



Architectural Design with Parametric Modeling & Customized Mass

Production: Explorations and Case Studies in Architectural Design and

Production Methods

Introduction

(...) quite a few things are not made of modular units, namely people, trees, and stars (...) In order for the buildings to be alive, its construction details must be unique and fitted to their individual circumstances as carefully as the larger parts (...) The details of a building cannot be made alive when they are made from modular parts.

Christopher Alexander, *The Search for Beauty from The Nature of Order: An Essay on the Art of Building and the Nature of the Universe*, 2003-2004

We use parametric modelling and customized mass production to design architectures where variety, spatial richness and a sensitivity to specific programmes, users and contexts go along with the economics of mass production and the easy adaptability and changeability of architectural solutions at all stages of the design process.

The specific conditions of each new design and building task, each new group of users or inhabitants and each new site has in the past century rarely found a place in an architecture that through the use of serial mass production had limited itself to a small formal repertoire and the repetition of equal or similar buildings and building elements. Customized mass production provides possibilities to economically produce

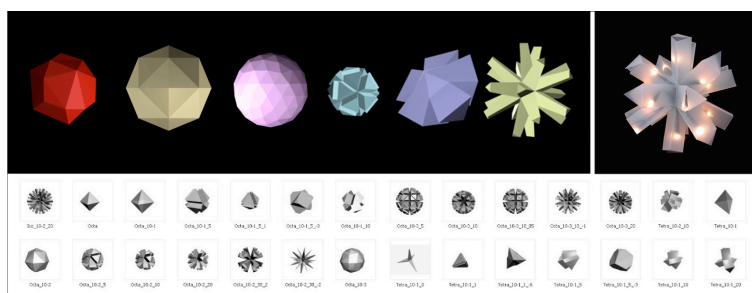
many elements, which are not identical like twins but similar like related family members.



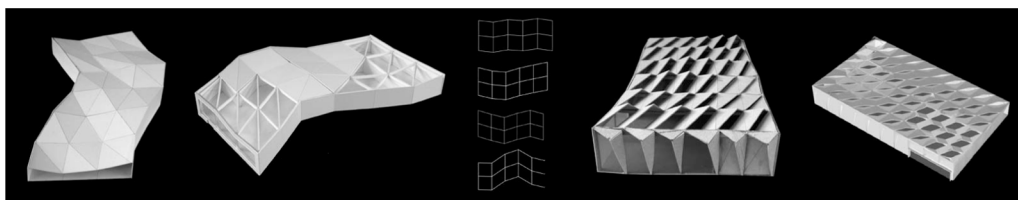
Specifics of context and users can inform the mass-produced object or building and thereby create a balance between regularity and variety. Monotonous repetition can be overcome and superseded by varied similarity.

1. Parametric modelling

Parametric modelling CAD programs are widely used in automobile, naval, aeronautical and product-design industries, where the process of planning is characterised by further developing and optimizing an existing product or its components. Rarely, a completely new design "from scratch" is being introduced as it is most often the case in architecture. Therefore, in these industries tools for easy handling of changes on an existing object have been initially introduced with CAD systems. Even though in architecture the process of planning is different, there are innumerable changes to a building over the course of developing it. And not only would the utilization of parametric models make changes easier to handle, it would also offer the possibility to easily produce variations of the design object and provide adaptability to user and location.



To employ this alternative design method, the object must first be described by a set of rules of geometric dependencies and constraints that are then "translated" into a digital parametric model. The definition of dependencies facilitates the variation of complex systems rather than the mere change in scale as in non-parametric systems. Defining constraints is part of the definition of rules and incorporates aspects such as material specification, sizes of parts and spaces, planning regulations etc.



2. Customized mass production

„Whenever architectural production technologies change, architecture will change.“

Konrad Wachsmann: *Wendepunkt im Bauen*, Krausskopf-Verlag Wiesbaden, 1959

From its beginnings, building was dominated by the following paradigm:

1. Choice of the building system
2. Development of the building design

In the 21st century we have reached a point in architectural production that enables us to rethink this dogma: 98% of the development process as planning, calculation, optimization and marketing are “in”-formation based. The gap between planning and building execution, between the virtual and the physical, is closed.

The principle of mass customization is to achieve a result, which is specifically suited to an individual design task. The concept is based on a combination of low unit costs

of mass production processes with the flexibility of individual numerically defined production methods.

