portfolio peter schmitt

... works by peter schmitt 2000-2014

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about

photograph by peter schmitt

Peter Schmitt (German, born in 1977) is an artist and roboticist with a Diploma in Fine Art, Sculpture, from the Academy of Fine Art (Kunstakademie) in Düsseldorf Germany (2005) and a PhD in Media Arts and Sciences from the Personal Robots Group at the MIT Media Lab (2011). Exposed to engineering and construction through his father’s business, Peter studied fine arts under Klaus Rinke who awarded him “Meisterschüler” in 2003 (the highest honor a professor can award to a student) for his work with kinetic installations and machine-like sculptures. He graduated in 2005 with Thomas Ruff exploring methods for digitally sculpted photographs. At the MIT Media Lab, Peter developed electric concept vehicles in combination with robotic wheel prototypes for the folding, electric CityCar in Prof. William J. Mitchell’s Smart Cities Group. After Prof. Mitchell’s sudden passing, Peter continued his PhD research under Prof. Cynthia Breazeal developing computational tools and methods for definition-driven ideation, creation and control of functional 3D printed machines and robots. After graduating, Peter launched Original Machines Studio. As part of his interdisciplinary practice, he is collaborating with Chris Bangle, CBA (Turin, Italy) and advising General Sensing Ltd (Hong Kong) as their Head of Design.

Peter Schmitt’s work addresses contemporary challenges in digital fabrication and 3D printing: break away from old approaches to making, reduce the inherent complexity and enable larger and more diverse audiences to claim authorship of physical, mechanical and robotic things. Applications spanning industry, consumer products and art can be realized using the object-oriented mechatronic method Peter developed as part of his PhD research. Automatic engineering and control solutions handle complexity for the user and drive software-based generation of functional, 3D printable parts. The resulting machines can be controlled by reconnecting them to the very same software which created them thus closing the loop between user, computer and 3D printer for faster and cheaper creation and iteration of design driven mechanical and robotic applications. “Form Drives Function” (rather than “Form Follows Function”) is the motto for Original Machines, the term Peter coined in his dissertation to describe the outcomes of object-oriented mechatronics and the name of his studio.

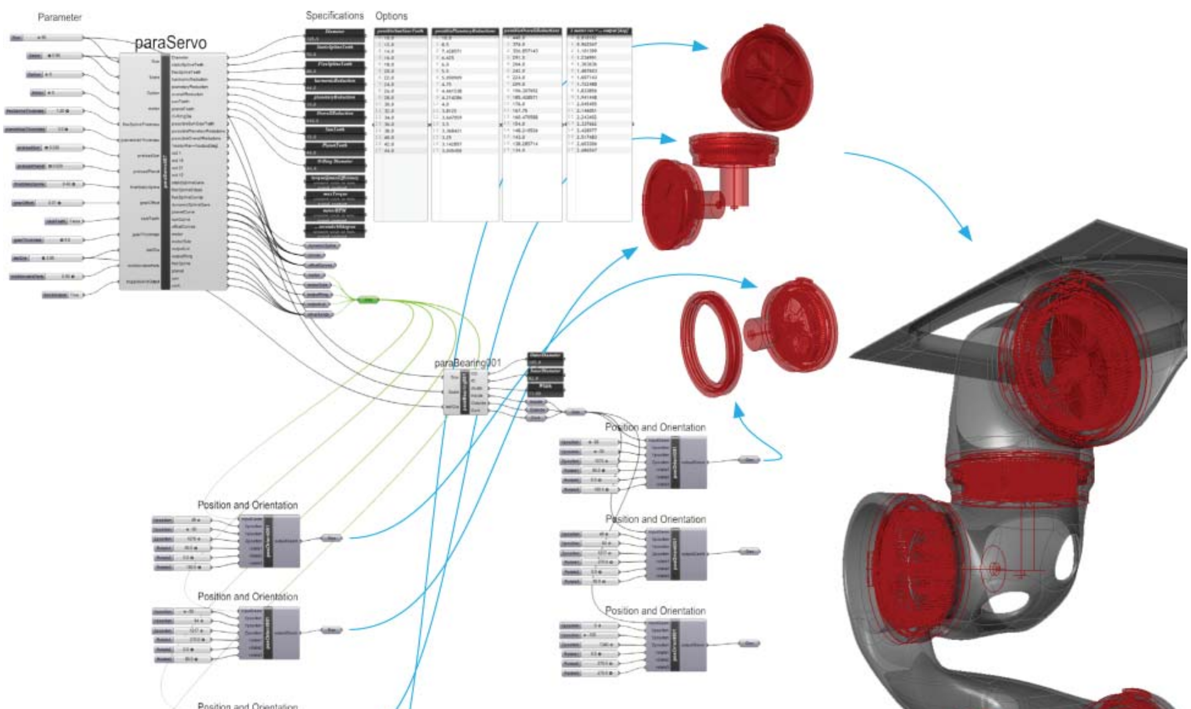
In 2009, with inspiration provided by Robert Swartz, Peter created the 3DprintedClock, a complete and assembled clock entirely created by a 3D printer. With the help of an added metal weight, the grandfather clock starts ticking as soon as it is removed from the 3D printer. The 3DprintedClock was exhibited at ARS Electronica (2009) and at the Disseny Design Hub Barcelona (2010) where it is now part of the permanent collection. During his time at MIT, Peter designed and built three winning cardboard boats (2008, 2009, 2010) for the Head of the Zesiger MIT cardboard boat competition applying parametric design and digital fabrication strategies. The 2008 boat “Bailout” is now part of the Nautical Collection at the MIT Museum. Together with Axel Kilian, John Snavely and Philip Block, Peter won the MIT Dept. of Architecture’s Mini-Skyscraper competition in 2005 for which the team built a (40-foot/12-meter) responsive structure utilizing pneumatic muscles. At the Media Lab, Peter served as Highlands and Islands Enterprise Fellow (2007 to 2008) and Hasbro Fellow (2010 to 2011). Peter was awarded a Cusanuswerk scholarship (2003-2005) to pursue his graduate education in the Fine Arts.

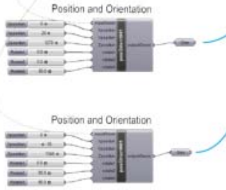
As an artist Peter Schmitt’s works in the field of kinetic installations and machine-like sculptures have been exhibited internationally and are part of the permanent collection at the Academy of Fine Art (Kunstaklademie) Düsseldorf, the Disseny Design HUB and private collections in Puerto Rico and the United States.

“The printed world”, The Economist: http://www.economist.com/node/18114221
“Off Book: Product Design”, PBS arts: http://www.pbs.org/arts/gallery/off-book-episode-11-product-design/off-book-episode-11-product-design/

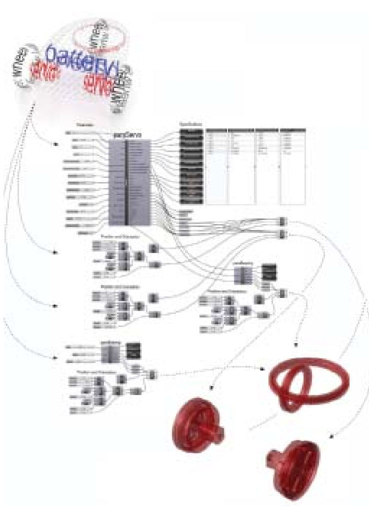
originalMachines: Object-Oriented Mechatronic (method)

Schmitt, P. A. (2011). originalMachines: Developing Tools and Methods for Object-Oriented Mechatronics. PhD Thesis. Massachusetts Institute of Technology.





