Design=Production

Material and Process Driven Design and Production

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With the comprehensive integration of software-based tools in actual processes of design development and fabrication, the boundaries between design and production become increasingly blurred. The methodology of the process of creation changes: the design development phase reaches up to the last produced model in a product series, in the same time the serial production cycle already starts with the first prototype.The aim of this research project is to explore and show the re-strengthening link between form, function, material and fabrication particularly driven by raising prominence of digital tools for design and production. Hereby the focus is on two points: the implementation of user data/input in the light of 'Open Innovation' as driver of form and function on one hand and the crafing inspired aproach of a comprehensive integration of material properties, behaviour tradional techniques of processing into the the design process.

Keywords: *Digital production, Mass customization, Parametric modelling, User-generated design, G-Code post processor*

INTRODUCTION

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The aim of this research project is to explore and show the re-strengthening link between form, function, material and fabrication particularly driven by raising prominence of digital tools for design and production. Hereby the focus is on two points: the implementation of user data in the light of 'Open Innovation' as driver of form and function on one hand and the crafting inspired approach of a comprehensive integration of material properties, behaviour traditional techniques of processing into the design process.

The group of presented studies and works are rooted in the field of 'digital crafting' and 'digital production' (see 2., 3.) and lead by the concept of 'open innovation' (see 3.) in the context of mass customization. Therefore the paper starts of with various topics, which represent the main drivers in the studies listed in this paper, followed by more detailed explanations of all four research projects.

OPEN INNOVATION

" It's the little things that make all the progress" (own translation of Reichwald and Piller 2009, p. 6)

Open innovation is based on communication and social interaction. It is "[...] a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough 2003). Excellent examples of open innovation, combined with parametric model based product configuration by the customer, in the business context are the Open Logo Project of Spreadshirt.com (a provider for individual clothing), the "Wikihouse" project (www.wikihouse.cc), where costumers respectively users use and further develop a CNC-production based housing system or the Sketch Chair study by Greg Saul, with which the customer can create his own chair design based on a construction template embedded in a configurative web application. These examples have in common, that they put the customer at the heart of value creation. Furthermore they induce playful synergies resulting from a constant dialogue between designer and user, object and function.

With the following research studies the enabling powers of such participative design strategies are to be explored. The concept of *interactive value creation* (Reichwald and Piller 2009) is about the active role of the customers, an external actor who leaves his marks or even inventively contributes to the design and development process of a product or object. "Customers are no longer just passive receivers and consumers [...]" (ibid., p.1, own translation). They represent much more a collaborator to the designer or producer in the creation of value, in the development but also the evaluation of a product.

A central role in this interactive process is represented by the communication interfaces between the actors, the customer (private or company) and developer (i.e. company or institution). Therefore an essential aspect of this interactive process is the way of involvement of the customer. Design and architecture is creation, and it is creative. One focus of the studies is to revive a playful experience and to forge a constant dialogue between designer and user, between object and function, allowing for engagement, growth and change. Playing means direct interaction with the environment, personal engagement and building knowledge. The user himself has a constant impact on his immediate environment, resulting in continuous transformation and interaction. This demands a process of participation where the user is deliberately asked for input and engagement. Participation thus means that designer and user join forces in a playful act of creation. Therefore the digital tool studies generally leave elements of design open, and users are encouraged to participate with their own input. The objective is that the products do not function to their full extent unless the targeted user becomes actively engaged. The research's design approach is thus playful in both conceptualization and the use of computational applications as well as in the attitude towards design referred to as the art of manufacturing. The manufacture is equally process and product comprising designer and user as producers of space and creative energy.

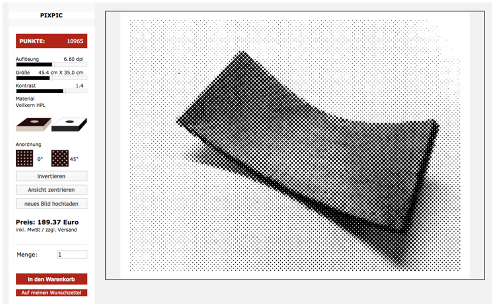

Figure 1
screenshot of the fully working web configurator on www.design-machine.com for CNC routed images, (C) Sebastian Bächer, Cologne, 2013

Strongly referenced to the presented studies, the web-based platform 'design-machine.com' (see fig. 1) was set up by the Bächer & Bergmann GmbH to explore and establish a comprehensive user interface for potential, individualized furniture systems. While the collection of parametric tool studies focuses on the implementation of material and manufacturing information and user input data in the design process, with design-machine.com the network also explores possible data management strategies and concepts on intuitively interactive user applications.