Optimized building principles become part of the architectural production and create a direct link between computer generated planning information and production machinery. The new production technologies can be differentiated in generative, subtractive and formative typologies.¹ Each method can fulfil different design requirements.

A logical planning process will start off with a thorough mapping of the design task; the generated knowledge is translated into design parameters, which inform the strategies of the structural, spatial and environmental solution. The result is co-developed in a virtual environment and physical environment. The final design solution is optimized by internal, i.e. functional, and external, i.e. structural and environmental, parameters. The result is transferred via the “digital chain”² to the production facility, prefabricated and assembled at the construction site.

A truly integral mass customized approach is guided by analytical facts, as structural, functional and environmental parameters, to generate a mass customized result.

3. Parametric Objects

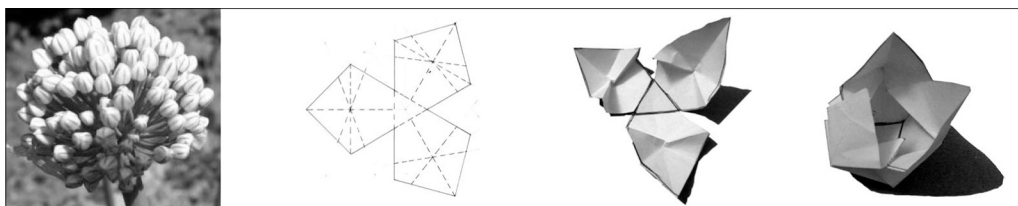
In a series of design courses exploring the previously described possibilities, different design tasks in varying ranges and scales were approached from small objects like lamps to larger furniture objects like a coffee bar to installation objects like a trade fair stand. It was experimented with the digital continuity from design to production and how the „digital chain“ could be achieved. This included the development of a

parametrized description, 3d modeling of the object in a parametric CAD software and the export of data for the digital production.

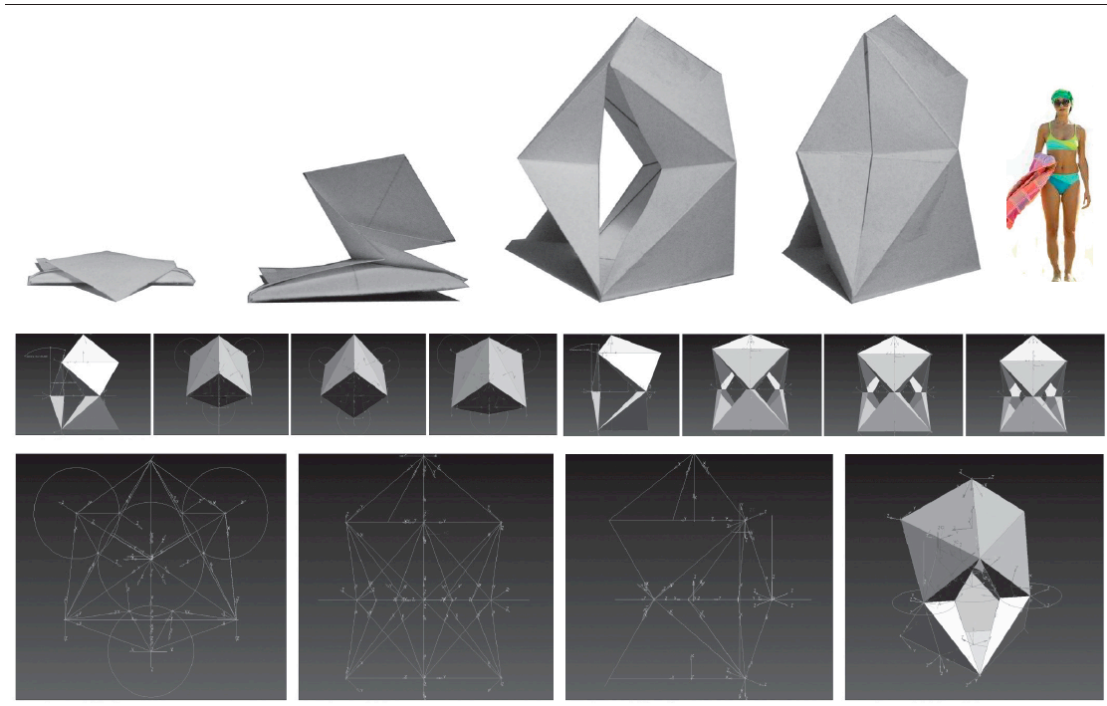
To understand the idea of a parametric design and the creation of variations, we used a methodology analyzing and experimenting with objects from nature, their geometry and rule definition. Our intention was not to copy forms from nature, but to examine and translate principles of shape and rule definition as a source of inspiration and creativity.