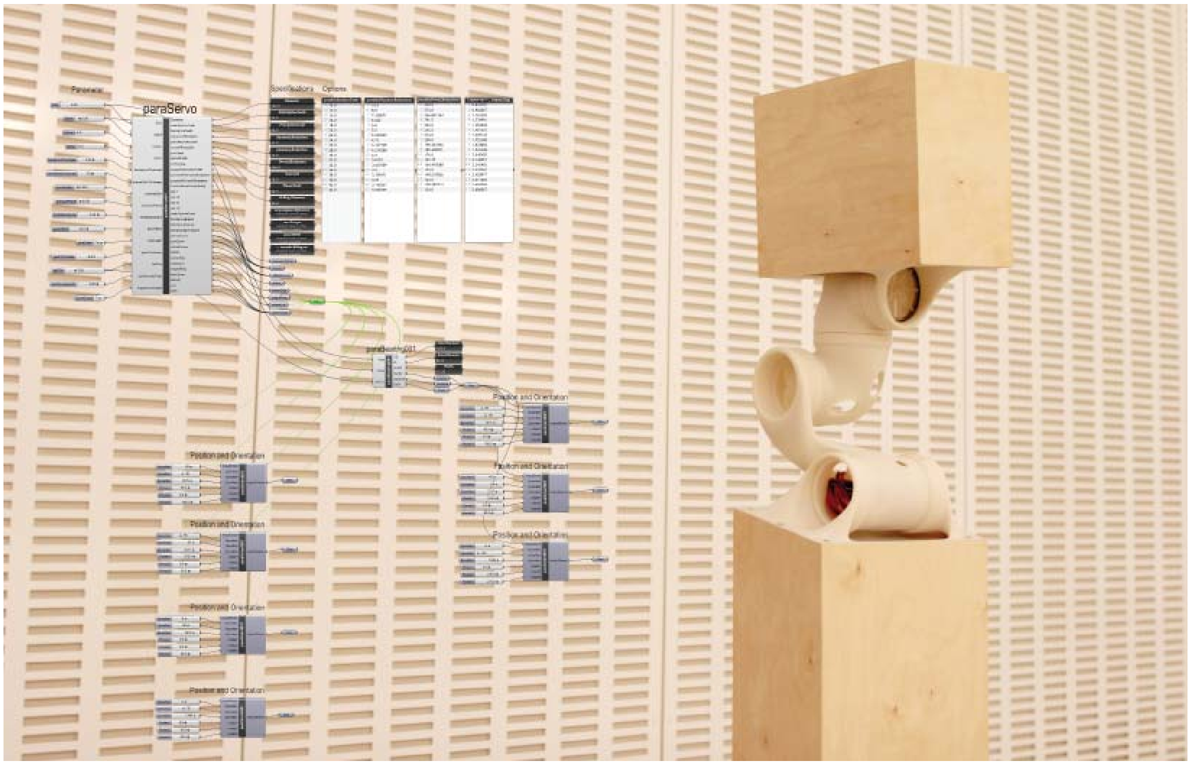
The digital revolution has fundamentally changed our lives by giving us new ways to express ourselves through digital media. For example, accessible multimedia content creation tools allow people to instantiate their ideas and share them easily. However, most of these outcomes only exist on-screen and online. Despite the growing accessibility of digital design and fabrication tools the physical world and everyday objects surrounding us have been largely excluded from a parallel explosion of possibilities to express ourselves. Increasingly, web based services allow professional and non-professional audiences to access computer-aided manufacturing (CAM) tools like 3D-printing and laser-cutting. Nonetheless, there are few (if any) design tools and methods for creating complex mechanical assemblies that take full advantage of CAM systems. Creating unique mechatronic artifacts or “originalMachines” requires more specific and sophisticated design tools than exist today. “Object-Oriented Mechatronics” allows the user to gain control over all aspects of the machine-object including not only its shape, form, size, and material properties, but also its functionality, control, and animation. It uses the computer and computational tools holistically to integrate design, fabrication and controls overcoming the limitations of both the kit-of-parts approach and the free-form process. It is a parametric design methodology that connects knowledge about mechanical assemblies and electronics with the requirements of digital manufacturing processes. Parametric instances like gears, bearing and servos are made available as objects within a CAD environment which can then be implemented into specific projects. The approach addresses the missing link between accessible rapid-manufacturing services and currently available design tools thereby creating new opportunities for self-expression through mechatronic objects and machines.



The dissertation has contributions on multiple levels. A host of actuator assembly examples and the parametric design tool present a body of novel work that illustrates the benefits of going beyond off-the-shelf actuator assemblies and kit-of-parts for original machines. The design methodology and the accompanying examples will empower more users to design original machines with custom actuator assemblies using the latest digital fabrication tools. Finally, these explorations will illustrate how new CAD/CAM tools can facilitate an interdisciplinary exchange between design-oriented and engineering-oriented users.

originalMachiens: Idling

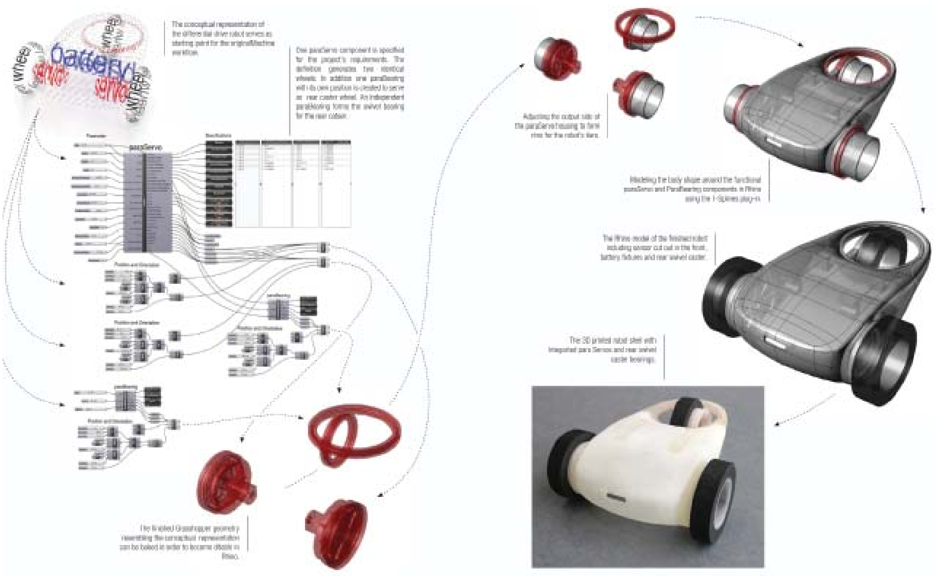
an example of an originalMachine as a 4DoF entirely 3D printed robotic neck assembly for human like head actuation.

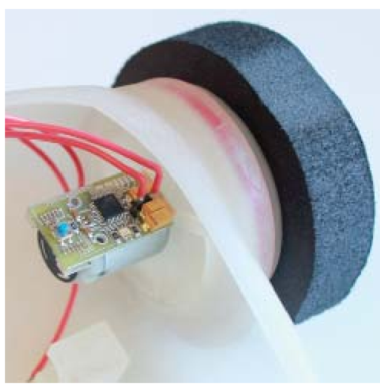


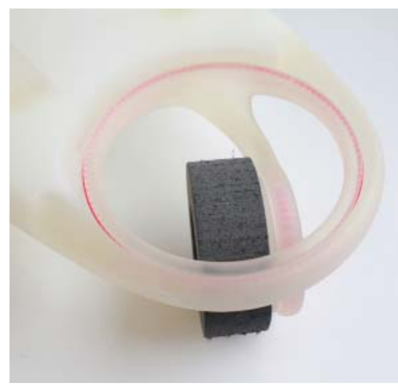
Idling is an example of an originalMachine involving multiple degrees of freedom with the intention to show the organic and fluid integration of actuators, bearings and a robot body. To emphasize the organic properties the robot links a cubical wooden pedestal and head block from which and into which it develops and dissolves. The robot's anatomy mimics a 4-DOF neck joint giving the head cube a human-like expressiveness. Idling refers to a kind of behavior where no concrete goal is pursued but rather a random pattern of "looking around" is executed. This type of motion evokes life-like associates enhancing the experience of observing "Idling". The design process followed the object-oriented mechatronic method. This process took approximately four iterations until a final shape was selected for 3D printing.

originalMachines: differential drive robot

an example of an originalMachine integrating actuated servo wheels, a large diameter ball bearing swivel caster and a vehicle chassis into an entirely 3D printed functional robot.