LIBERATION OF GEOMETRY

"We no longer apply a pre-set form on inert matter, but lay out the parameters of a surface of variable curvature. A milling machine that is commanded numerically does not regulate itself according to the build of the machine; it rather describes the variable curvature of a surface of possibility. The image-machine organization is reversed: the design of the object is no longer subordinated to mechanical geometry; it is the machine that is directly integrated into the technology of a synthesized image." (Cache and Speaks 1995, p. 95)

Significant advantages of digital design and production processes are that, numerous local and global factors relating to the product context can be integrated and processed individually during the design and development processes. The same goes for structural requirements such as the final use, structural engineering and various technical functions. Thus a higher degree of adaptivity can be integrated in the design, development and production process and the subsequent use of an object. Thus when it comes to materialization, especially physical parameters and constraints dominate the design of an object. There is a strengthened and more correspondent relation between the development and fabrication process combined with a higher flexibility considering the geometry: in the phase of design and manufacturing but also in the final shape.

A British research group has shown that 3D printing may well trigger a revolution in production techniques of airplanes. The group "EADS Innovation works" aims to use this technique to produce whole aircrafts in the near future. Individual connection elements printed from metal are already being in use in Airbus airplanes and can be easily modified in any individual airplane model (see Fig. 2). In addition the 3D printing method provides great opportunities to save material and weight.

Figure 2
3D printed metal part of Airbus 380 (front) and original, industrially produced part (back),

DIGITAL PRODUCTION

The aspect of an efficient application of materials and individual operations in the production process also represents a key driver in the development of the design tools presented in the following topics.

Similar to the 18th and 19th century industrial revolution, we are, today, in a process of societal change that, among other factors, significantly influences architecture and design. This proceeding digital revolution 'refers to the advancement of technology from analogue electronic and mechanical devices to the digital technology available today' [1]. But while information technology and digital, rule-based, robotic processes already dominate large parts of our private and business live, 'traditional' industrial processes still primarily govern the production of consumer goods.

But although industrial production still dominates the world of products and consumption, digital techniques have helped - even if mostly exemplarily - in reinstating basic principles of craft production in design and architecture " [...] in which material and form are naturally intertwined into a tradition of making [...]" (Oxman 2010, p. 304). The principals of digital design and manufacturing processes are rather linked to a way of craft production than industrial processes as they emphasize the qualities of the materials used and provide higher flexibility during the development and production process. The connection of digital design and digital manufacturing can be resumed as 'Digital Crafting' (see 'Design Tool Studies'), which describes the combination of work techniques typical of craftsmen with computer-supported processes' (Sachs 2012, p.12). The computer extends the principles of traditional crafts by numerous options such as simulation, generation and the connection and controlling of production processes. Furthermore this approach combined with the potentials of generative modelling - 'the generalization from objects to operations: A shape is described by a sequence of processing steps, rather than just the end result of applying operations' [2] - inevitably pushes us towards new concepts of design making and thinking and subsequently leads to new design aesthetics.

The potential of digital processes in manufacturing is currently being thoroughly investigated and applied in various areas. So-called FabLabs are exploring the themes of interdisciplinary, also of a more 'democratic' design and production. "A FabLab (short for fabrication laboratory) is an open [...] high tech workshop providing fabrication techniques for one-off pieces to private individuals" [3]. In these FabLabs, individual design objects and technical products are created, often by using 3D printers that people have built themselves and some of which are i.e. self-replicating and by using CNC machines, laser cutters and even discarded industrial robots. Based on the principles of open source, CNC production data is distributed and further developed via the Internet and new knowledge regarding >>materialisation<< is being shared. Ideally, production knowledge is shared using Creative Commons licences and a global network of mini factories "...is created with these networked, digital production methods" (Moorstedt 2010, p.82). These laboratories most likely represent only forerunners of new product development practices in the future. Under the banner "Open Innovation" this movement of sharing, linking and reflecting production knowledge and product data is getting more and more relevant in companies marketing and design strategies.

