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Generico
A case study on performance-based design

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Abstract

The paper discusses a case study for a seating element that takes into account human factors as well as aspects of structural performance, material properties and production parameters within an integrative design approach. Generico is a prototype for a new way of design thinking, developed with a holistic approach. The design is based on the requirements of comfortable sitting and responds to load forces and ergonomic conditions. The Generico chair – resulting from an all-embracing line of thought, from design to production, is an ideal field of application for 3D-printing-technology as it allows for an optimal material distribution.

Keywords: Human-centered design; Performance-based design; Generative design; Structural analysis; Additive manufacturing

Introduction

The generative production techniques (e.g. additive manufacturing) are part of our reality and define new qualities in architecture and design. They offer the possibility to adapt the products, objects and spaces that surround us to our individual needs – an ostensive paradisiacal condition. Since we have these means and methods what are we going to produce - even more products in less time to fit our constantly changing demands? As soon as a product reaches the market it is already outdated and the value of a single product decreases more and more until it looses its significance completely. We have to find criteria for an evolutionary process that allows for the creation of an individual, personal design with inter-subjective values.

The information society has displaced the product society. In this sense experience, adventure and knowledge - thus information - replaces the significance of the object itself. In addition the generative technologies bring up the questions whether this new paradigm - as part of our accelerating society – offers options for better products or will it even change our cultural understanding of products? Already the wording - Rapid Prototyping - implies an acceleration of production processes using these technologies, which goes in line with a global celerity of time in the digital age.

Computation provides today the basis for mass-customization - the producing of goods and services to meet individual customer's needs with near mass production efficiency. At its core is a tremendous increase in variety and customization without a corresponding increase in costs. The variation within the design and production processes generates a new freedom and different demands at the same time. Next to the possibilities of individualized manufacturing we can observe a shift from a result to process-oriented design as well as a change of design strategies from top-down to bottom-up. An increasing number of consumer products can be expected from the development described above and globalization even accelerates the distribution of these new products. Within this mass of products the significance becomes the crucial factor for the perception, acceptance and success of a product. The rest remains indifferent and irrelevant, but will exist in a huge quantity - materialized and physical. The significance of a product can as well be described as the value for the user and for society in general. This brings us back to the position of the designer and his responsibility for design. The generative technologies support an individualized mass-customization, which could basically place everybody in the position of the designer and the producer at the same time. The personal fabricator offers a generic rather than a specific production method, so everything seems possible. The design itself is on the other hand strongly connected to the possibilities of handling the 3D-modeling software.

Even though these technologies are fascinating for architects and designers - because they incorporate new possibilities and results - it's obvious that the pure materialization of digital designs will not result coactively in significant products and spaces. The way to experience the potentials and limits of new methods is often driven by an experimental approach rather than a predefined strategy. Try and error as well as excessive use and interpretation are part of this approach. It's absolutely legitimate – if not necessary - to operate like this, especially in architecture and design, in order to break new grounds. But after a period of several years of experience with rapid technologies it is time for a redefinition of the goals. The materialized object, as goal by its own is not enough, even if the process and the results are promising and intriguing.

Generative design

Computational models can be used to create structures that permit adaptation, and which can therefore respond to external influences such as exposure to sunlight and wind loads, or internal influences, such as user behavior and functional sequences. The form arises from the way in which individual parameters are connected and prioritized. Against this background design is undergoing a shift from a formal graphic process to a strategic evolutionary process, with the designer generating a system or strategy rather than a concrete result. One advantage of this approach – aside from making visible the dependencies in the design – is that it is flexible, allowing the designer to alter the programming at any time and therefore to quickly develop and evaluate different concepts or variations for a design solution. This makes objects and spaces, in all their complexity, more accessible and controllable for the designer.