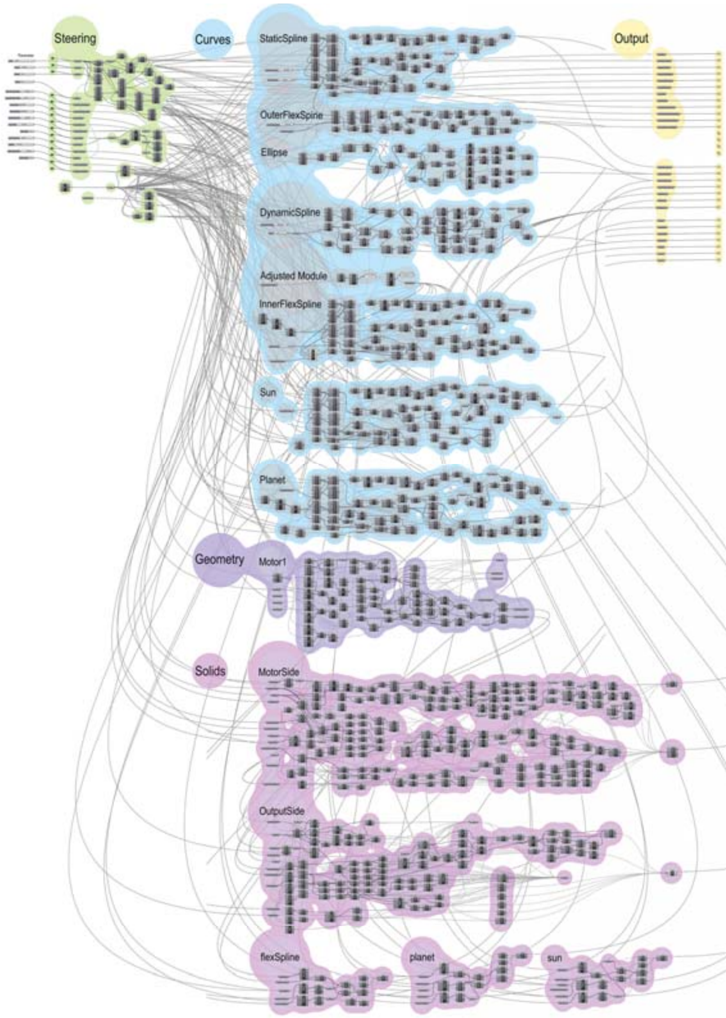


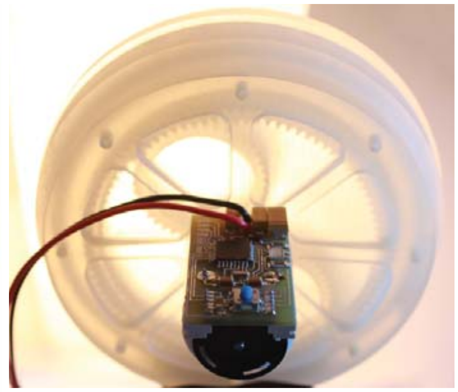


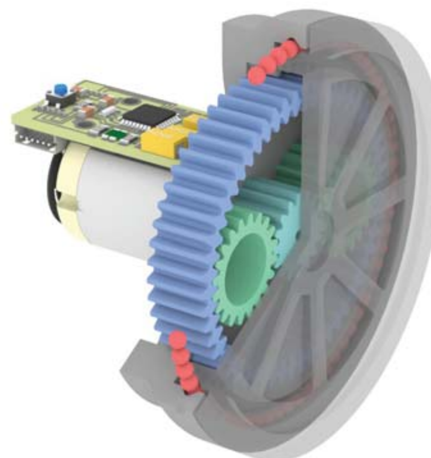
The type of robot referred to as "differential drive robot" is fairly common and used as basic teaching example for robotics. The robot has three wheels two of which are the co-axial drive wheels and the third one is a free spinning caster which can be in the front or back. Some types use two casters one in the front and one in the back resulting in a four wheeled (diamond configuration) robot. The drive wheels are identical in terms of motor, gearing and wheels diameter. The control of the robot results from the identical co-axial drive wheels which can move the robot forward in a straight manner while spinning at the same speed or steer the robot while spinning at different speeds. The body of the robot needs to house the power source which in most cases is a battery, the drive, control and communication electronics and sensors needed for navigation. Applying the object-oriented mechatronic approach the mechanical functional components of the differential drive robot can be created procedurally. The bearings in the back enabling the swivel caster are a subset of the paraServo object basically striped down to only create the load-bearing output. All these components are then integrated in the vehicle chassis in order to create and 3d print the entire robot within 21 hours

paraServo

parametrically self creating and updating 3D printed harmonic drive Servos





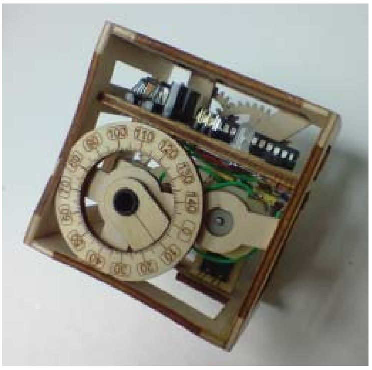


An important building block for machines and robots is a servo motor as it provides precise actuation for various applications. Servos consist of motors gearbox, drive and control electronics which has to function together in order to provide actuation. The paraServo turns most of the components required for a servo motor into an executable which is based in a CAD environment. A user calls a DoF (Degree of Freedom) object (paraServo) with specific parameters like gearing and bearing types, motor options and control and communication capabilities. The DoF object then creates the corresponding geometry which can be connected and integrated with other actuators, shells, hulls, forms and geometry within the CAD environment and 3D printed as a whole.

The paraServo in particular contains a harminoc drive gear reducer with planetarry wave generator in combination with a four-point contact bearing for load bearing outputs. The motor and servo electronics consist of an Arduinocompatible circuit with an integrated H-bridge and optical interrupter as sensor.

plywood servo

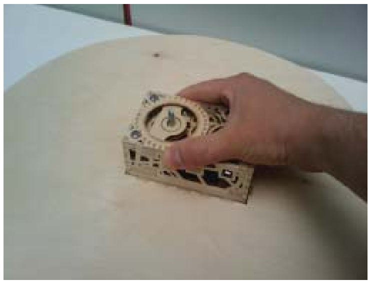
Plywood Punk: A Holistic Approach to Designing Animated Artifacts, Schmitt, P., Seitinger, S., (2009) Proceedings of the Third International Conference on Tangible and Embedded Interaction (TEI'09), Feb 16-18 2009, Cambridge, UK

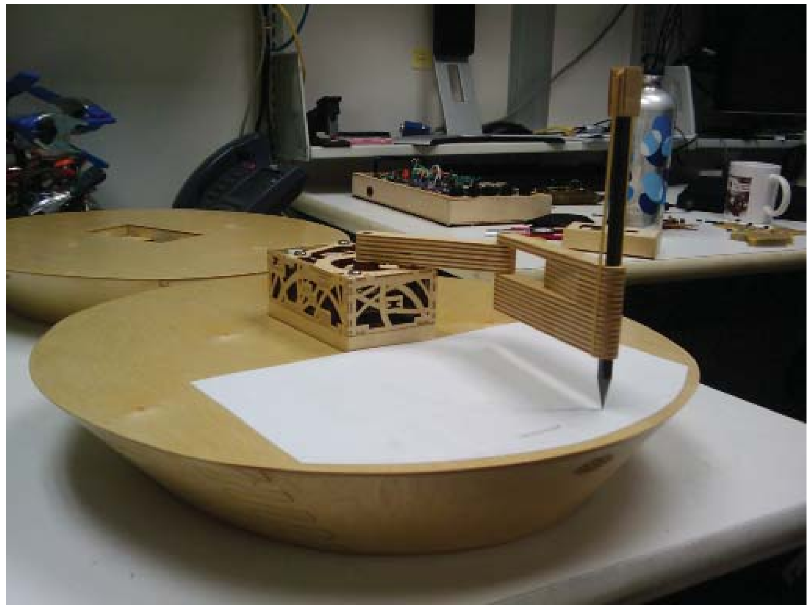


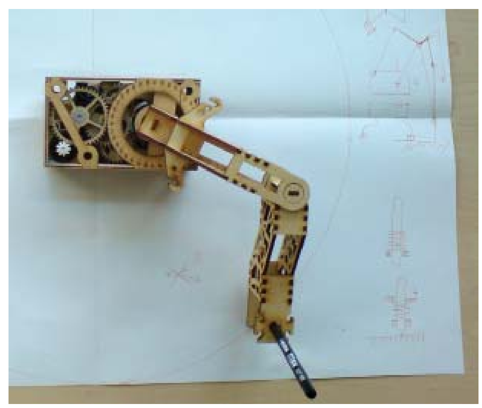
Animated artifacts require many different electronic and mechanical components as well as appropriate drive software. This complexity has led to a kit-of-parts thinking in designing robotic assemblies. For example, Dynamixel or Lego Mindstorms provide designers, enthusiasts and children standard components from which they can assemble a multitude of creations. Despite the open-endedness of these kits, the most basic component parts such as servos present a designer with a set of constraints such as form that she cannot control. The underlying logic for these factors derives from mass-production rather than specific design requirements. The resulting black box becomes a factor around which design is created rather than an integral part of the completed artifact. The plywood servo explores the benefits of designing animated artifacts holistically. It can be compared to an RC servo that had been re-designed in plywood and electronic components. This juxtaposition demonstrates how formfactors, materials and materiality, tactile and visual qualities and the performative aspects of a design can be reintroduced into design thinking for animated artifacts.

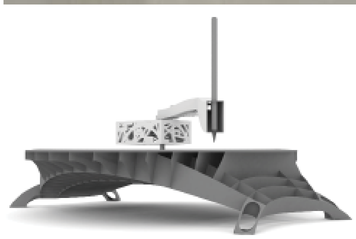
Audiograph

Rudiments 1, 2 & 3: Design Speculations on Autonomy, Helmes, J., Taylor, A. S., Cao, X., Hook, K., Schmitt, P. & Villar, N. (Jan, 2011). Conference on Tangible Embedded, Embodied Interaction, TEI ‘11, pp. 145-152.