The project of a folding beach cabin started with the analysis of a nature object to establish its geometric principles and rules. In our example, the chosen fruit consisted of folding plant petals. The geometric principle of "folding" with an opening and closing mechanism was then abstracted and classified according to principles like spiraling, packing, cracking, tiling etc.³

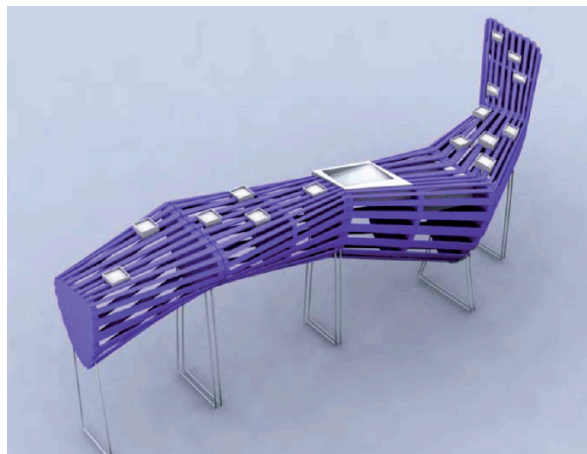
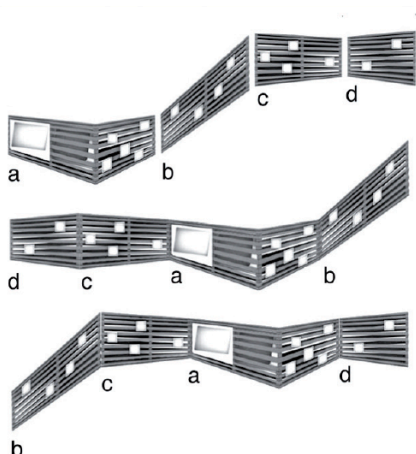
The construction principles were then transposed into a parametric object.



The folding elements of the plant petals of the nature object acted as the source of inspiration for a folding beach cabin. The cabin hereby consists of folding elements that are defined by a set of rules to generate the desired shape to serve the use. Size, shape and material are parameters that are not fixed, but vary according to the user. The parametrically defined object can subsequently be produced as personalized beach cabins by feeding it with personal data, i.e. height, size, sex etc. of the user.



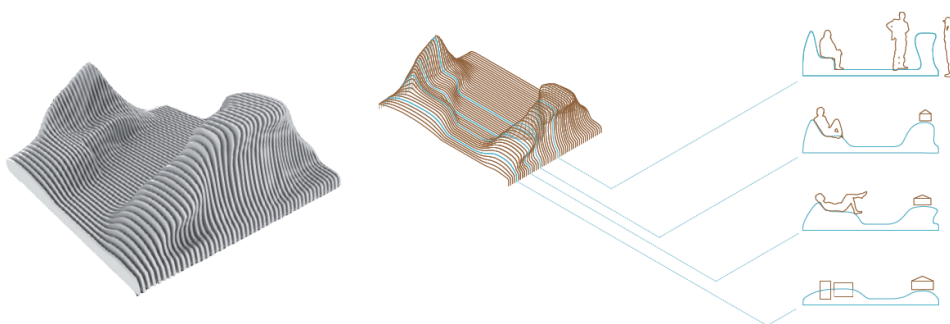
In the 1:1 design project a coffee bar the object was developed as a set of parametric pieces of furniture. The modules are conceived of different shapes and sizes in a way that each one can fulfil different tasks, i.e. containing a coffee machine, sink, fridge or storing cups and glasses. The geometry of one module is defined by its two end shapes, the distance and angle in space between them. This definition generates a set of modules that are similar in shape and size. A rule of size and location of the end pieces enables diverse layouts of the modules according to various requirements. The compound shape of the modules was manufactured in timber elements; therefore, the complex 3 dimensional geometry was dissected in flat 2d elements that were manufactured through cnc milling.



The trade fair stand as an installation object represents the department of architecture by displaying architectural models and publications, but also in the design shape and materialization itself by exhibiting the result of contemporary digital construction methods. The development of the design as an parametric object manufactured with cnc technologies enabled the design team to experiment with shapes in a way that would have not easily been possible to execute with conventional non-digital means.