DIGITAL CRAFTING

In this paper the research on crafting inspired computational design and manufacturing will be discussed and presented by a variation of self-developed crafting related digital tools. Most of them have been developed in cooperation with close partners such as the Bächer & Bergmann GmbH and Cologne University of Applied Sciences. On top of these software tools to automatize form finding and production processes a web-based user-interface 'design machine' (design-machine.com) has been developed in collaboration with Sebastian Bächer to give the user the opportunity to individualize and order his 'product on demand'.

The flexibility of such tools enables design modifications to an overall design layout up until the very last moment before an automated generation of manufacturing data. In the broader sense they do not only serve as foundation for experimental interaction between customer and parametrically structured 3D objects but can also act as an interface between design software and manufacturing device. In the presented project studies of these tools certain crafting techniques have been used to create structural templates of design objects that can be modified, adapted and 'printed' (in the sense of produced or sent to production) by the user itself.

The developed studies in this paper are also based on the application of the concepts of "material based design computation" which represent "[...] an approach to the design of computational environments which might inculcate material attributes directly into the process of computationally supported design, during its various stages" (Oxman 2010, p. 304). The digital shaping tools evolve from the objective to inform the design process with a 'genetic design code'.

In this concept the design development is rather driven by the process of making than pure strategic thinking: thinking by making. On the contrary to industrial production, in this concept of 'making', a wide range of data about form, function, material, processing and individual user demands are constantly and repeatedly intertwined. The way of honouring material and its strong - but ever changing - relation to manufacturing processes leads not only to new design aesthetics but also to a new, crafting oriented way of design thinking. "Every good craftsman conducts a dialogue between concrete practices and thinking; this dialogue evolves into sustaining habits, and these habits establish a rhythm between problem solving and problem finding." (Senett 2008, p.18) With the integration of computation into these processes of making and thinking these method of creation can be applied in a much wider context regarding developers and collaborative users. Thus such tools are certainly not only questioning traditional top down planning methods in various fields but also the concept of mass production and consumption in general.

DESIGN TOOL STUDIES

Orlov Act, 2014-2015

Orlov Act is a 9x5x4m architectural media sculpture made of 1179 individually folded 0.8 mm metal sheet elements and 127 different opaque projection and lighting screens made of acrylic glass (see Fig. 3). On behalf of the architecture studio 'superartitecture' and 'Flying Orlov UG', Cologne, a comprehensive, fully parametric 3D model definition was developed to support the architects and planners in two areas, the form finding process and the generation of all production data implementing material data, behaviour and processing information including assembly logistics. The project was developed with Grasshopper 3D for Rhino with various elements of 'Visual Basic' script.

Based on a pre-defined triangulated shape, the definition generates manufacturing data based on the users input considering material properties like thickness, composition (single layer, multi layer, plastic, aluminum etc..), the related folding behaviour. The software labels all procuced parts automatically to install all elements in its defined position. Depending on the choice of material and folding behavior of

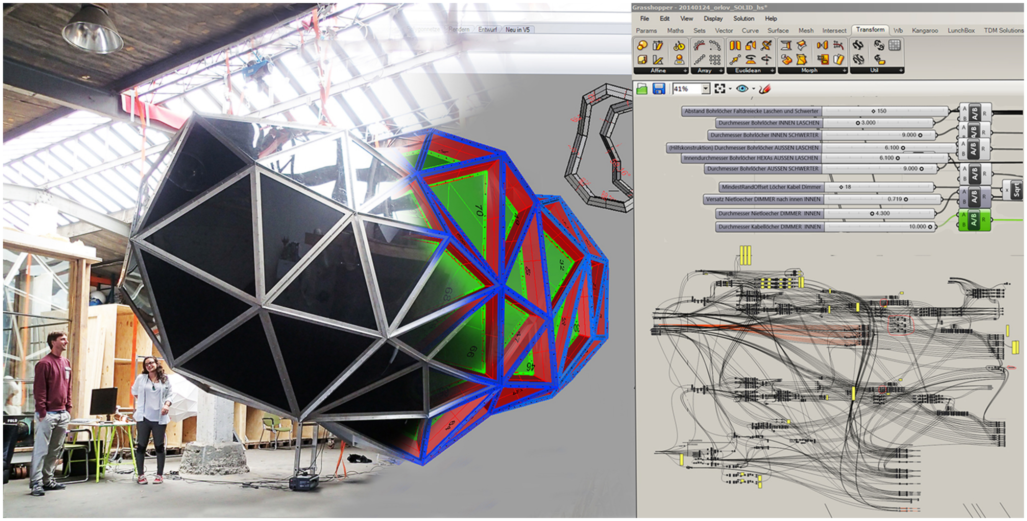

Figure 3
'Orlov Act' - physical prototype and Rhino-Grasshopper 3D sequence model, (C) Hans Sachs, Cologne, 2014