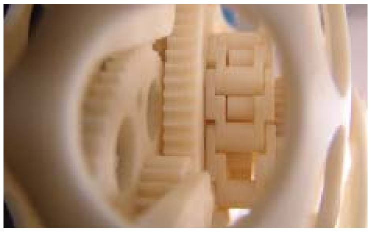
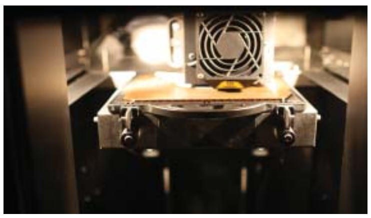
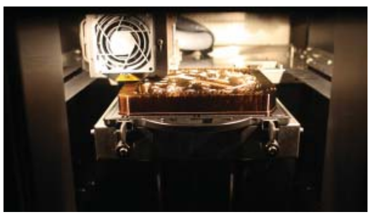
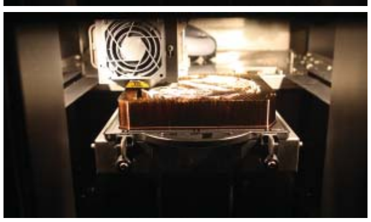
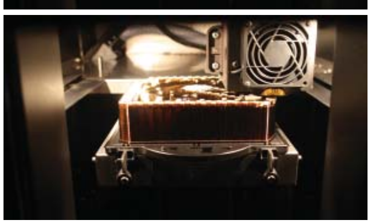
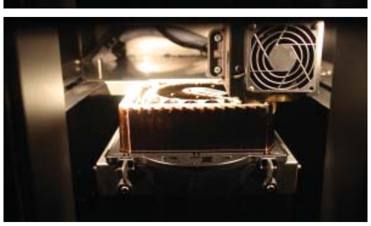
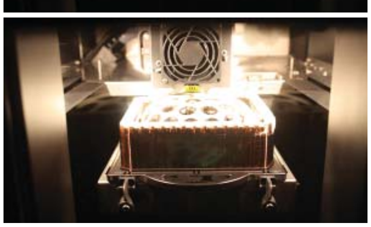
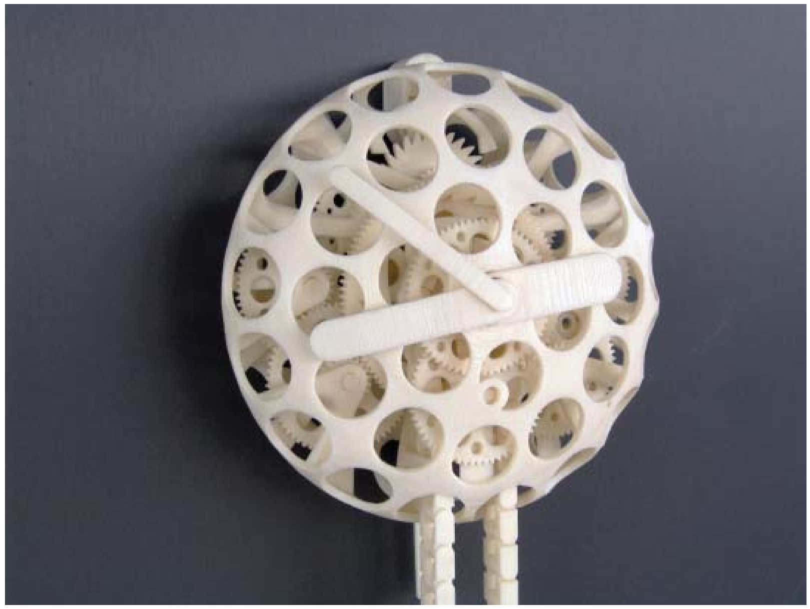




The “Audiograph” happened in collaboration with Alex Taylor at Microsoft Research Cambridge UK. It is based upon the PlywoodServo mechanism and part of a series of artifacts called “rudiments” (Helmes, Taylor, Cao, Hook, Schmitt, P. & Villar 2011). The interdisciplinary research team from design, ethnography and embedded hardware aimed to create surprising and novel objects that have no precedent in order to explore people’s reactions to them in a home setting. This requirement seeded an integral quality of originalMachines, namely the integration of various components to create an appearance different from customary home electronics or appliances. To achieve the desired aesthetic and behavioral qualities, Taylor and Schmitt used the PlywoodServo as a building block integrated into an assembly of the same material to create an unusual drawing machine. Sensors in the base of the Audiograph localize the direction from which sounds in the environment are coming. The PlywoodServo at the center of the object then moves an arm towards the sound. As the arm moves it draws a line with a pencil and distorts it as a result of a free hinge in the middle of the arm.

3DprintedClock

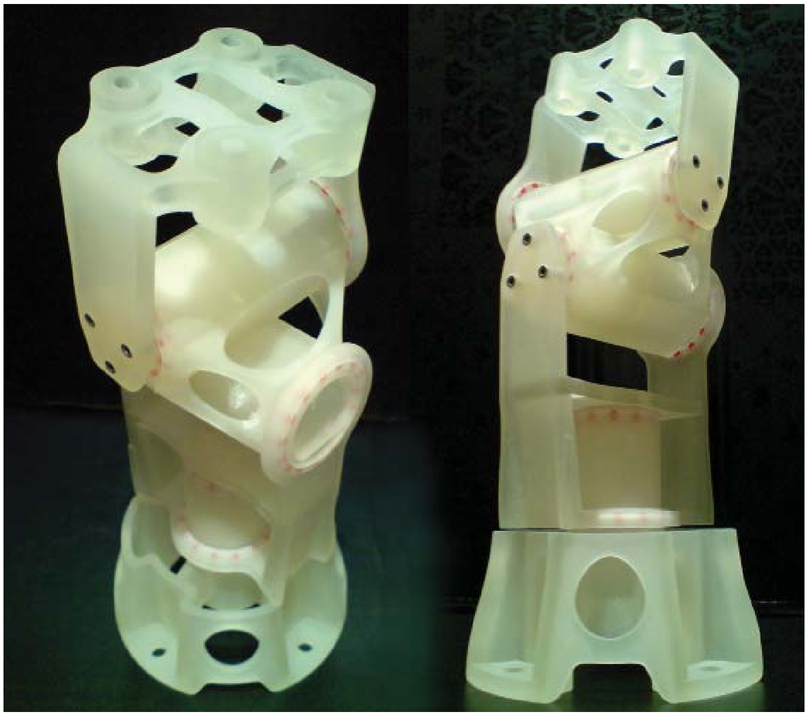
a functional clock entirely and assembled 3D printed, working right out of the printer.

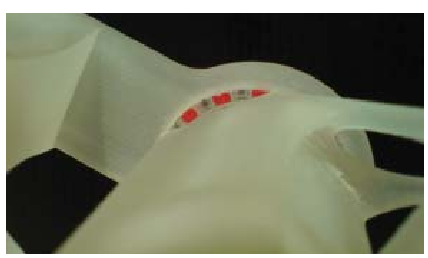










The 3DprintedClock (in collaboration with Bob Swartz, MIT Media Lab) presents a fully functional clock using a pendulum and descending weight to keep track of time. It was modeled in CAD software after an existing clock while ensuring gaps and clearances in between its components matched 3D printer specifications. The entire clock was 3D printed in one piece with the exception of the metal weight. A 3D printed container meant to be filled with sand or water could replace the metal weight but for build size requirements the metal weight solution was chosen. The CAD model also included drainage holes and channels to fully remove the support material after the print. After the printing process the support material has to be removed before the clock can be mounted on a wall. Once the metal weight has been added it will start ticking. The design underwent several iterations staring with the first version having an open gear train and frame while the following iterations enclosed the gear train within the casing to demonstrate the gears being created within the case to emphasize the lack of any post-printing assembly. The biggest challenge throughout the design process presented itself in the form of friction between the 3D printed parts. Ball bearings were added to the main axle to ensure all force created by the weight is be transmitted through the gear box to the escapement mechanism.

3DoF Head

an early exploration integrating design and mechanics through 3D printing.

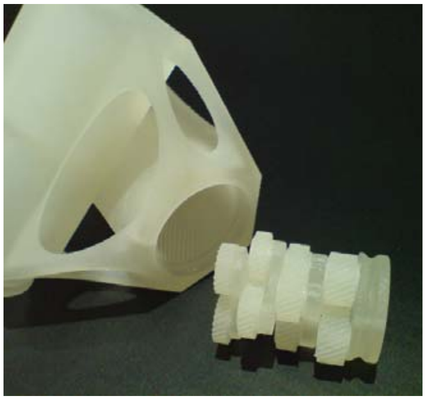
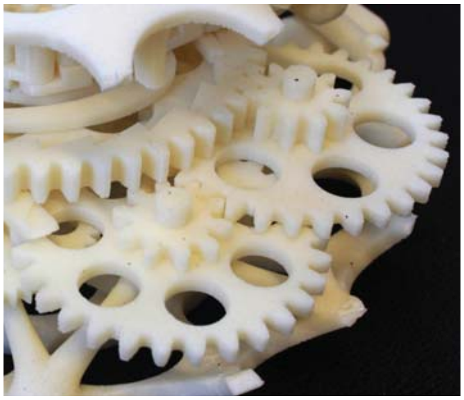
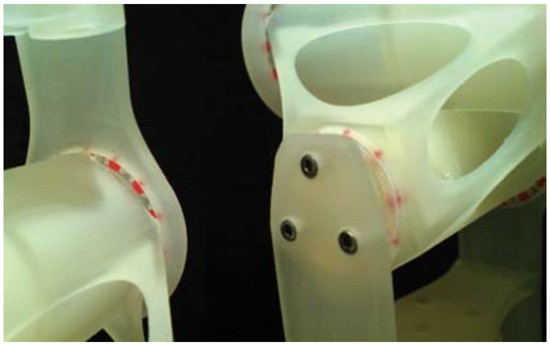




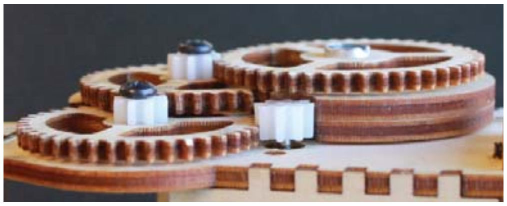
The three degree of freedom (DoF) head tries, as an early example, to integrate overall object design with mechanical parts and assemblies like bearings and gear boxes and their necessary actuation sources (motors). It would serve the purpose of positioning some sort of end effectors around the three axis of motion like a camera or a tool.