The undulating shape of the stand is conceived to attract attention through its unconventional form and material, but also to incorporate various uses necessary in a trade fair stand: Information desk and seating area as well as display for books and design models. These different uses are defined by a specific shape each that is developed according to its requirements. A rule defines the "growth" of the different shapes from the base by applying the parameters of height and angle. The next step constitutes the distribution of the required uses (represented by shapes) within the stand. Through interpolation between the segments the final continuous undulating area is created.

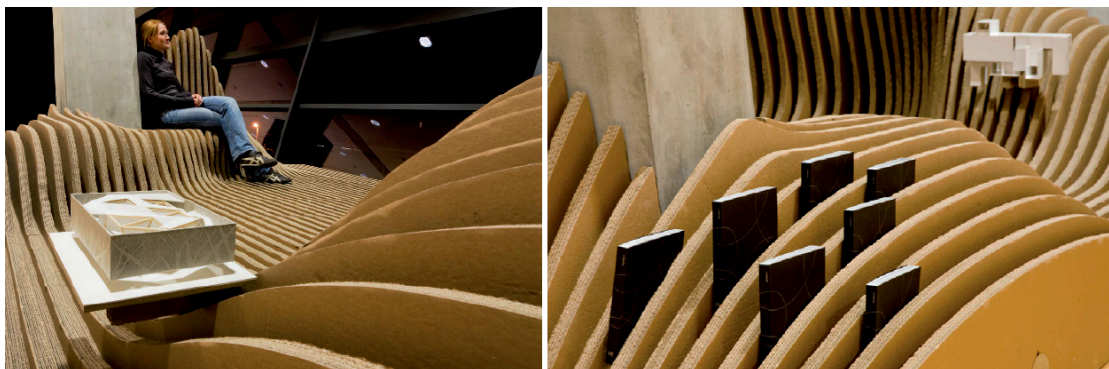


The parametric shape was developed in physical and digital 3d models. The individually adaptable parameters were applied to suit the characteristics of the environment of the trade fair stand and digitally optimized through the applied CAD software. The goal was to establish a seamless transfer from the planning software to the production facility. In the modelling software Rhino 3d the contours were extracted as 2D data and subsequently controlled for consistency in the engineering software AutoCAD. Through a compilation software the CNC cutting data was generated and hence prepared for the cutting machine. The cutting data incorporated all information, as connection holes and coding information, to prepare the object's segments for final assembly.

Three different numerically controlled production technologies were analyzed:

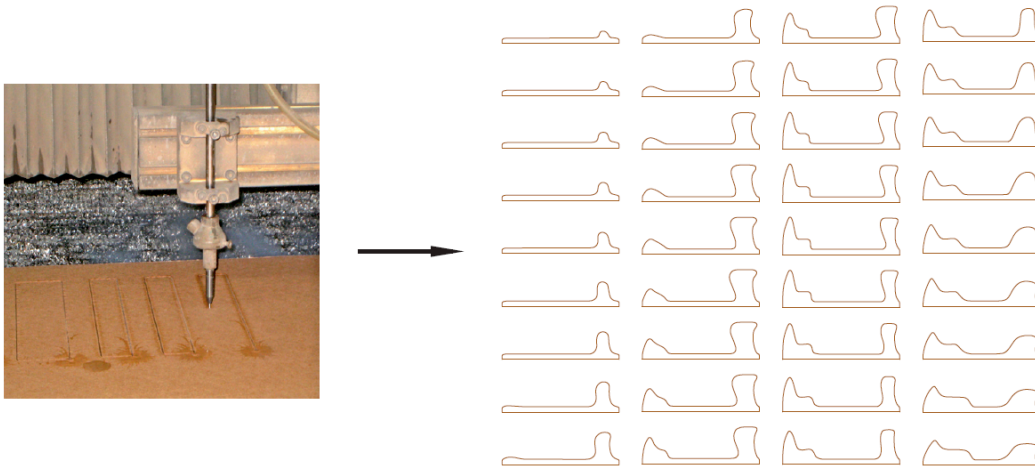
1. CNC controlled laser cutting
2. CNC controlled cutting plotter
3. CNC controlled water-jet cutting

Tests proved the water-jet the most efficient technology to shape the 35mm cardboard plates into the final contour for the trade fair stand.



