Generating topologies
Transformability, real-time, real-world

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Abstract
Customization is a contemporary trend, which should not be ignored by architecture. An increasing demand and decreasing resources will necessitate the reuse and the sharing of space. Transformability will facilitate these tasks. On the basis of a case study, this paper demonstrates the technical feasibility of a continuously transformable structure, which enables the transformation and manipulation not only of shape, but of topological qualities as well. However, this fully and universally transformable architecture itself cannot only be seen in the context of customization, but also as a further development of architecture as a discipline.

1. Customizing the future environment

Form in the digital age finally lost its functional reference. Where in the mechanical age you could read off functionality from the classical machine, electronic devices started to hide away how they work. As the computer finally infiltrated the man-made environment, shape lost its iconographic meaning. Of course, you always could enclose, and thus hide, the functional parts of a machine. The significant difference now is, that any type of machine can be reduced to one kind, the computer. This technological leap in return offers sheer unlimited possibilities of customization and combinations of the original functions.

The gadget industry is thriving. From washing machines to cars, from television sets to airplanes, nothing escapes the digital age. Eventually, with the mobile phone, with its increasing number of functions, few human beings can be found without a digital device. The concept of customization thus proves successful. At least partly, this is because of the so developed ability to adjust to in itself diverse and changing societies on the one hand, a greater cultural diversity of societies to be dealt with on the global level on the other hand, another consequence of the phenomenon, commonly referred to as globalization.

"Observers of current and future trends" predict that "the nature of working and living will change drastically such that society will require completely new types of structures"\(^1\). An increasingly busy world economy and the rise of the so-called emerging markets result in higher construction activities. Already now, concrete is referred to as "the most widely used substance on the planet after water"\(^2\). Its production process releases large amounts of carbon dioxide. Given the political situation, it seems quite impossible to address these issues in a general, standardised way. Yet, assuming, that a good portion of construction activities are the result of remodelling, reconfiguring or modification of buildings, this might be another field, where concepts of customization might be suited to contribute to solutions.

While building technology is permanently upgraded, and the optimization of heating and airconditioning systems, water and energy supply, security systems and the ergonomics of lightning systems is at least possible the core competence of architecture is rarely
considered. Providing beauty and functionality through spatial configurations, forms and relations. Specializing space can be seen as one of architecture’s primary goals. Thus, customizing architecture will particularly deal with transforming space: changing size and form, and, even more important, correlations, dependencies, connections.

Transformable structures could be the sustainable answer to an unexpected and unpredictable future.

2. Space not form - what to customize

In the current architectural discourse, actual transformations of built structures, if at all at stake, usually are restricted to homeomorphic change. However, there is a long tradition of radical transformation in architecture, decisively contributing to the functionality of any building. Each time, we open or close a door, a window or an operable wall, we change a building’s topology (fig. 1). These changes can be extended by more far-reaching topological transformations, like adding or subtracting handles, changing the orientation of a surface or tying and untwisting knots (fig. 2).

fig. 1: topological change, when opening a door

The specific form of an object, especially of a machine part, can be extremely powerful. A screw, a nozzle, a car, they all can only function by their very shape. In architecture, the topological structure seems to be more important than the specific shape. Various functions can be accommodated within the same shape, yet, some topological changes might become necessary, when transforming a church into a residential building. Still, also this relation will rarely be as compelling and as definite as the form-function relation of mechanic elements. As Bill Hillier puts it: "space does not direct events, but it shapes possibilities."3

If Greg Lynn argues in Animate Form4 that the form of a building should be optimized like the hull of a boat, he pursues a task, which architecture as a spatial art will only be able to perform metaphorically. Although his design generates spatial patterns, it does so as a by-product of form. Form and space are not given the same attention. Thus the final outcome of these patterns and with it the related possibilities are left to randomness, prejudice and tradition more conceived by the sub-conscious, than a well-considered act.