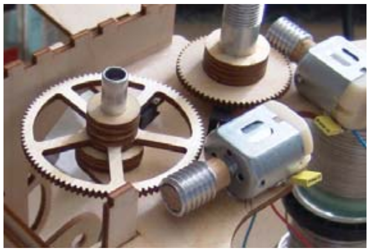
cook book

a series of design explorations investigating mechanical components and assemblies for digital fabrication.



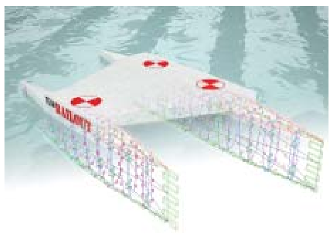





The cook book contains a series of explorations investigating the boundaries of available rapid manufacturing techniques for use with mechatronic components and assemblies. The main focus is on power transmission elements like gear boxes and bearings as they represent a primary building block for any actuated object. A range of commonly used power transmission assemblies is included: planetary gear boxes (including spur and helical gears), cycloidal gear reducers, harmonic drives and worm/ball worm drives. In addition to power transmission elements joints and bearings are also explored as they play a key enabling role for any kind of motion. The explorations focus on elements rendered in different materials like wood, plastic and metal with different rapid manufacturing tools like the laser cutter, cnc mill and various 3D-printers. The challange is to find appropriate translations, settings and strategies depending on the intention for the desired mechanism, the material and the tools flavoring the explorations to be more like a cook book.

cardboard boats

applying parametric design and digital fabrication to the annual MIT Cardboard boat competition



The Head of the Charles Regatta® on the Charles River inspired the annual Cardboard Boat Competition at the Massachusetts Institute of Technology (MIT) which has been held at MIT since 2007. Unlike the Head of the Charles, the competitors in the Cardboard Boat Competition design and build their own boats for the race under strict guidelines that constrain material selection, size, and weight. The builders also compete themselves for the Head of the Zesiger, the MIT athletics and pool facility. The Cardboard Boat Competition is the latest example in a longstanding interest at MIT and at the MIT Media Laboratory for amateur boat building which combines engineering skills, creative problem-solving and physical ability.

In October 2008, "Bailout" won the most Cardboard Boat Competition in the time trials and for its construction. It explored how parametric design and fabrication tools support do-it-yourself boat design and construction. The project was so successful and sparked so much interest that we are launching a research forum intended to foster a discussion on amateur boat building. Bailout is now part of the nautical collection at the MIT museum.

In October 2009 "Clunker" and October 2010 "Oily" did win the MIT Cardboard Boat Competition. The team during all three years consisted of Dale Joachim, Arthur Petron and Peter Schmitt.

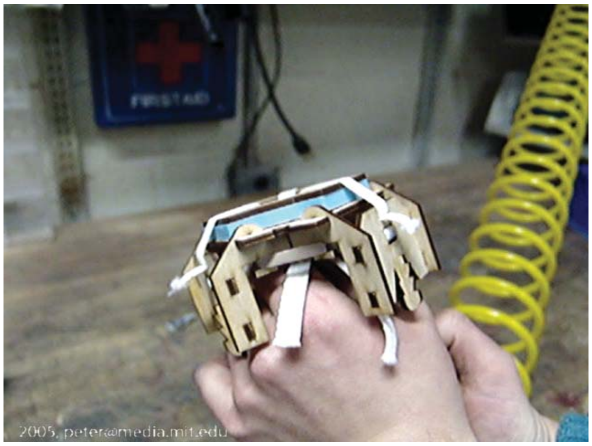
mini Skyscraper

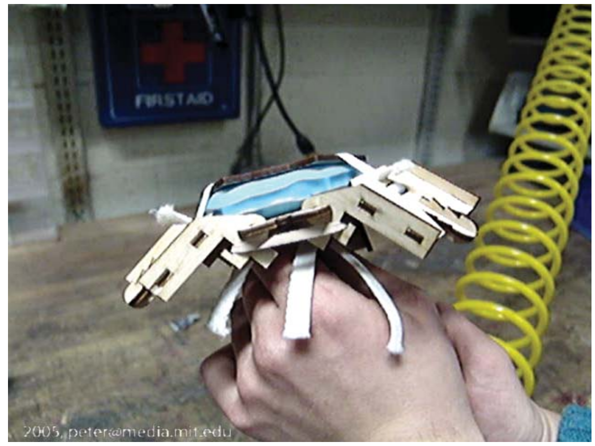
building a responsive structure as the winning entry for the MIT Dept. of Architecture’s Mini Skyscraper competition (2007).

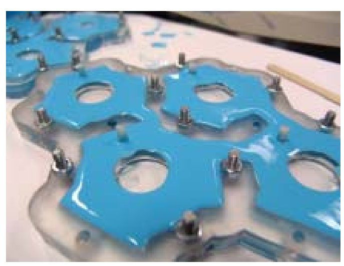
In a team with Axel Kilian, John Snavely, Phillip Bolck and Peter Schmitt the Mini Skyscraper was build to demonstrate the advantages of integrating actuation into structural design. As in noise canceling headphones pneumatic muscles were used to cancel mechanical vibrations thus stabilizing an architectural structure. A functional model was build be Schmitt to demonstrate the concept at the competition. Through many iterations the final design was refined and build in fiberglass using pneumatic muscles sponsored by Festo.

Industrial Design Intelligence

actuating a surface membrane from within.







For the Industrial Design Intelligence course thought by Ted Selker at the MIT media lab in 2005 Schmitt developed and prototyped an “actuator integrated membrane”. The incentive is to create a surface capable of deforming itself while solely relying on integrated actuators rather than being suspended or supported from the outside. For this purpose pneumatic cushions were casted which when inflated will span open a kind of umbrella mechanism. Each umbrella mechanism is connected with surrounding nodes forming a surface which’s thickness is determined by the height of the mechanism. If actuated one mechanism will increase surface area in its particular spot thus forcing this spot to arch out forming a dome. A prototype was made using laser cut plywood, silicon casted pneumatic cushions and rubber bands.

wheel robots and concept vehicles

developing wheels that self contained drive, steer, brake and suspend cars while enabling modular vehicle architecture

During his master's program with William J. Mitchell at the MIT Media Lab Schmitt worked on various concepts for wheel robot iterations and modular vehicle architecture.

text

Bernd Glaser writes about kinetic sculptures by Peter Schmitt (translated into english by SusanneSeitinger)

academy of fine arts duesseldorf germany, photo by peter schmitt

Die Werke des Bildhauers Peter Schmitt führen in eine eigenartige, aber klar strukturierte Welt. Der Künstler verwendet vorwiegend technische Materialien (Aluminium, Kunststoff, Stahl) und gefundene oder gesuchte Fertigteile oder Halbfertigteile aus dem Maschinen- und Apparatebau (Wellen, Zahnräder, Lager, Motoren), die er nach einer Funktionsidee zu Maschinen montiert. Es entstehen poetische Geräte von eindringlicher Exaktheit, die dem kollektiven Bewußtsein unseres usammenlebens mit vielerlei Geräten des Alltags zu entstammen scheinen. Ausgangspunkt ist für Peter Schmitt sein technisches Interesse und die Auseinandersetzung mit den Möglichkeiten der Bildhauerei in der Gegenwart. Die nummerierten Skulpturen sind zunächst für den Betrachter geheimnisvolle „Organismen“, deren Funktionalitäten zwar erfasst werden können, deren Ziele und Wirkungsweisen
aber offen bleiben. Läßt man sich als erwachsener Betrachter nicht auf die Poesie der Geräte ein, entsteht nach der anfänglichen Verwunderung zunächst ein Gefühl der Sinnlosigkeit. Sieht man jedoch das Spielerische in den Arbeiten, wie es Kinder intuitiv in allen Dingen automatisch erkennen, dann eröffnet sich ein neuer Möglichkeitsraum, der erst noch erkundet werden muß.

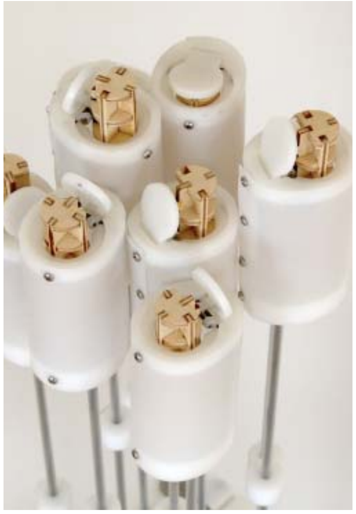
Bernd Glaser (http://bernd-glaser.de/)

Peter Schmitt‘s sculptures invite the observer to participate in a well-ordered, but unusual world. Each piece consists of digital and mechanical components that he has either custom-made in metal, wood and composite materials or found and re-appropriated according to their aesthetic (e.g. wiring, fabric) or functional characteristics (e.g. motors, bearings, gears). Together these components form poetic sculptures of machine precision that reveal the collective subconscious of our machine-laden everyday
lives. By emphasizing the aesthetic qualities of our increasingly technologized surroundings Schmitt proposes new opportunities for contemporary sculpture. The pieces are numbered like natural specimens whose behavior, i.e. functionality, can be observed, but whose purpose remains undiscovered thus blurring the boundaries between organisms and machines. Each sculpture moves
according to a unique set of programmed behaviors. Some (adult) observers may find these routines repetitive and meaningless. In this reading, the sculptures are instantiations of absurd machines like robots in shop windows replicating the same movement. Other (more childlike) observers can glean the existence of a playful and almost willful poetic organism that challenges us to reconsider our
machine creations.