By focussing the water-jet to a diameter of 0,02mm and a pressure of 3000 bar the fluid cutting medium has no negative effect on the cardboard material.

The manufacturing process in CNC technology enabled the team to produce 324 different elements in the same time and at the same cost as 324 identical parts would have consumed.



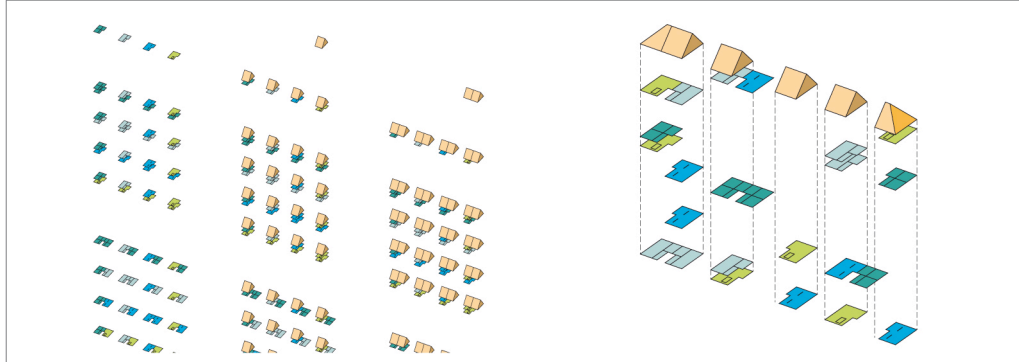
The trade fair stand is conceived to be assembled and dismantled easily. Therefore, the 324 elements are preassembled in groups of 6 segments for easy transport and handling. The structural interconnection of the elements is achieved by 10 thread rods which effectuate a pulling force to the external elements and hold the whole ensemble in position.

4. Parametric Typology

The typology of stacked row houses has been chosen for its applicability in contexts with varying degrees of urbanity, its need for unification as well as individualization. This research project is being developed in collaboration with a housing company with the aim to produce prototypes and develop the system into a marketable product. By defining parameters, a system for a typology is created that can be individually adapted to context and users and economically produced through customized mass production. Compared to the objects described previously, the sets of rules are much

more complex and are therefore expressed in a sequence of descriptions.

The diversity of life and family constellations in our society represent an increasing demand in diversely useable and flexible apartments.



The chosen typology of stacked row houses merges housing with single-storey flats and row houses and can therefore be applied to produce not only economically affordable housing, but also to customize flats according to the user's preferences. To fully use the potential, synergistic benefits of development and manufacturing methods will be employed.

