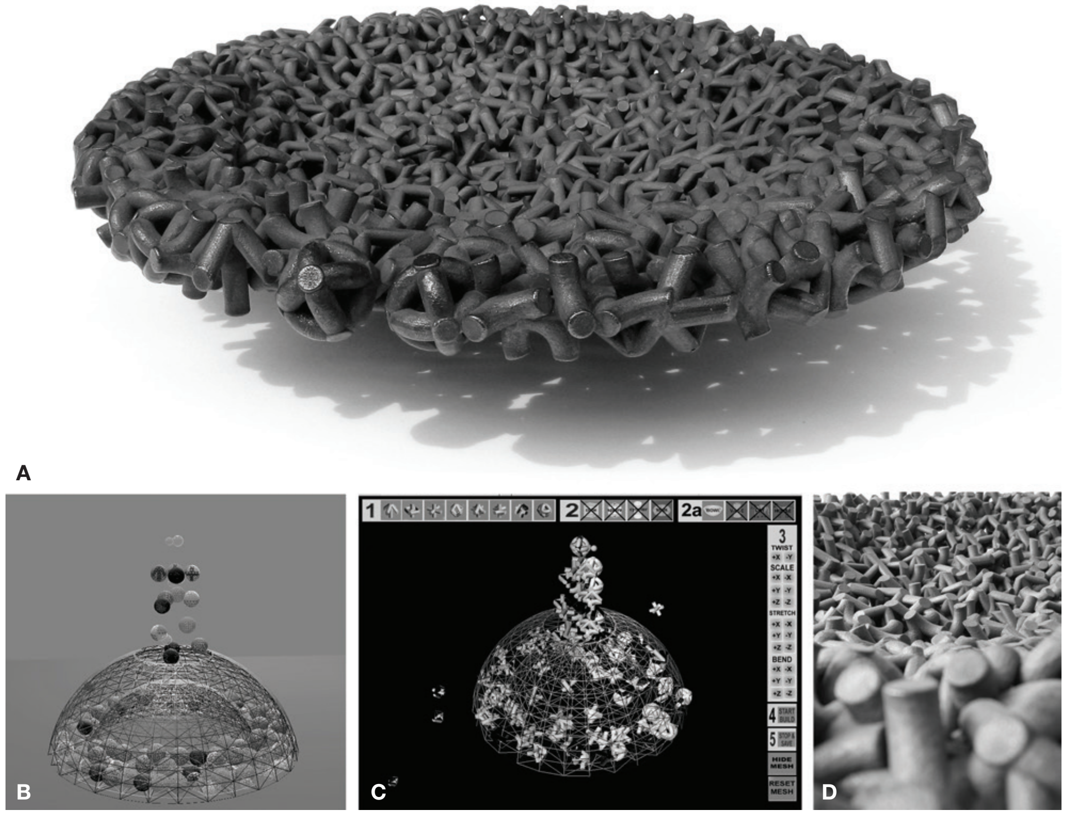


Figure 6. [A] The *Random Generative Large Bowl* by Justin Marshall (2.5kg, 37x50x8cm) and [B-C] its making process using CAD software that combined user input with limiting shape and generative construction. [D] The final copper electroplated SLS nylon. Photos © 2012 Justin Marshall.

Justin Marshall is a practitioner, researcher and Associate Professor of Digital Craft at Falmouth University. He has been investigating the integration of digital design and production technologies into art and craft practices for more than 10 years. Like Brosh, Marshall's interest goes beyond design into the social impact of hybrid practice:

> I am interested in both the development of new making processes that creatively use digital tools and how these open up the possibility for new forms of localized and flexible working practices/businesses that link the post-industrial to the pre-industrial … opening up the potential to refigure the relationship between consumption and production in twenty-first-century culture. —Justin Marshall

Made from copper-electroplated SLS nylon, Marshall's *Random Generative Large Bowl* is a digital one-off created with Automake [14], a bespoke generative design software that Marshall co-created (Figure 6). It was achieved by creating form-building software that combined user input with some limiting design parameters, as well as opportunities for unique and uncontrolled outcomes produced by generative algorithms.