the respective material, the unrolled 2D cutting and folding diagrams include specified offset calculations in order to, once produced, result in the exact size of the generated 3D model. Finally, when all input parameters are set and the material is chosen, the software generates a 3D model including all (varying) material properties and processing behaviour. These are then automatically unrolled and provided with all connector elements (holes/folds etc.) and all logistic assembly data.

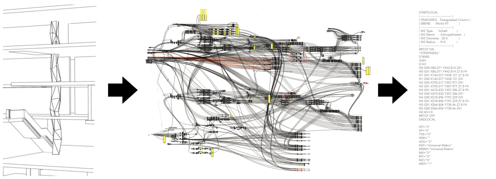

Figure 4
Process: 3D Model > Grasshopper definition > Machining-Code, (C) Hans Sachs, Sebastian Baecher, Duesseldorf, 2014

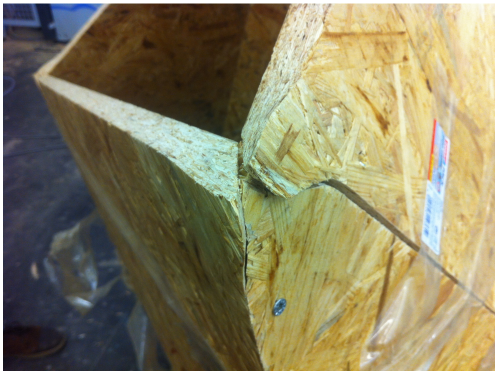

Figure 5
Prototype model Triangulated Column, (C) Hans Sachs, Sebastian Baecher, Duesseldorf, 2014

Triangulated Column, 2014

a 20 m high interior, sculptural column as 'Kunst im Bau' for the new faculty of architecture (PBSA) of the University of Applied Sciences in Düsseldorf (see Fig. 4/5). In cooperation with Sebastian Bächer, the Professorship of Design by Prof. Oliver Kruse, construction business partner PERI, a group of master students and the schools' CNC workshop we developed and realized a 'digital processing tool', that generates an accurate 3D model and all necessary G-Code data for a Homag 5-axis CNC mill to precisely produce all parts for a concrete form work for the 20 tons of vertical concrete structure extending over 4 floors. The project has been developed with Grasshopper 3D for Rhino in combination with 'Visual Basic' script for the G-Code post processor that generates the machine code from the model data in real time (see Fig. 4).

Customized Cardboard Surfboards, 2012-2015

This cardboard surfboard core is generated by a grasshopper "quarter iso grid" definition, which is inspired by Mike Sheldrake's great cardboard surfboards. Until now the 3D board models are created in the open source surfboard-shaping software "Board-CAD" and then imported to Rhino 3D to generate the form specified cardboard parts as connector system. The project's goal is to create individual, customer-shaped cardboard core surfboards based on a web-based configurative shaping tool (see Fig. 6).

A comprehensive Grasshopper definition, developed based on the connector system first developed and applied by Mike Sheldrake, creates partitions of the imported 3D model and creates a structured 3D model of the corrugated cardboard core. Specific algorithms are applied on differentiated zones of the 3D model while these separated 'part generators' still refer to neighbouring connector parts, so that the different systems can be joined easily in the assembly process. Based on the 3D model, including all 3D cardboard parts, the cutting patterns of all system parts are generated to cut them from corrugated cardboard with a CNC cutting plotter or laser cutter. This project is kindly supported by Mike Sheldrake (www.sheldrake.net/cardboards), Tischlerei Bächer GmbH (www.tischlereibaecher.de) Sebastian Bächer, Till Hartmann and Maik Holtiegel. In example with the Chaise "Hive" further application opportunities in field of interior design and architecture are being tested (see Fig. 7).