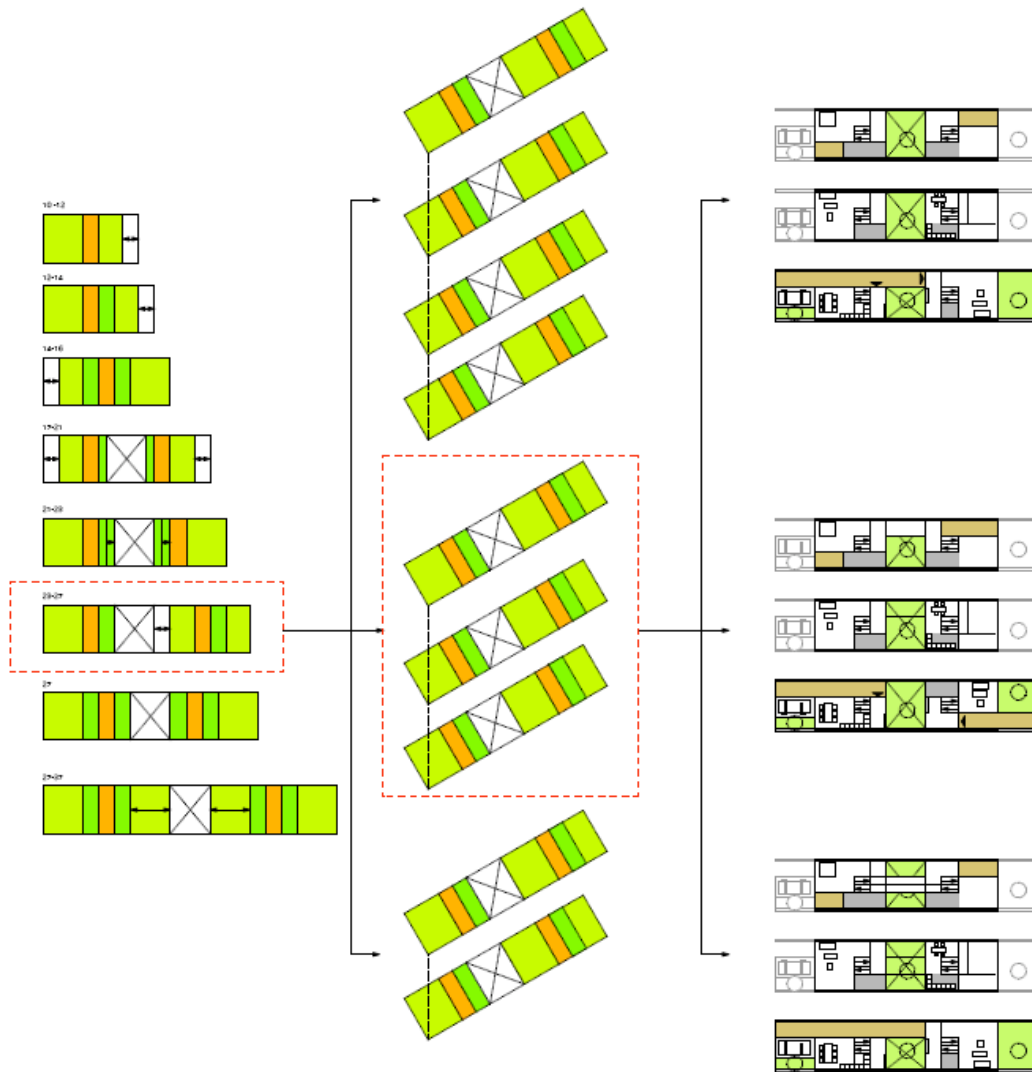
The research project investigates into the interdependency between the design process and the industrial manufacturing process with the aim to develop a tool for planning stacked row houses. This tool will be created as a "plug-in" into the CAD program Revit architecture as well as described in algorithms. Within this tool all information of the typology are specified and it constitutes the genotype of the typology. The tool will be applied in case studies and generate - through the impact of the specific boundary conditions - the phenotype of the building typology which is optimized in the given situation.

In analyzing design processes and developing a rule-based description for typologies, there are two works based on Stiny's and Gips' shape grammar description⁴ we would like to mention in relation to our work method:

William Mitchell introduces a system for the design process of palladio's house typologies.⁵ With the aid of a very exact set of geometric rules and dependencies, Mitchell can not only reconstruct palladian houses, but also generate new variations. The rules follow an additive system: starting from a single achsis point the geometry and the arrangement of rooms are added. The result constitutes the phaenotype (of the original palladian genotype) in the proportion and arrangement of rooms.

Similarly, José Duarte examines an existing building type, the "Malagueira houses"⁶ by Alvaro Siza to subsequently set up the incorporated rules. Duarte hereby combines shape grammar with a description grammar which make it possible to fully describe the building type. With the established instrument, existing house types can be reconstructed and new types in the "Malagueira style" can be generated. In addition to parameters of space and geometry, functional dependencies and calculation of costs are integrated. In contrast to Mitchell's system, Duarte's is not adding spaces, but dividing up the overall geometry into smaller units.

Our research project, however, is not based on an existing house type. Therefore, a typology is being developed for the subsequent rule-definition. The linear approach is verified and adjusted by feedback loops.



1. identification and determination of the relevant criteria for the development of the typology

Hereby the following factors are incorporated:

- a. manufacturing methods with a high level of prefabrication and mass customization, significant for supporting structure, construction, span and material.
- b. variety in organisation of layout and form of appearance
- c. flexibility in layout for newly-built and conversion
- d. energy efficiency in layout zoning, daylight income, heat accumulator
- e. cost-effectiveness

2. development of typology system

Here, the relevant criteria defined previously is being considered.

3. function diagram (first abstraction)

Definition of rules for the typology showing the associations, dependencies and constraints of the typology elements.

4. algorithm (second abstraction)

The function diagram is being expressed in an algorithm, a written description from which a plug-in tool can be produced.

5. plug-in tool

The final tool is being implemented in the CAD software.

The implementation of the plug-in tool is being done in the following steps:

1. site and user information

Input of factors like size and height of the site, planning regulations, orientation of the sun, location of access etc. and information about the user and specific requirements.

2. generation of phenotype

According to the defined criteria and the specific boundary conditions, the tool generates an optimized building with an optimized internal layout.