Susanne Seitinger (http://susanne.media.mit.edu/)

009#07

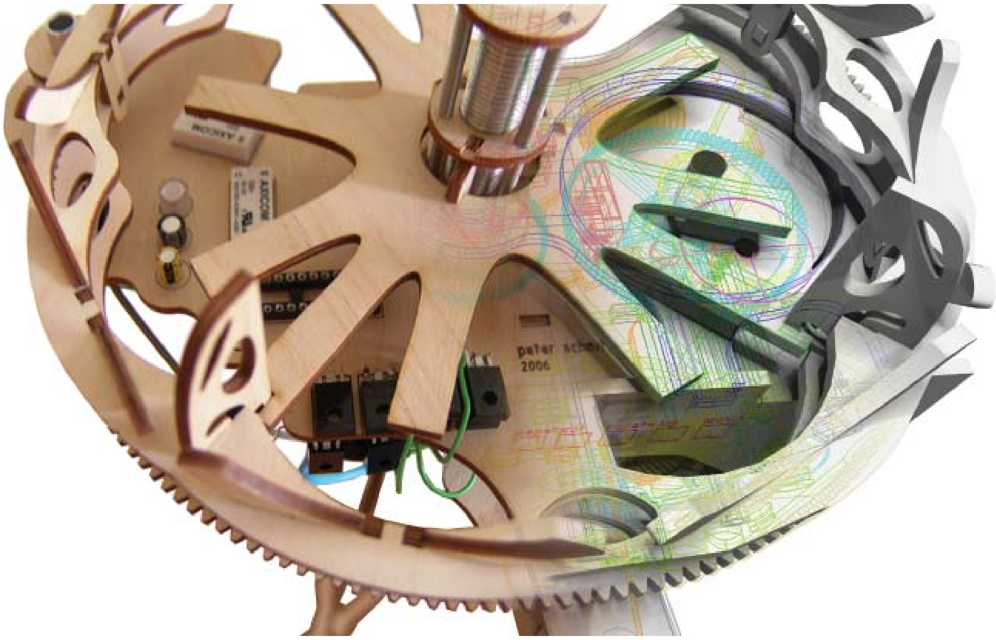
small mechanical flower (2007)

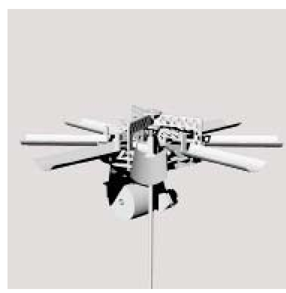


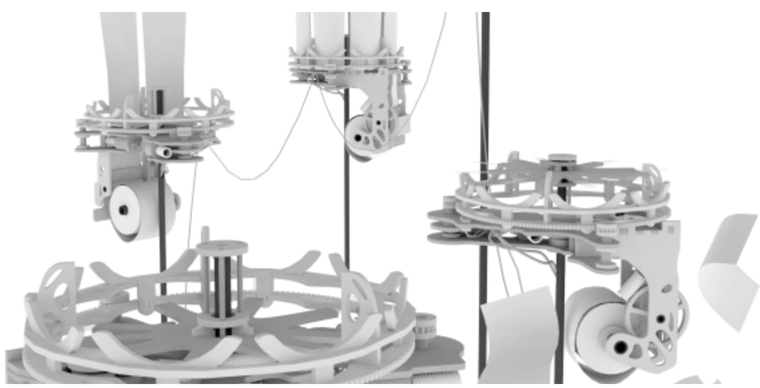
The small mechanical flower kinetic art piece draws from natural phenomena of changing materiality through blooming. The “blossoms” made from Delrin plastic sheets each contain plywood inner pieces which get exposed every cycle at the uppers position (115cm). The plate on which the nine rods carrying the blossoms are mounted is moved up and down by a threaded rod turned by a motor in the base. Each cycle takes 20min to complete.

008#06

paper flower (2006)



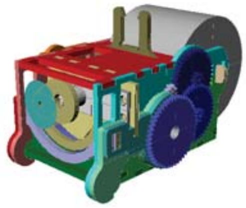


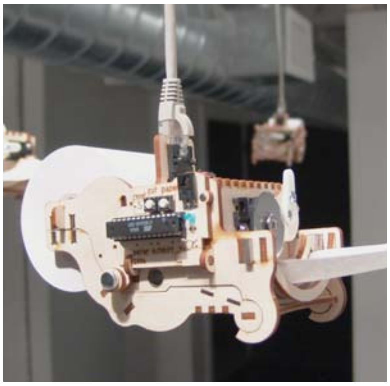


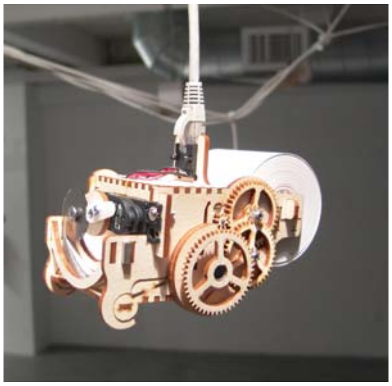
The paper flower 008#06 are inspired by the earlier paper tree installations. Each flower piece is made from various materials like plywood, composite rod, adding machine paper role, worm gears, electric motors, blades, electronic, microcontroller, software, wire switches, sensors, power supply.

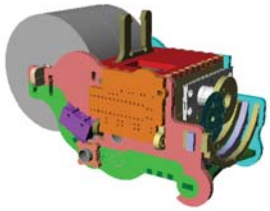
007#06

paper tree Space Other (2006)





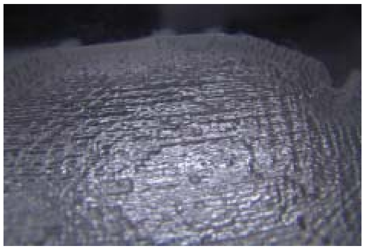


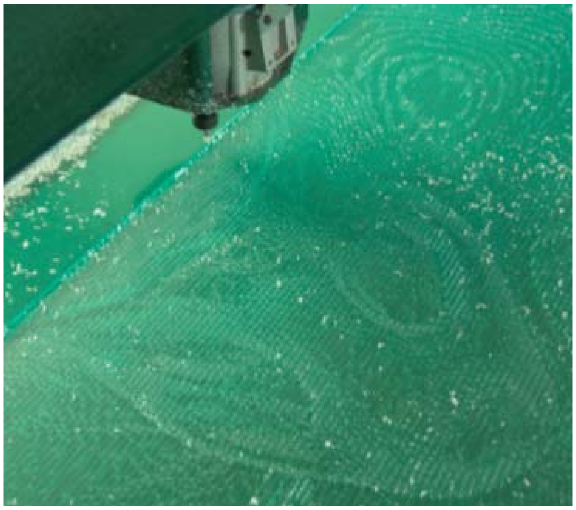


The paper tree installation at Space Other in Boston in 2006 is created after the 004#03 piece using laser cut plywood. The 27 leave units each contain a microcontroller circuit and are suspended from their cables which form braches and trunk of a tree. 007#06 is a limited edition of three pieces.

006#05

casted portraits (2005)

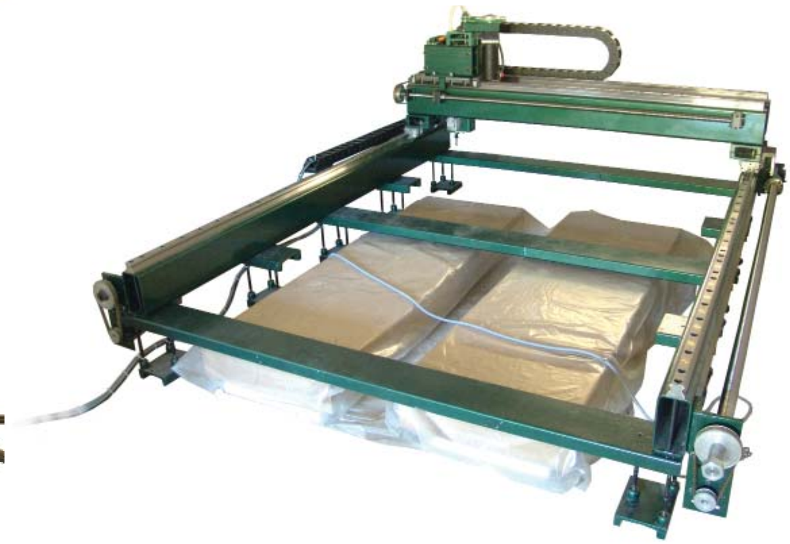




006#05 is a 200cm by 300 cm by 1.2cm (thin) sculpture in which the 1.2cm relief of a sleeping woman head is milled (using 005#04) into a polycarbonate plastic sheet and then casted with UV stable resin mixed with oil painting pigment. The “thickness” of the cast determines the brightness thus resembling the image of the sleeping woman. This technique was developed by Peter Schmitt.