In the second and third of his three spatial laws, Hillier links spatial structures to social behaviour.5 The first law refers to the "construction of space", which is "the generation of spatial patterns by means of walls, apertures, etc."6 As with the "configurations", he refers to, these means can be interpreted as a certain range of topological qualities. His interest and argument does not consider change, though. In the context of his research the
unchanged within a cultural context seems to be of higher significance. By searching for an "inequality genotype", equal to e.g. a wide range of floorplans from different ages, Hillier identifies “some kind of cultural principle for giving different social relations and activities a spatial form”7. Focused on urbanistic problems, rather than design aspects, he also does not look into a more detailed level, where other topological qualities such as windows, or possible change such as the opening and closing of doors would be of importance. Still, he gives evidence of significant relation between topological qualities and society and even function.

This might be surprising in the context of Animate Form. However, the definition of architecture as a spatial art goes back to the 19th century.8 The relation between function, society and configuration can be demonstrated with the Kings Road House in West Hollywood9. The significance of this house is not to be seen in a fancy form, which it has not. Its importance lies within the changed programm. Besides kitchen, bathrooms and garage, its main rooms are not specialized according to traditional functions like parlour, office or library. They are labeled by the names of its inhabitants. It was a remarkable attempt towards a customized, individualized space. The house was designed to accomodate two friendly couples. However, it assigned each of the inhabitants its own room, each couple a courtyard, a bathroom and an outdoor sleeping basket on the roof and one kitchen for all together. Each of the couple’s area has its own entrance. As you can access the kitchen, which again has its own entrance form outside, from both areas, it is not the structure of a semi-detached house. Its programm still is unthinkable for commercial housing developement plans. Its topological structure is customized for a unique social programm, which still would be seen as unusual.

If we ask, how architecture could contribute to customization, the question is, what architecture specializes and by what means. Of course, there is an architectural language, signs and forms, which are equally involved in specializing space and greatly involved in producing rich architectural experiences.10 But, as with the example of the church converted to a residential building, their contribution to its functional specialization is less significant. For some design tasks, the very shape is crucial, e.g. an auditory. A specific function, assigned to a certain space, requires a certain topology. This topological structure, however, must be given the right scale and proportion. Topology, scale and proportion specialize the space in question. Where topology defines the relation and structure of spaces, scale and proportion assigns specific volumes to spaces. Customizing spaces, not once and for all, but again and again, thus calls for transformability of these three qualities.

3. Beyond customization - implications of continuously variable structures

An issue, becoming evident with the example of the converted church, is that of iconographic form. As stated above, functionality itself, does not necessarily generate a self-referential form. It is significant for the digital age, that icons often refer to outdated products, like the mail envelope as an icon for e-mail applications or a vintage telephone receiver to depict the funtionality of the call button on mobile phones. However, a building, capable of continuously changing its topology, will also be able to change its shape, thus its iconographic meaning. Freeing architecture from function-related form will be another merit of transformable architecture opening new realms of communicating spaces.

Time, essential to any transformation process, is another issue. A continuously variable structure radically changes this dimension’s effect on architecture, which usually is tied to the beholder’s or user’s movements. The analogy of architecture and music was often
stated and searched for. It is one of architecture´s old topics and can be traced back to the fifth century. It still was an important inspiration to many 20th century architects. Whatever methods were developed to respond to sound and compositions, music is strictly subject to time´s inevitable linearity. Only the continuous transformation of spatial qualities, real-time, real-world, will allow for fusing these arts. In static architecture, the effects of time can be experienced only through a specific, subjective view-point. A transformable architecture will enable objective, time-based spatial concerts.

Though, the analogy between music and architecture, is just one aspect of a greater realm of ephemeral design patterns. Nature has also been and is still a source of inspiration for architectural design. The Alps have been inspiration to the roof structure of the Olympia stadion in Munich as well as the New Trade Fair in Milan of Massimiliano Fuksas, 40 years later. By means of traditional architecture, the beauty of more ephemeral natural phenomena could rarely be exploited. The cloud analogy of COOP Himmelb(l)au´s BMW World is strictly metaphorical, and merely commits the design to massive cantilevered structures and light weight construction. Diller & Scofidio succeeded in realizing a cloud-like experience with their Blur Building for the Swiss Expo 2002. Of course, their interactive design approach can hardly be called traditional. Unfortunately, the actual interactive component of this project, the Braincoat, could not be realized. A permanent transformation of social spaces would have taken place. However, on the level of physical space the Blur Building is limited to one design inspiration. Transformable architecture, can realize a wider range of ephemeral designs.