The use of 3D printing in traditional craft creates entirely new design opportunities, challenges and limitations. However, CNC tools such as digitally controlled milling machines have longer historical roots in fabricating machine parts, models or molds, and have been subtly integrated with traditional craft practices. The main obstacle until recently was the cost of such fabrication facilities and the relative complexity of operating them. This is changing as machine costs drop and more DIY tools and knowledge become available online. One example is Katie Bunnell's *SuperSlip-Pi*, a low-cost CNC machine for ceramic surface decoration.

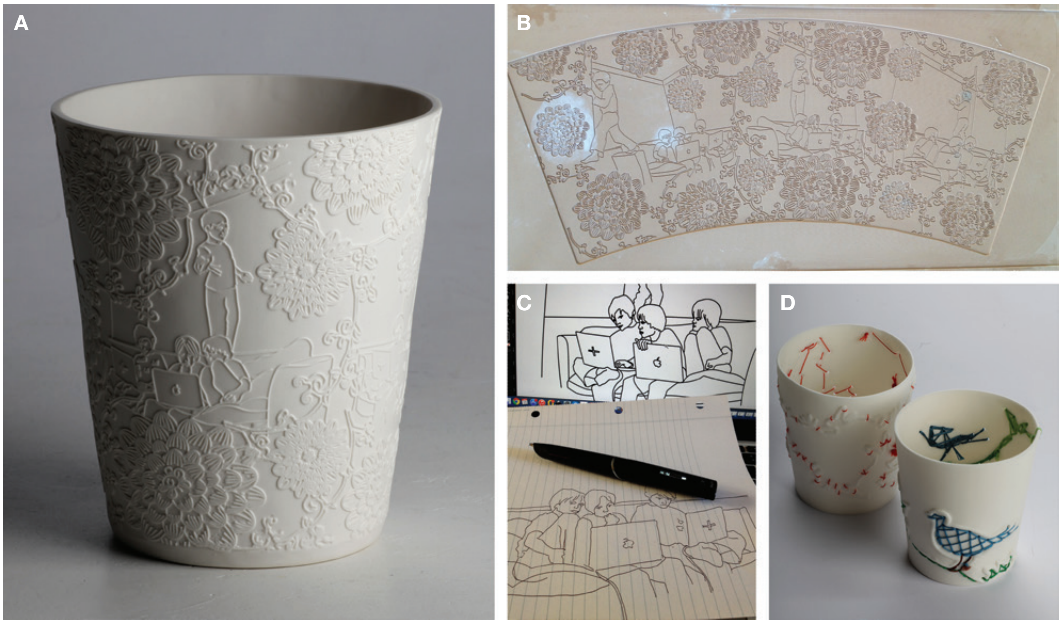


Figure 7. [A] Katie Bunnell's porcelain Minecrafting cup; using [B] CNC press mold based on [C] digitized hand drawings; [D] two smaller cups. Photos © 2015 James Mann and Katie Bunnell.