005#04

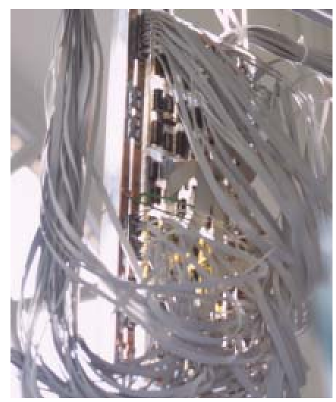
CNC Milling Machine (2004)



005#04 is listed as a art piece and build by Peter Schmitt yet fulfills the purpose of a tool serving the creation of art pieces by Peter Schmitt. It is made from various materials like steel, linear rails, recirculating ball screws, wire, stepper motors, computer, software. Its dimensions are 270cm by 340cm by 110cm. It can cut/mill parts as big as 180cm by 250cm by 25cm.

004#03

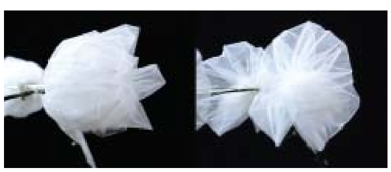
paper tree academy of fine arts duesseldorf(2003)



Made from 87 “mechanical leaf” units casted in epoxy resin each containing two motors one pushing out paper from a role and one cutting off the paper both at control signals randomly given by a microcontroller unit this ceiling suspended mobile installation imitates a cherry tree in the spring time developing white blossoms and having the blossom leaves blown away by the wind. The 250cm diameter and 210cm height kinetic installation is made from various materials like epoxy resin, adding machine paper roles, blades, electric motors, electronics, wires, microcontroller, software.

003#02

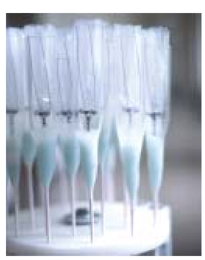
orchids (2002)

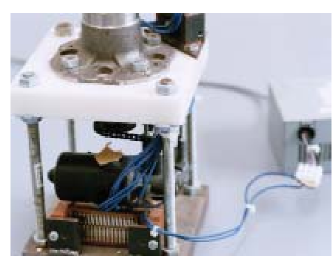


The orchids are three kinetic art pieces modeled after actual orchids. They are made from various materials like steel, aluminum, electric motors, linear rails, tulle, green wire and switches. A pivoting and linearly movement causes the orchids the twist and elongate while growing from their initial height of 80 cm up to their final height of 240cm. The tulle fabric blossom is opened by releasing fishing wire from a winch which allows the spring steel rods woven into the tulle fabric to fully spread out and gain volume. Green wire is used to along the mechanical stem.

002#01

palm tree (2001)

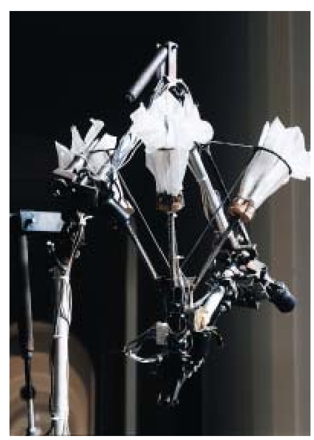




The palm tree is a single kinetic art piece made from various materials like steel, aluminum, electric motors, plastic foil, wire and switches. It containing 24 rods on which upper ends spring loaded blossoms sit in cylindrical containers being moved up and down continuously by a plate their lower ends are mounted on. At the top of each movement the blossoms are forced out of the containers and spread out. A threaded rod in the center of the plate driven by an windshield wiper motor causes the motion in a quiet and slow manner (20 min per cycle, 120cm to 210cm in height).

001#00

mechanical flower (2000)



001#00 is a single kinetic art piece resembling a mechanical flower build from various materials like steel, aluminum, electric motors, canvas, wire and switches. It moves, grows very slowly from its smallest position (120cm) to its final height of 460cm in about 25min. Three canvas umbrellas “bloom” for about 5min before the flower contracts again.

press

"The printed world", Economist, 10 Feb. 2011 (http://www.economist.com/node/18114221)

3D printing

The printed world

Three-dimensional printing from digital designs will transform manufacturing and allow more people to start making things

Feb 10th 2011 | FILTON | from the print edition

FILTON, just outside Bristol, is where Britain's fleet of Concorde supersonic airliners was built. In a building near a wind tunnel on the same sprawling site, something even more remarkable is being created. Little by little a machine is "printing" a complex titanium landing-gear bracket, about the size of a shoe, which normally would have to be laboriously hewn from a solid block of metal. Brackets are only the beginning. The researchers at Filton have a much bigger ambition: to print the entire wing of an airliner.

Far-fetched as this may seem, many other people are using three-dimensional printing technology to create similarly remarkable things. These include medical implants, jewellery, football boots designed for individual feet, lampshades, racing-car parts, solid-state batteries and customised mobile phones. Some are even making mechanical devices. At the Massachusetts Institute of Technology (MIT), Peter Schmitt, a PhD student, has been printing something that resembles the workings of a grandfather clock. It took him a few attempts to get right, but eventually he removed the plastic clock from a 3D printer, hung it on the wall and pulled down the counterweight. It started ticking.

Engineers and designers have been using 3D printers for more than a decade, but mostly to make prototypes quickly and cheaply before they embark on the expensive business of tooling up a factory to produce the real thing. As 3D printers have become more capable and able to work with a broader range of materials, including production-grade plastics and metals, the machines are increasingly being used to make final products too. More than 20% of the output of 3D printers is now final products rather than prototypes, according to Terry Wohlers, who runs a research firm specialising in the field. He predicts that this will rise to 50% by 2020.

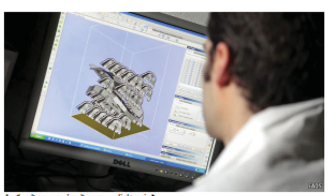
Using 3D printers as production tools has become known in industry as "additive" manufacturing (as opposed to the old, "subtractive" business of cutting, drilling and bashing metal). The additive process requires less raw material and, because software drives 3D printers, each item can be made differently without costly retooling. The printers can also produce ready-made objects that require less assembly and things that traditional methods would struggle with—such as the glove pictured above, made by Within Technologies, a London company. It can be printed in nylon, stainless steel or titanium.

Click to manufacture

The printing of parts and products has the potential to transform manufacturing because it lowers the costs and risks. No longer does a producer have to make thousands, or hundreds of thousands, of items to recover his fixed costs. In a world where economies of scale do not matter any more, mass-manufacturing identical items may not be necessary or appropriate, especially as 3D printing allows for a great deal of customisation. Indeed, in the future some see consumers downloading products as they do digital music and printing them out at home, or at a local 3D production centre, having tweaked the designs to their own tastes. That is probably a faraway dream. Nevertheless, a new industrial revolution may be on the way.

Printing in 3D may seem bizarre. In fact it is similar to clicking on the print button on a computer screen and sending a digital file, say a letter, to an inkjet printer. The difference is that the "ink" in a 3D printer is a material which is deposited in successive, thin layers until a solid object emerges.

The layers are defined by software that takes a series of digital slices through a computer-aided design. Descriptions of the slices are then sent to the 3D printer to construct the respective layers. They are then put together in a number of ways. Powder can be spread onto a tray and then solidified in the required pattern with a squirt of a liquid binder or by sintering it with a laser or an electron beam. Some machines deposit filaments of molten plastic. However it is achieved, after each layer is complete the build tray is lowered by a fraction of a millimetre and the next layer is added.



And when you're happy, click print

The researchers at Filton began using 3D printers to produce prototype parts for wind-tunnel testing. The group is part of EADS Innovation Works, the research arm of EADS, a European defence and aerospace group best known for building Airbuses. Prototype parts tend to be very expensive to make as one-offs by conventional means. Because their 3D printers could do the job more efficiently, the researchers' thoughts turned to manufacturing components directly.

Aircraft-makers have already replaced a lot of the metal in the structure of planes with lightweight carbon-fibre composites. But even a small airliner still contains several tonnes of costly aerospace-grade titanium. These parts have usually been machined from solid billets, which can result in 90% of the material being cut away. This swarf is no longer of any use for making aircraft.

To make the same part with additive manufacturing, EADS starts with a titanium powder. The firm's 3D printers spread a layer about 20-30 microns (0.02-0.03mm) thick onto a tray where it is fused by lasers or an electron beam. Any surplus powder can be reused. Some objects may need a little machining to finish, but they still

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There are other important benefits. Most metal and plastic parts are designed to be manufactured, which means they can be clunky and contain material surplus to the part's function but necessary for making it. This is not true of 3D printing. "You only put material where you need to have material," says Andy Hawkins, lead engineer on the EADS project. The parts his team is making are more svelte, even elegant. This is because without manufacturing constraints they can be better optimised for their purpose. Compared with a machined part, the printed one is some 60% lighter but still as sturdy.