Such a design concept is not necessarily conceived by the same person, or by a person at all. As the structure is redesigned over and over again, starting from opening and closing holes without changing enclosed volumes to restructuring all topological qualities, several layers of design can be found: the primary design, being the construction of the transformable structure itself, the secondary design of the generated topological and geometric properties and the tertiary design of the number and quality of additional holes, bumps and forms. The secondary design defines and connects volumes. The tertiary design has its substantial impact on the enclosing elements. As such a structure has to be fully programmable, it can well be applied to interactive concepts. Where the primary design in its initial state would be architecture, the redesign of the secondary and tertiary level could be called meta-architecture.

With Transformer 3 the author realized an actually transformable construction, Desert Cloud being its meta-architecture, its programm. The project was another contribution to the cloud analogy. Literal change and a translucent light weight construction, relying only on tension and pneumatic elements, should render ephemeral qualities to physical form and space. However, all change would have to take place within one given topological structure. The spatial structures themselves, thus, would not be subject to transformation and the ephemeral. The range of possibilities still are not as universal, as a fully customizable architecture should be.

In analogy to the computer, the universal machine, which has replaced or integrated into nearly every tool, it is tempting to create prototypes of a universal architecture, which integrates into nearly any spatial environment.

4. ConVarSys 5 - generating topologies, real-world, real-time
On the basis of ConVarSys 5, a specific project of the author, this paper will show and study the feasibility of a topology generating structure, not only enabling homeomorphic change, but also allowing for the generation of different spatial topologies.

4.1 The material components - from Generic Detail to Generating Detail

New design strategies deal with increasingly abstract design methods, such as Parametric Modelling, Behaviour Models or Genetic Algorithms. Generic Details can thus be developed at a conceptual stage, when the specific geometric form is not yet designed. In this context, ConVarSys 5 will be a built representation of a parametric model. Its details are constantly transformed, actualizing and informing the structure in real-time, a Generating Detail. The architecture itself becomes abstract, freed from the handicap of beforehand defined shape. It is ready to be customized according to the user’s need.

Starting point for ConVarSys 5 is its universal detail. Universal in this context means, that only one element is used throughout the construction of the whole structure. The universal detail sets the constraints to develope the script behind the parametric model, while being itself constrained by matters of feasibility and producibility.

One of these matters is the limited availability of actuators, and the economic rule to employ the least possible means. Actuators are the actively changing elements within a transformable structure. Ideally, form change is subject to only one transformation principle. Not anticipating the universal detail’s final appearance, it is envisioned as a building block, which can be horizontally and vertically displaced against its neighbour. The transformation process is driven by one of the simplest possible kind of actuators, the linear actuator. In previous projects the author could show, the wide range of possible transformations by exclusively relying on linear actuators.

The possible translation of each building block first is limited to a certain range, which will be given by the constraints of its physical counterpart. It can be further restricted by other design considerations.

The script allows for the input of two parameters related to the building blocks:
- The proportion and scale of the block itself and the range of translation expressed as a proportion of the building block’s width and height.
- Tube-like strings, are lined up by these basic building blocks, as they are always, and in the same way connected to two opposing neighbors. While they are never disconnected, gaps and openings between the tubes are possible, creating a sufficient potential of transformations. The building blocks subsequently will be enabled to perform all the additionally necessary tasks, forming a structural building skin. A mechanism of the universal detail ensures fixation and release from string to string, if it is necessary to transfer dead loads and live loads.

An arbitrary number of strings can be arranged side by side to form a field. The fields can be piled up, of course accordingly to their bearing capacity.