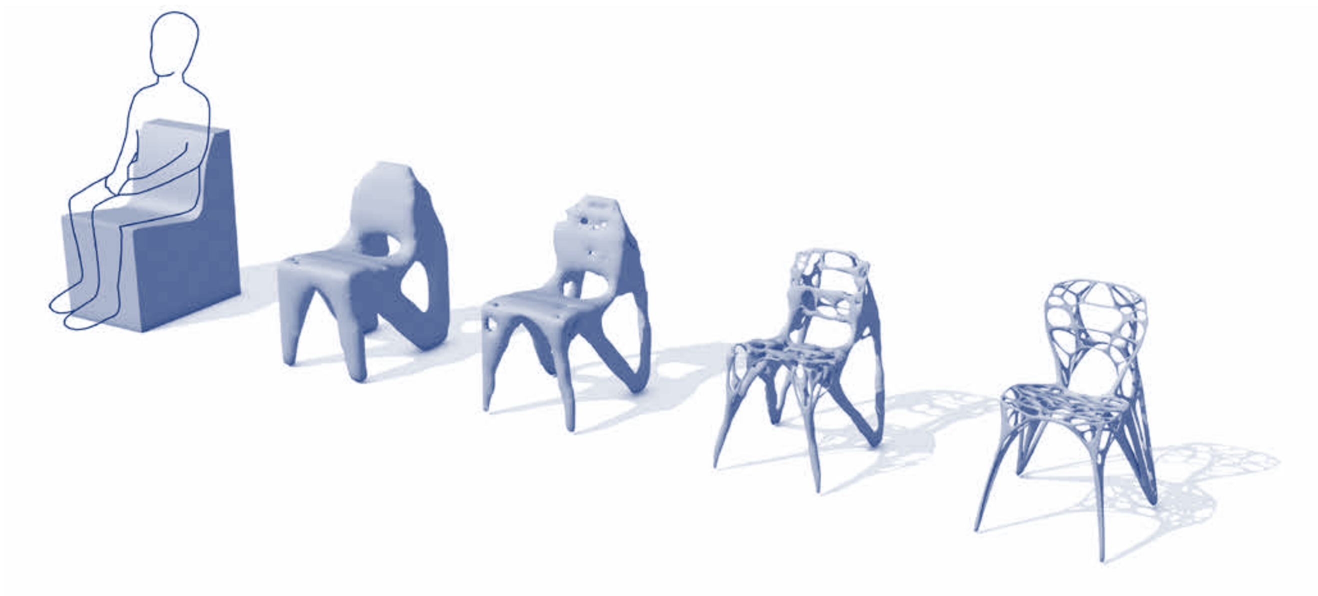
Referring to nature as a reference system the famous French writer Antoine de Saint-Exupéry states in his memoir "Wind, Sand and Stars" from 1939: "Perfection is not attained when there is nothing more that can be added, but when there is nothing more that can be taken away". Notwithstanding the apparent contradiction contained in its diversity, nature is structured so that it constantly fulfills this condition. Optimization is essentially a never-ending stage-by-stage selection process. And this is precisely what the digital process makes possible. It is also the next challenge for architecture and design: how can a state of progressive constant improvement – an evolutionary progression – be introduced into all processes? If we extend this thought, we arrive at a cycle comparable with the cycle of nature – a state of true sustainability. This involves developing materials and processes that approximate to nature and its principles. Ultimately, by transcending user-orientation and replacing it with affordance – of the kind that we see in the natural world and its self-sufficient complexities – we obtain the key to defining an aesthetic and the way forward for a new unity of nature and design.

Generico - topology optimization

In this context the design for the Generico chair is developed out of the demands, conditions and constraints of sitting. The generative form-finding process takes into account structural performance, material properties and ergonomic demands as well as parameters of production in a holistic approach. In order to accommodate the idea of a generative design development the concept for the realization is based on generative/additive manufacturing technologies. In a first step the constraints for the form generation were defined in a parametrical 3D-model. Next to ergonomically relevant aspects - like seating height, position and angle of the backrest as well as direction of motion - structural parameters were integrated in the modeling strategy.

Therefore the loads and the positions for the supports were defined as boundary constraints for a topological form-finding calculation, using *SolidThinking Inspire*. The topology optimization generated an ideal material layout for the given conditions while also reducing local stresses and maintaining structural stiffness for the design. In an iterative process the calculation resulted in a reduction of the necessary material to meet the performance requirements.

Figure 1: Form-finding process through topology optimization.



This method is often used in mechanical engineering at the concept level of the design process. Topology optimization is distinct from shape optimization since typically shape optimization methods work in a subset of allowable shapes, which have fixed topological properties, such as having a fixed number of holes in them. Therefore topology optimization is used primarily to generate concepts and shape optimization is used to fine-tune a chosen design topology. Dutch designer Joris Laarman applied this topology optimization in 2006 for the development of his bone chair.

Generico - final form-finding

In contrast to the bone chair, Generico is not only developed from a topology optimization, but based on a holistic approach taking also into account human factors, like changing positions, movement and sitting comfort as well as aspects of structural performance, material properties and production parameters within an integrative design approach.