Form follows function

Lightness is critical in making aircraft. A reduction of 1kg in the weight of an airliner will save around $3,000-worth of fuel a year and by the same token cut carbon-dioxide emissions. Additive manufacturing could thus help build greener aircraft—especially if all the 1,000 or so titanium parts in an airliner can be printed. Although the size of printable parts is limited for now by the size of 3D printers, the EADS group believes that bigger systems are possible, including one that could fit on the 35-metre-long gantry used to build composite airliner wings. This would allow titanium components to be printed directly onto the structure of the wing.

Many believe that the enhanced performance of additively manufactured items will be the most important factor in driving the technology forward. It certainly is for MIT's Mr Schmitt, whose interest lies in "original machines". These are devices not constructed from a collection of prefabricated parts, but created in a form that flows from the intention of the design. If that sounds a bit arty, it is: Mr Schmitt is a former art student from Germany who used to cadge time on factory lathes and milling machines to make mechanised sculptures. He is now working on novel servo mechanisms, the basic building blocks for robots. Custom-made servos cost many times the price of off-the-shelf ones. Mr Schmitt says it should be possible for a robot builder to specify what a servo needs to do, rather than how it needs to be made, and send that information to a 3D printer, and for the machine's software to know how to produce it at a low cost. "This makes manufacturing more accessible," says Mr Schmitt.

The idea of the 3D printer determining the form of the items it produces intrigues Neri Oxman, an architect and designer who heads a research group examining new ways to make things at MIT's Media Lab. She is building a printer to explore how new designs could be produced. Dr Oxman believes the design and construction of objects could be transformed using principles inspired by nature, resulting in shapes that are impossible to build without additive manufacturing. She has made items from sculpture to body armour and is even looking at buildings, erected with computer-guided nozzles that deposit successive layers of concrete.

Some 3D systems allow the properties and internal structure of the material being printed to be varied. This year, for instance, Within Technologies expects to begin offering titanium medical implants with features that resemble bone. The company's femur implant is dense where stiffness and strength is required, but it also has strong lattice structures which would encourage the growth of bone onto the implant. Such implants are more likely to stay put than conventional ones.

Working at such a fine level of internal detail allows the stiffness and flexibility of an object to be determined at any point, says Siavash Mahdavi, the chief executive of Within Technologies. Dr Mahdavi is working on other lattice structures, including aerodynamic body parts for racing cars and special insoles for a firm that hopes to make the world's most comfortable stiletto-heeled shoes.

Digital Forming, a related company (where Dr Mahdavi is chief technology officer), uses 3D design software to help consumers customise mass-produced products. For example, it is offering a service to mobile-phone companies in which subscribers can go online to change the shape, colour and other features of the case of their new phone. The software keeps the user within the bounds of the achievable. Once the design is submitted the casing is printed. Lisa Harouni, the company's managing director, says the process could be applied to almost any consumer product, from jewellery to furniture. "I don't have any doubt that this technology will change the way we manufacture things," she says.

Other services allow individuals to upload their own designs and have them printed. Shapeways, a New York-based firm spun out of Philips, a Dutch electronics company, last year, offers personalised 3D production, or "mass customisation", as Peter Weijmarshausen, its chief executive, describes it. Shapeways prints more than 10,000 unique products every month from materials that range from stainless steel to glass, plastics and sandstone. Customers include individuals and shopkeepers, many ordering jewellery, gifts and gadgets to sell in their stores.

EOS, a German supplier of laser-sintering 3D printers, says they are already being used to make plastic and metal production parts by carmakers, aerospace firms and consumer-products companies. And by dentists: up to 450 dental crowns, each tailored for an individual patient, can be manufactured in one go in a day by a single machine, says EOS. Some craft producers of crowns would do well to manage a dozen a day. As an engineering exercise, EOS also printed the parts for a violin using a high-performance industrial polymer, had it assembled by a professional violin-maker and played by a concert violinist.

Both EOS and Stratasys, a company based in Minneapolis which makes 3D printers that employ plastic-deposition technology, use their own machines to print parts that are, in turn, used to build more printers. Stratasys is even trying to print a car, or at least the body of one, for Kor Ecologic, a company in Winnipeg, whose boss, Jim Kor, is developing an electric-hybrid vehicle called Urbee.


Jim Kor's printed the model. Next, the car

Making low-volume, high-value and customised components is all very well, but could additive manufacturing really compete with mass-production techniques that have been honed for over a century? Established techniques are unlikely to be swept away, but it is already clear that the factories of the future will have 3D printers working alongside milling machines, presses, foundries and plastic injection-moulding equipment, and taking on an increasing amount of the work done by those machines.

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Morris Technologies, based in Cincinnati, was one of the first companies to invest heavily in additive manufacturing for the engineering and production services it offers to companies. Its first intention was to make prototypes quickly, but by 2007 the company says it realised "a new industry was being born" and so it set up another firm, Rapid Quality Manufacturing, to concentrate on the additive manufacturing of higher volumes of production parts. It says many small and medium-sized components can be turned from computer designs into production-quality metal parts in hours or days, against days or weeks using traditional processes. And the printers can build unattended, 24 hours a day.

Neil Hopkinson has no doubts that 3D printing will compete with mass manufacturing in many areas. His team at Loughborough University has invented a high-speed sintering system. It uses inkjet print-heads to deposit infra-red-absorbing ink on layers of polymer powder which are fused into solid shapes with infra-red heating. Among other projects, the group is examining the potential for making plastic buckles for Burton Snowboards, a leading American producer of winter-sports equipment. Such items are typically produced by plastic injection-moulding. Dr Hopkinson says his process can make them for ten pence (16 cents) each, which is highly competitive with injection-moulding. Moreover, the designs could easily be changed without Burton incurring high retooling costs.

Predicting how quickly additive manufacturing will be taken up by industry is difficult, adds Dr Hopkinson. That is not necessarily because of the conservative nature of manufacturers, but rather because some processes have already moved surprisingly fast. Only a few years ago making decorative lampshades with 3D printers seemed to be a highly unlikely business, but it has become an industry with many competing firms and sales volumes in the thousands.

Dr Hopkinson thinks Loughborough's process is already competitive with injection-moulding at production runs of around 1,000 items. With further development he expects that within five years it would be competitive in runs of tens if not hundreds of thousands. Once 3D printing machines are able to crank out products in such numbers, then more manufacturers will look to adopt the technology.

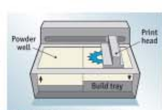
Will Sillar of Legerwood, a British firm of consultants, expects to see the emergence of what he calls the "digital production plant": firms will no longer need so much capital tied up in tooling costs, work-in-progress and raw materials, he says. Moreover, the time to take a digital design from concept to production will drop, he believes, by as much as 50-80%. The ability to overcome production constraints and make new things will combine with improvements to the technology and greater mechanisation to make 3D printing more mainstream. "The market will come to the technology," Mr Sillar says.

Some in the industry believe that the effect of 3D printing on manufacturing will be analogous to that of the inkjet printer on document printing. The written word became the printed word with the invention of movable-type printing by Johannes Gutenberg in the 15th century. Printing presses became like mass-production machines, highly efficient at printing lots of copies of the same thing but not individual documents. The inkjet printer made that a lot easier, cheaper and more personal. Inkjet devices now perform a multitude of printing roles, from books on demand to labels and photographs, even though traditional presses still roll for large runs of books, newspapers and so on.

A customised future

How would this translate to manufacturing? Most obviously, it changes the economics of making customised components. If a company needs a specialised part, it may find it cheaper and quicker to have the part printed locally or even to print its own than to order one from a supplier a long way away. This is more likely when rapid design changes are needed.

Printing in 3D is not the preserve of the West: Chinese companies are adopting the technology too. Yet you might infer that some manufacturing will return to the West from cheap centres of production in China and elsewhere. This possibility was on the agenda of a conference organised by DHL last year. The threat to the logistics firm's business is clear: why would a company airfreight an urgently needed spare part from abroad when it could print one where it is required?



Our TQ article explains the technology behind the 3-D printing process

Perhaps the most exciting aspect of additive manufacturing is that it lowers the cost of entry into the business of making things. Instead of finding the money to set up a factory or asking a mass-producer at home (or in another country) to make something for you, 3D printers will offer a cheaper, less risky route to the market. An entrepreneur could run off one or two samples with a 3D printer to see if his idea works. He could make a few more to see if they sell, and take in design changes that buyers ask for. If things go really well, he could scale up—with conventional mass production or an enormous 3D print run.

This suggests that success in manufacturing will depend less on scale and more on the quality of ideas. Brilliance alone, though, will not be enough. Good ideas can be copied even more rapidly with 3D printing, so battles over intellectual property may become even more intense. It will be easier for imitators as well as innovators to get goods to market fast. Competitive advantages may thus be shorter-lived than ever before. As with past industrial revolutions, the greatest beneficiaries may not be companies but their customers. But whoever gains most, revolution may not be too strong a word.

from the print edition | Briefing