4.2 The virtual components - SpaceSeeds and SpacePower

To fully exploit the possibilities of such a construction, it is essential to enable interaction and programming, not by controlling the location of single building blocks, but by a mechanism, which generates, configures, separates and unifies space.

A virtual component thus is introduced to the script, the SpaceSeed. Each SpaceSeed is assigned a certain, changeable range of influence, the SpacePower.
According to the location of the SpaceSeed and the „force“ of SpacePower the blocks recede, keeping a minimum distance, eventually opening or closing holes, resulting in different topological objets (fig. 2).

![Fig. 2: Material and virtual components](image)

Space between the strings can thus be "inflated" or "deflated" by concerted translational procedures through the actuators. Spaces are in-formed, combined and separated, opened and closed, knotted and straightened. A great topological variety can be achieved (fig. 3).

![Fig. 3: Topological variety](image)

The structure is conceived and simulated, using Virtools software development plattform, which was successfully applied to process data and control actuators of dynamic structures at Hyperbody, a sub-department of TU Delft’s Faculty of architecture, led by prof. Kas Oosterhuis.

A full representation of ConVarSys 5 is scripted. The script allows for the output of the values of translational displacement. A permanent stream of data coordinates and actuates the performance of each building block.

5. Consequences - running the structure

By means of universally transformable structures, like ConVarSys 5, space becomes fully programmable and open to customization as well as optimization. The elements of architecture are not designed but emerge from the behaviour pattern of the universal building blocks - either directly from the interaction between material building blocks and virtual SpaceSeeds or by assigning additional behavioural information.

Any opening, such as a door or a window, is a direct consequence of the configuration of SpaceSeeds. A stair can be generated by either placing the SpaceSeeds in a specific manner
or by limiting the translation between building blocks, so that they only produce reasonable ratios of rise and tread. A parapet or railing is generated by an additional information: after input of the parameters of gap width and parapet height, any hole - within a certain range or which is generated by a certain SpaceSeed - which exceeds the given gap width, will produce a parapet of given height (fig.4)\textsuperscript{17}

![fig. 4: a generated parapet](image)

The SpaceSeeds can be placed or moved, again according to a script. They can gather to form specific shapes. This script can be designed to consider and interact with a specific user’s behaviour, customizing the spatial environment.

As a consequence of customization not only change is enabled, but paradoxically also its contrary, durability. By memorizing a specific configuration, environments can be re-called, just as the seat of a Mercedes Benz memorizes your preferred settings. Given a ConVarSys structure this can be done at any place in the world. By change, even durability can be taken to another level, ensuring intimate spatial qualities to its inhabitant, wherever he or she is taken by the dynamics of globalization.

6. Conclusion

ConVarSys 5, even if its material part is not yet realized, shows the technical feasibility of a continuously transformable structure, which enables the transformation and manipulation not only of shape, but also of topological qualities. As has been demonstrated, these qualities are essential to architecture. Customization of architecture thus has to address spatial configurations as well as scale and proportion. With ConVarSys 5, this is achieved by introducing virtual elements, the SpaceSeeds.

The effort itself can not only be seen in the context of customization, but also as a further development of architecture as a discipline, enabling to realize many age-old dreams, such as the analogy of music and architecture, a wider range of natural inspirations or a fully interactive real-world architecture.

Endnotes

1 Durmisevic E. Transformable building structures: design for disassembly as a way to introduce sustainable engineering to building design & construction. Doctoral theses, Delft University of Technology, 2006, p.8
4 Lynn G. *Animate Form*, New York: Princeton Architectural Press, 1999
6 ibd. p.165
7 ibd. p.173
9 The Kings Road House now houses the MAK Center L.A., it is open to the public. It´s address is 835, North Kings Road, West Holywood, CA 90069
10 The work of FOA shows, that topological qualities contribute to the richness of architectural experience no less.
14 Kilian, A. *Design Exploration through Bidirectional Modeling of Constraints*, Ph.D., Massachusetts Institute of Technology, 2006
17 Note the different proportion of the building blocks, compared to fig.3.