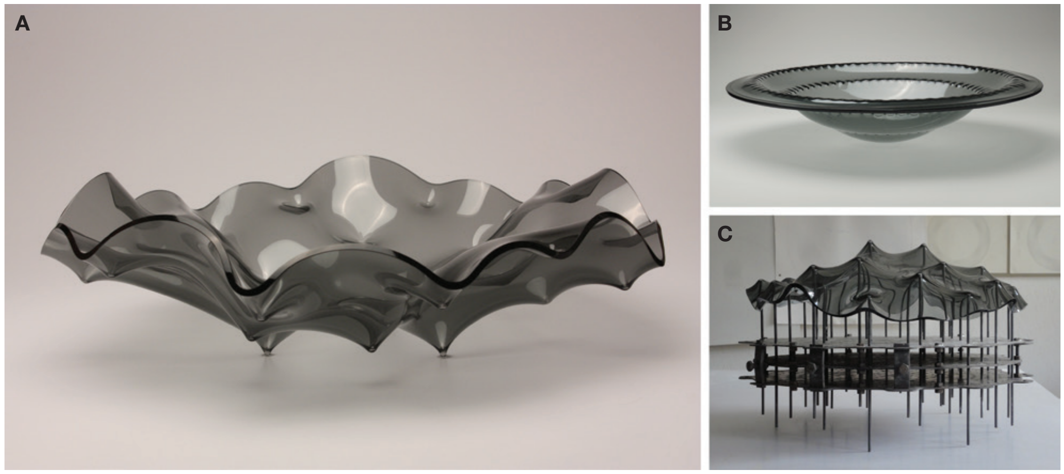
Katie Bunnell is a ceramic designer, Associate Professor of Design at Falmouth University, the founder of Autonomatic, and a trustee at the Leach Pottery in St. Ives. She has worked in the field of digital craft since 1995, when she started her PhD investigating the creative application of digital technologies to her practice as a ceramic designer-maker. Bunnell's research is based on "an open and exploratory approach to integrating digital technologies with traditional making, exploiting digital tools in unexpected and sometimes subversive ways, looking for creative opportunities" (Katie Bunnell).

In *Minecrafting,* Bunnell draws upon traditional Chinese ceramic surface patterns and narrative composition (Figure 7), rendering scenes of contemporary family life in low relief amongst stylized chrysanthemums. Three children line up on the family sofa, two play Minecraft on laptops, and the third watches intently, while a fourth child climbs the walls. The piece combines digital design and production methods with hand drawing, traditional slip casting and hand-building processes for high-fired porcelain.

Our last artist from Autonomatic Research Group is Tavs Jorgensen, a research fellow, designer and researcher who explores the creative use of new digital design and fabrication tools. He initially trained as a craft potter in his native Denmark, but after establishing a design consultancy in 1995, he spent more than a decade working as a designer for the ceramic industry. Today, Jorgensen maintains an active creative practice, regularly exhibiting his work at international venues while teaching in several different places.

In his project *Neo-Industrial Biography, Glass Working and Re-configurable Toolmaking,* Jorgensen developed tooling systems based on the concept of Reconfigurable Pin Tooling (RPT). Despite captivating descriptions of RPT as a *universal* or *ideal* tooling method, its potential for using a single mold to produce an infinite range of forms has not seen many successful real-life applications. However, digital technologies have allowed the concept to be re-investigated and the complex toolmaking required to be carried out with far greater ease. The tooling systems in this project have been developed almost entirely with digital design tools, while the actual use of the final system is completely analog.

Figure 8. [A-B] Two of Tavs Jorgensen's gray float glass pieces made using [C] Reconfigurable Pin Tooling and a free fall slumping technique. Photos © 2014 Tavs Jorgensen.