Figure 6
diagram indicating user-driven / algorithmic modeling and digital production

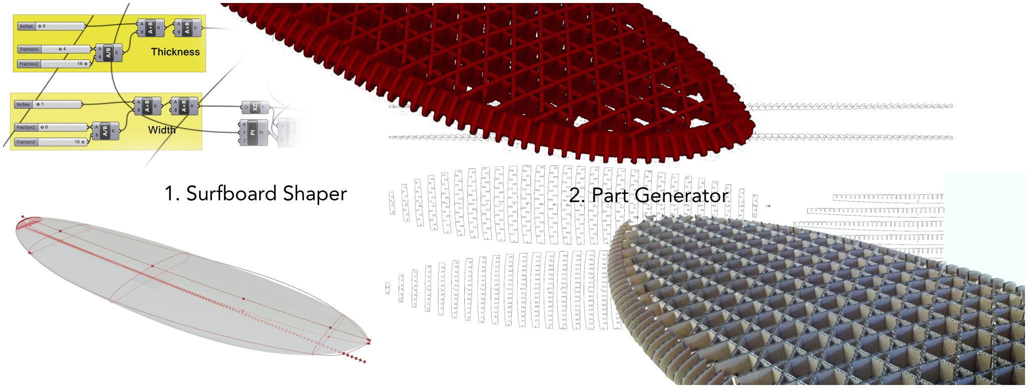

Figure 7
Iso quarter grid cardboard , (C) Hans Sachs, Cologne, 2015

Bended, 2012-2015

'Bended' is a software tool to simulate and generate fabrication data for single curved boards. The tool enables surface curvatures with changes in direction by applying different radiuses. To explore the full potential of its application, a Python based software tool for Rhino 5.0 has been developed which generates G-Code for the CNC milling already in the design process. Based on the user input like edge radii, bending angles and material properties the G-Code for various CNC machines will be generated by the built in post processor. It can be used in a wide range of design and architectural applications from individual furniture production to free form concrete formwork in architectural construction (see Fig. 8).

The software asks the user to select a closed curve, which represents the outside boundary of the sheet to be bended. The user must also define a straight centre line of the curved area, running through two opposite edges of the plane sheet. In addition several parameters including material thickness, cutting slot depth, cutting slot width (laser cut width, milling tool or sawing blade width), the radius on the respective edges and the curvature angle have to be determined. From this constraints and design input parameters a cutting pattern, but also milling paths will be generated (see Fig. 9).

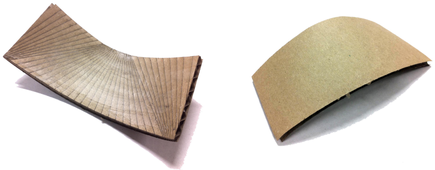

Figure 8
Studies with 'bended' applied on corrugated cardboard with a laser cutter, (C) Hans Sachs, Cologne, 2012

Figure 9
'Bended' prototype - 24mm multiplex board, (C) Hans Sachs, Cologne, 2013

CONCLUSION

Even though computers and software have developed significantly during the past decades, the way of developing architectural-, but also design objects with CAD is still widely misinterpreted as technical drawing assistance. In keeping with the motto 'Computer Aided Drawing' instead of the more reasonable (and correct) definition 'Computer Aided Design' the perception of designing with computers still rather bases on a concept of industrial design thinking.

A first mention should be made of the fact that, during the development of this research and included studies, the dissolution of boundaries between the disciplines evolved to be a crucial part. During the industrial revolution in the 19th century, the exchange between different disciplines with regard to choice of materials and technology was essential in bringing about change and development in architecture and design. Today industrially produced and used materials, especially when used in the field of building construction are applied far below their technical and physical capacities. Digital, responsive and interactive systems, used in design, fabrication but also in the aspect of exchange of object and material behaviours represent a -still partly uncovered- but fundamental base for a real paradigm shift in architecture and design. Therefore a more interdisciplinary approach, a lively exchange of various fields and resources is required and to be intensified.

Although these studies do not present an elaborate concept for a truly interactive and material- and process-informed production of architectural and design goods, they point out that the linkage of the referred processes represents a powerful instrument for individual and in the same time efficient creation of things. Hereby the studies also mediate opportunities and challenges of a broader implementation of mass customization in architecture and design.

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