Hence, in a further optimization process the digital 3D-model was reviewed again against the background of usability and human factors, e.g. smoothness of surface, user comfort, contact zones. The re-modeling was carried out using *Rhinoceros* and *3DSmax* for a final shape optimization with a subdivision calculation to smoothen the polygon mesh

In order to verify and optimize the structural performance of the chair design and the material concept again, the model was analyzed (FEM) with the structural engineering software *ANSYS (V14)*. After meshing the geometry the boundary conditions for three load cases were defined and calculated:

- seating (1000N)
- chair-back (410N)
- leading edge of the seating area (1000N)

As a result some of the members showed exceedance of deformation or stress, while others were partly oversized compared to the load profile. In a further optimization process the local stress induced gradients were used to expand or shrink the profile geometry accordingly. In a final design step before production all findings were integrated into a definitive 3D-model (*Rhinoceros*).

Generative production

Throughout the entire design phase various models were 3D-printed in scales 1:10 to 1:3, using different printing technologies and materials, to test and verify the findings from the digital form-finding and optimization process. Some materials proved to be heat sensitive (e.g. Stratsys/Objet VeroBlue) and showed deformations over time. Other materials/printing technologies showed too low mechanical resistance. Finally ABS material (Acrylonitrile Butadiene Styrene) in combination with a FDM printing technology (Fused Deposition Modeling) was chosen for the 3D-print in scale 1:1. As a result the physical performance of the chair matched the envisioned result. The prototype retains its shape under load and with a weight of a merely 2,2 kg it is remarkably light.

In a further development step the materials shall be adapted even more to comfort and functionality. Therefore Stratasys/Objets Digital Materials, with different degrees of hardness and softness, will be integrated in the form-finding strategy, both on the digital and physical level of the process. Theses composite materials with predetermined mechanical properties allow for a specific and individual distribution within the 3D-printing process without the need to change the production method. A first physical scale-model (1:3) clearly enhanced the comfort and tactile quality of the chair.

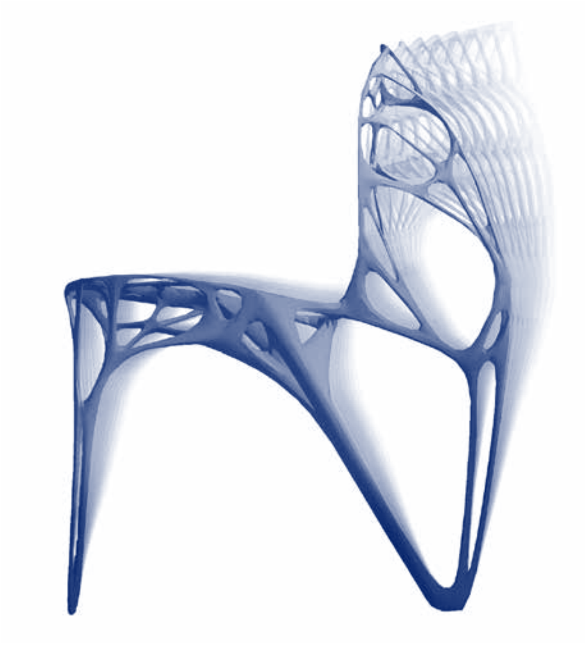


Figure 2: FEM-analysis: stress and deformation profile.

Figure 3: 3D-printed Generico chair, scale 1:1.

Discussion

The case study „Generico“ explores ways of adapting digital design methods and computer aided manufacturing methods to humans and their needs. A flexible adaption is achieved through the specific use of algorithm parameters for form and material determination which are identified in analyses on human beings, either from forces that are derived from the use or beyond due to the use of production technologies that enable a response to human body and movement: Performance determines the design process.

Digital design and production makes it possible to combine industrial production with individually tailored items. This development offers the possibility of being able to relate to objects again in the way that we once related to manually produced objects – something that has been lost to us in everyday life in a culture of industrial mass-production – thereby restoring to objects their true value. Hence it is necessary to adapt the process not just to technology but first of all to humans and to find methods to do so. This paradigm shift and the resulting changes in method will need a philosophy that places the emphasis on certain qualities. It will not be a question of generating a "brave new world" with more complex, seemingly fantastical designs, but of marrying the seemingly inexhaustible possibilities of parametrically developed design to a sense of responsibility. This responsibility on the part of the designer is not restricted to the process of turning a digital product into a tangible product – the tangible object itself will be changed, as projection of the digital becomes a reality.

Interaction, communication and utility are coming increasingly to the fore, as the objects themselves become subordinated to the effect that they achieve. In this way, spaces and objects which derived from digital processes will, in the best outcome, develop a self-sufficient quality founded on user-orientation and adaptivity, suitability of materials and production technique, and effective sustainability.

Acknowledgments

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