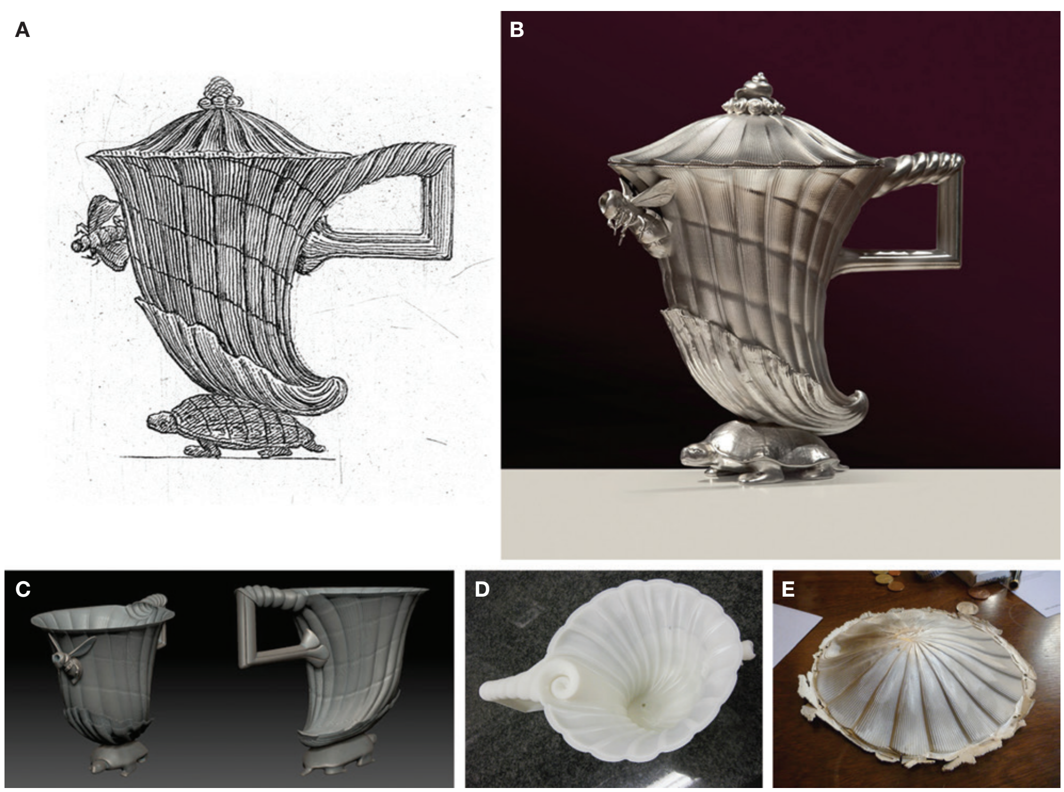


> I believe that technologies such as CNC milling and certain 3D printing methods have now achieved such a widespread level of diffusion that the most interesting use for these technologies is in a tool-making role—rather than methods for the direct fabrication of artifacts. —Tavs Jorgensen

The gray float glass pieces (Figure 8) are the results of exploring this technology. Using a *free fall slumping* technique, Jorgensen created these bowls by heating glass disks and letting gravity force the glass against pins positioned in a matrix of holes in the tooling device.

As Jorgensen and Bunnell position digital tools in the practice of contemporary craft, commercial institutions have started offering products and services that use computers to preserve cultural heritage. Based in Madrid and Bologna, Factum Arte consists of a team of artists, technicians and

Figure 9. The Silver Coffee Pot from the *Piranesi Collection* by Factum Arte. [A] Original drawing by Piranesi; [B] finished Coffee Pot; [C] CAD model; [D] 3D printed and [E] casting process. Photos © 2010 Factum Arte.



conservators dedicated to “digital mediation”—both in the production of works for contemporary artists and in the production of facsimiles as part of a coherent approach to preservation and dissemination. The Factum Arte team has designed artifacts and processes and developed software to obtain optimum results in both recording and outputting digital information related to art and craft production and restoration. Merging the potential of digital technologies with traditional craft skills is at the heart of all the work produced by Factum Arte.

The *Piranesi Collection* was inspired by the work of the Italian artist Giovanni Battista Piranesi (1720-1778), using digital tools to realize work in 2010 that he designed between 1760 and 1770. The objects were digitally modelled using ZBrush (by Adam Lowe with Voxel Studio, Madrid), 3D-printed in high detailed stereolithography at Materialise, and then made in cast, hand-chased, and polished. This presentation includes two objects from the collection, the Helix Tripod and the Silver Coffee Pot (Figure 9).

Factum Arte’s *Piranesi Collection* shows a high degree of precise and complex modeling, with CAD and 3D printing being used as stepping stones for the final artifact. In the historical context of model making, skilled modelists manipulated raw materials to achieve accurate representations of still lifes or figurative objects. Similarly, some digital makers explore the use of 3D printing to model accurate artifacts and figures.