3. application of the phenotype

With the aid of case studies the tool is exemplarily tested and evaluated. The flexibility of the layout is illustrated in case scenarios.

The manifold changeability of parameters produce a multitude of design solutions. They can be used to optimize the creative planning process in regards to the result. The building itself can be optimized according to the requirements of user and location incorporating the factors mass customization and cost-effectiveness, energy efficiency, variety in appearance and flexibility in layout.

5. Comments and Outlook

We are convinced that methods of parametric design and customized mass production can not only enhance design creativity and extend design and production capacities but also enhance the final product by optimizing it for user and location.

Using the described digital parametric tools generally demands a different approach in the application than conventional CAD software. Since these tools are much more complex with integrated parametric modeling and offer the definition of associations, dependencies and constraints, the handling is more complex and the introduction of formulas might require the participation of an expert in this field or program, i.e. informatics or mechanical engineer.

The advantages of customizing software are already widely used in mechanical engineering and product design, but hardly known in most areas of architecture. Similarly, the potential of production methods changing from manual to digital production are yet to be fully appreciated and applied to realize customized production at the price of serial production.

Heike Matcha

Department of Architecture

Technical University Darmstadt,
Institute of Design & Technology, Professor Dr. Klaus Daniels
El-Lissitzky-Straße 1
D-64287 Darmstadt
Germany
Email: h.matcha@techno-tud.de

Rüdiger Karzel
Dipl.-Ing. Architect MAS ETH
Ibid.
Email: karzel@ekon.tu-darmstadt.de

Gero Quasten
Dipl.-Ing. Architect
Ibid.
Email: quasten@hbk.tu-darmstadt.de

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¹ Peters, Kalweit, Paul, Wallbaum: Handbuch für technisches Produktdesign: Material und Fertigung, Entscheidungsgrundlagen für Designer und Ingenieure; Springer 2006

² Ludger Hovestadt, Strategien zur Überwindung des Rasters. *CAAD Spezial, archithese*, 2006

³ Aranda, Lasch, *Tooling*, Pamphlet Architecture 27, Princeton Architectural Press 2006

⁴ George Stiny and James Gips, Shape grammars and the generative specification of painting and sculpture. *IFIP Congress 1971*. North Holland Publishing Co., 1971

⁵ William J. Mitchell, *The Logic of Architecture*. MIT Press Cambridge, 1990

⁶ José Duarte, Customizing mass housing: a discursive grammar for Siza's Malagueira houses. *PhD-Thesis*. Faculty of Architecture, Massachusetts Institute of Technology, 2000

Figure 01. Faces: Identical and similar

Figure 02. "Geometric variations of parametric lighting object", student design project, winter 04/05, Mohan Zeng, Technical University Braunschweig

Figure 03. "Supermarket with parametric organisation, structure and facade system", student design project, winter 04/05, Mohan Zeng, Christian Behnke, Technical University Braunschweig

Figure 04. "Study of structure and geometry principles in nature", student design project, winter 06/07, Edda Gaudier, Susann Zimmermann, Technical University Darmstadt

Figure 05. "Folding beach cabin and parametric model in NX Unigraphics", student design project, winter 06/07, Edda Gaudier, Stephan Mehlhorn, Susann Zimmermann, Technical University Darmstadt

Figure 06. "Coffee bar with parametric modules with shapes differing according to contents", student design project, summer 05, Mohan Zeng, Technical University Braunschweig

Figure 07. "Trade fair stand for department of architecture", student design-build project, winter 07/08, Technical University Darmstadt,

Photograph by Thomas Ott, www.o2t.de

Figure 08. "Physical and digital model dissected in layers", student design-build project, winter 07/08, Technical University Darmstadt

Figure 09. "Photos showing details of material and display", student design-build project, winter 07/08, Technical University Darmstadt,

Photograph by Thomas Ott, www.o2t.de

Figure 10. "Cnc manufacturing method via water-jet cutting and extract of 324 different parts", student design-build project, winter 07/08, Technical University Darmstadt

Figure 11. "Isometric diagram of variations", ongoing research project, 10/07 - 02/09, Technical University Darmstadt

Figure 12. "Generative algorithm for shape of house and user-related variations", ongoing research project, 10/07 - 02/09, Technical University Darmstadt

Figure 13. "Parametric typology diagram", ongoing research project, 10/07 - 02/09, Technical University Darmstadt