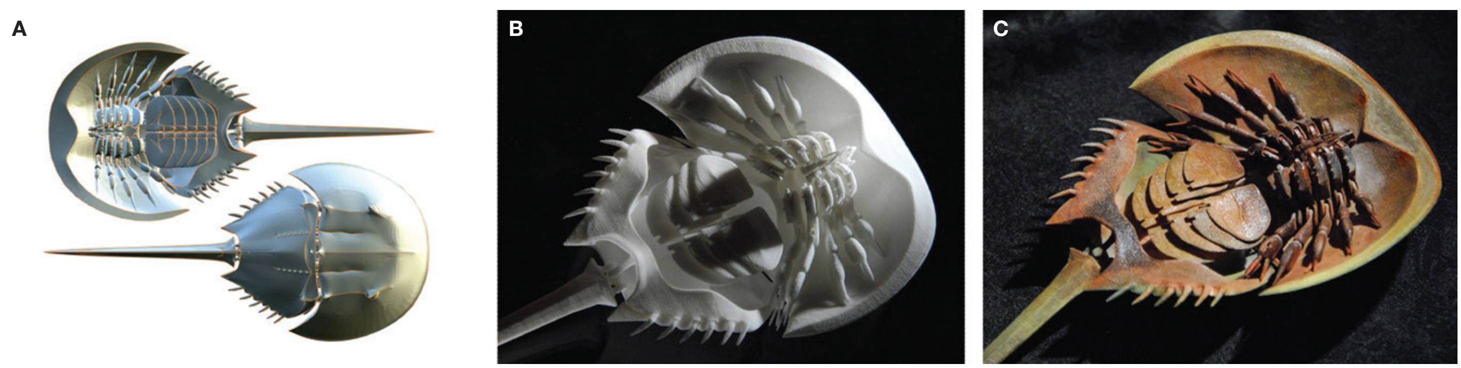


Figure 10. One example of the *Articulated 3D-Printed, Hand-Painted Sculptures* by Brian Chan. [A] CAD model of horseshoe crab; [B] 3D-printed model and [C] hand-finished model. Photos © Brian Chan.

The *Articulated 3D-Printed, Hand-Painted Sculptures* by Brian Chan (whose *Folding Musical Instruments* appeared earlier in the exhibition) are models printed in one pass, with integral joints allowing lifelike motion (Figure 10). They are modeled from scratch, not 3D-scanned, and printed in Shapeways SLS nylon.

With these 3D-printed figurative models in mind, Shane Hope proposes a unique use of digital fabrication in the realm of contemporary visual art. Hope received his master of fine arts from the University of California, San Diego, and worked as a research assistant in the Department of Art at the University of California, Los Angeles. His work has been shown in a range of venues and galleries. In his work, Hope sculpts structure virtually, using Python scripts that automate alternative derivations algorithmically.

> It’s one thing to algorithmically push pixels around, or even molten plastic and such for that matter, but it’ll be quite another thing altogether when it’s atoms. I’ve been hand-hobbling together from scratch DIY 3D printers to behave (or misbehave) like my painting assistants and materialize my molded molecular models, all the while exhibiting expressionistic potential. —Shane Hope

Figure 11. Selection of works by Shane Hope, 3D-printed polylactic acid (PLA) molecular models and paint on plexiglass, each 24'' x 24''. (The work presented in the show may differ.) Photos © Shane Hope.

In *Species-Tool-Beings* (3D-printed PLA molecular models and paint on panel, 24 x 24 x 2 inches), Hope demonstrates the results of his approach, which relies on modified molecular modeling software and DIY 3D printers.

Peter Schmitt, a Boston-based German artist and roboticist, further explores the relationship between organic forms and digital fabrication in *The Hunt for Butterflies*. Schmitt received his PhD in Media Arts and Sciences from the MIT Media Lab in 2011. Coming from a craft-oriented background, Schmitt began creating kinetic artworks using off-the-shelf industrial components. His current practice involves making his own computational methods and machine tools to create functional artworks that express motion through form and material. In this work, Schmitt uses CAD, CNC machine tools, wood, plastic, metal, electronics and mechanics to "explore the question of how computational methods, machine tools and fabrication resources can be used outside the paradigm of application, function, purpose and profit.… What would a

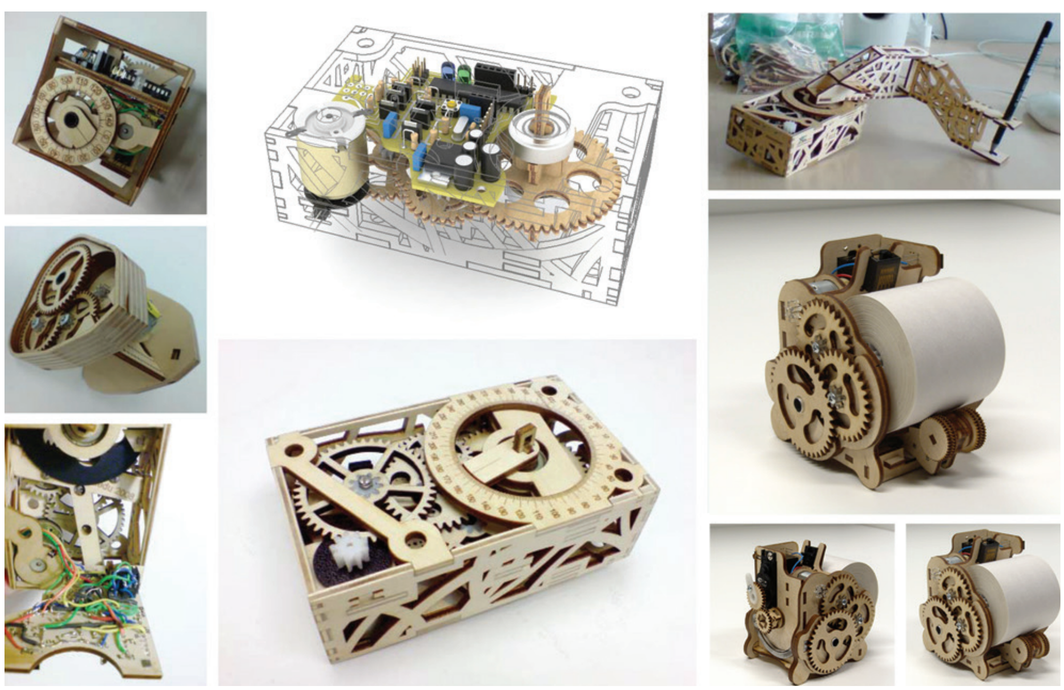


Figure 12. Selections of digitally and manually fabricated plywood machines by Peter Schmitt, using CAD, CNC machine tools, plywood, plastic, metal, electronics and mechanics. Photos © 2006-2010 Peter Schmitt.

Figure 13. ***Living Wall***, **an interactive wallpaper by Leah Buechley that can be programmed to control lighting and sound, and generally serve as a way to enrich environments with computation. (The work presented in the show may differ.) Photos © 2010 Leah Buechley.**

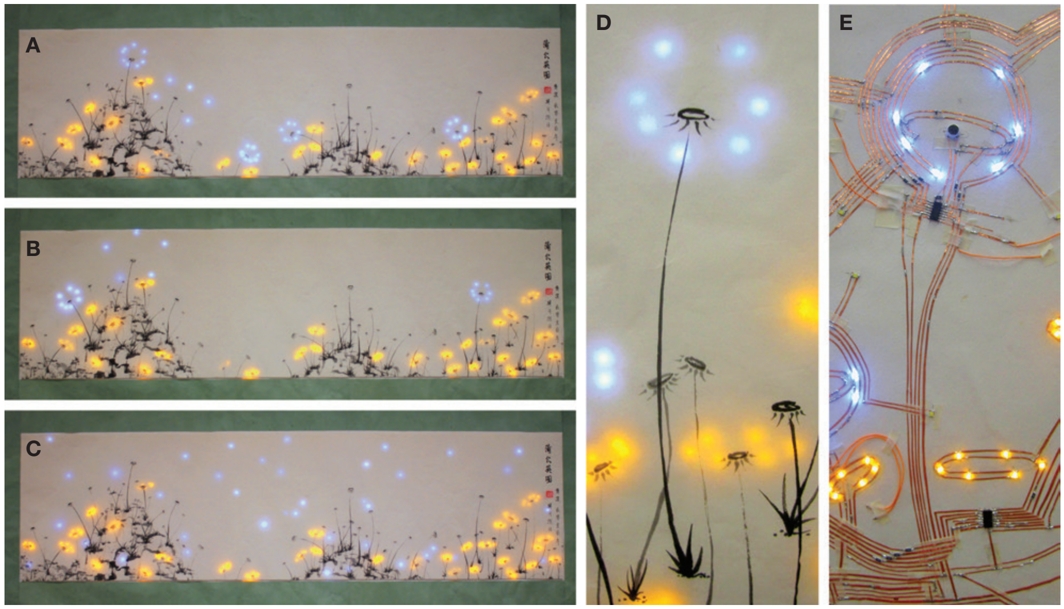
machine look like and how would it move if it was made as an artistic expression in a culturally relevant context rather than a purely economic one?" (Peter Schmitt)

The next two projects explore other aspects of technological hybrids, more in the realm of interaction design than of CAD. *Wallpapers IV* by Leah Buechley is part of a series that explores how unique wallpapers—decorative and interactive—can be constructed from thin, flexible electronics. Buechley is a designer, engineer, artist and educator whose work explores intersections and juxtapositions of "high" and "low" technologies (Figure 13), new and ancient materials, and masculine and feminine making traditions. Her inventions include the LilyPad Arduino toolkit. From 2009 to 2013, she was a professor at the MIT Media Lab, where she founded and directed the High-Low Tech group.

> I delight in unexpected juxtapositions of materials, cultures and making practices.… I strive to blur boundaries between engineering, design, craft and art and to invite people to experiment with and appropriate tools and materials from other cultures.
> —Leah Buechley

The *Dandelion Diptych* by Jie Qi explores the relationship between physical painting with ink on paper, digital painting with LEDs controlled by code, and the handcrafted circuitry that connects the two (Figure 14). Qi is a doctoral candidate in the MIT Media Lab. Her research investigates new materials and techniques for blending electronics with traditional arts and crafts media to create expressive and personally meaningful technology. This piece is made up of two interactive paintings of dandelions. Viewers blow on the work to activate it. One of the paintings reflects reality—as you blow on the dandelion, its seeds disperse and float away. The other inverts it—as you blow on the empty stem, the seeds are drawn back to the flower. The only difference between the paintings is one line of code.

Figure 14. [A-C] *Dandelion Painting* using ink on paper by Jie Qi, digital painting with LEDs controlled by code, and [D-E] the handcrafted circuitry that connects the two. (The work presented in the show may differ.) Photos © 2012 Jie Qi.



> When I'm working with this combination of electronics, programming and craft, it feels like I'm playing with a set of magical crayons that turn fantasy into reality, even though it's just physics, circuits and code. My goal is to enable everyone to express themselves this way, so that they too think of technology as "magical crayons" to turn what existed only in their dreams into reality. —Jie Qi

Finally, I would like to wrap up this discussion on hybrid crafts with a unique project by Jennifer Jacobs. Jacobs, a PhD student in the MIT Media Lab, examines ways to expand participation in computer programming by building computational tools for aesthetic design, digital fabrication and craft. In *Line Number,* Jacobs contributes to the design of the Hybrid Craft exhibition itself by using parametric design tools to create patterns decorating the exhibition's walls and pedestals.

> I find that making, drawing and programming are all important opportunities for personal expression. As an artist, my goal is to reconcile all three creative forms into a unified practice. —Jennifer Jacobs

Line Number combines drawing, programming and making; the patterns in the piece (Figure 15) are created by an algorithm that repeats a series of simple forms by modulating their scale, position and rotation in relationship to a series of manually drawn curves. A series of these forms is then translated to wooden panels using CNC milling techniques.

Within the SIGGRAPH 2015 event, the spatial design of the gallery follows Jacobs' rationale of parametric patterns. In the same line of thought, the exhibition, co-designed by Başak Şenova, has been shaped by taking inspiration from Jacobs' work as the matrix of the architecture, structure and visual identity.

Summary

Today, there is a growing number of design venues dedicated to 3D printing, while Maker Faires celebrate the DIY of electronic products or computationally made designs. Within this trend, we wish to highlight human skills and master craftspeople who use technology as part of their creative palate, integrating computationally enabled designs and objects with traditional crafts,

Figure 15. *Line Number* patterns by Jennifer Jacobs [A-B], created by an algorithm that repeats a series of simple forms [C] by modulating their scale, position and rotation in relationship to a series of manually drawn curves. Photos © 2015 Jennifer Jacobs.

such as tools, instruments and machine making, jewelry, containers and model making, artwork, graphic and pattern design. Within the SIGGRAPH 2015 Hybrid Craft exhibition we position makers and their creative use of hybrid technologies in the center of our discourse, advocating for human-centered development of future design tools.

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References

1. "Making in America: U.S. Manufacturing Entrepreneurship and Innovation." The Executive Office of the President, The White House, Washington. June 2014.
2. "The third industrial revolution: The digitisation of manufacturing will transform the way goods are made—and change the politics of jobs too." *The Economist*, 21 April 2012, <www.economist.com/node/21553017>, last accessed 23 March 2015.
3. Gershenfeld, Neil, *FAB: The Coming Revolution on Your Desktop—From Personal Computers to Personal Fabrication* (New York: Basic Books, 2007) 3–27.
4. Morin, Brit. "What Is the Maker Movement and Why Should You Care?" *Huffington Post*, 7 February 2013, <www.huffingtonpost.com/brit-morin/what-is-the-maker-movemen_b_3201977.html>, last accessed 23 March 2015.
5. Clinch, Matt. "3-D printing market to grow 500% in 5 years." CNBC, 1 April 2014, <www.cnbc.com/id/101542669>, last accessed 23 March 2015.
6. Xie, Jun, Aaron Hertzmann, Wilmot Li and Holger Winnemöller. "PortraitSketch: Face sketching assistance for novices," in *Proceedings of the 27th annual ACM symposium on User interface software and technology* (UIST '14). ACM, New York, NY, USA (2014).
7. Pavlidis, Theo and Christopher J. Van Wyk. 1985. "An automatic beautifier for drawings and illustrations," in *Proceedings of the 12th annual conference on Computer graphics and interactive techniques* (SIGGRAPH '85). ACM, New York, NY, USA (1985).
8. Schulz, Adriana, Ariel Shamir, David I. W. Levin, Pitchaya Sitthi-amorn and Wojciech Matusik. "Design and fabrication by example," *ACM Transactions on Graphics*. 33, 4, Article 62 (July 2014).
9. Zoran, Amit. "Hybrid Basketry: Interweaving digital practice within contemporary craft," in ACM SIGGRAPH 2013 Art Gallery (SIGGRAPH '13). ACM, New York, NY, USA. (2013).

10. Zoran, Amit and Joseph A. Paradiso. 2013. "FreeD—A Freehand Digital Sculpting Tool," 31st international conference on Human factors in computing systems (CHI '13). ACM, Paris, France (2013).
11. Zoran, Amit and Pattie Maes. 2008. The reAcoustic eGuitar, in ACM SIGGRAPH 2008 posters (SIGGRAPH '08). ACM, New York, NY, USA, Article 40, 2 pages (2008).
12. Zoran, Amit. "The 3D Printed Flute: Digital Fabrication and Design of Musical Instruments," *Journal of New Music Research* (JNMR), volume 40, issue 4, December 2011, pages 379-387 (2011).
13. Risatti, Howard. *A Theory of Craft: Function and Aesthetic Expression*. The University of North Carolina Press; Reprint edition (29 October 2007).
14. Automake (www.automake.co.uk) was part of the Post Industrial Manufacturing Systems (PIMS) research initiative instigated by Paul Atkinson of Sheffield Hallam University in the UK, and a collaboration between Justin Marshall and Ertu Unver of Huddersfield University, also in the UK.