MATERIAL, INFORMATION AND FORMATION IN PARAMETRIC DESIGN EXPERIMENTS IN THE RESEARCH LABORATORY OF THE STUDENTS OF THE FACULTY OF ARCHITECTURE OF POZNAN UNIVERSITY OF TECHNOLOGY

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Abstract
Several experiments combining analog design with digital parametric design have been presented, where the relationship between material properties and the designed shape of an architectural element play an important role. This approach allows to create digital material formations or to structure freeform surfaces, control their tectonics, through parametric modulation. Similar research tasks were initiated in the years 2003-2004 during the classes conducted at the Architectural Associations School of Architecture in London. In Poland, for the first time, making use of that experience, a number of similar teaching experiments were carried out in 2013 under the academic supervision of Krystyna Januszkiewicz and Mateusz Zwierzycki, at the newly established Research Laboratory of the students of the Faculty of Architecture of Poznan University of Technology.

Keywords: Digital Tools; parametric design; analog design; material; performance; information; formation; experimentation

Digital design tools carry an enormous potential, which could integrate architecture and building technology, assign a new form of expression, high quality and precision to architecture, by efficient and economic structures. Traditional search for a form is being replaced by a digital “formation”, which must be associated with the term “information”, as well as the response of a form to the environmental conditions and the characteristics of a material. Today, it is known as *performance*, which relates both to the material and its structural effort, depending on the shape of the form[1].

When architecture is informed by the results of performative analyses, then it ceases to be a form as such – it is considered as a material formation. Therefore, the essence of such a design lies in the rules governing relationships and the model illustrating structural and material relations. Digital models obtained in this way are structural models, in which the relationship between material parts and the whole form can be modulated parametrically. This is a completely new approach, especially in the aspect of solving tectonic and structural problems, in relation to design of free forms of complex geometry.

Experiments with multiple parameters, with a wide variety of formative forces acting at the same time, are almost a new venture - especially when it comes to assessing diversified criteria including spatial, structural and material characteristics, as well as properties resulting from the use. Such research tasks were initiated in the years 2003-2004 during the classes conducted at the Architectural Associations School of Architecture in London[2]. In Poland, for the first time, making use of that ex-

[1] see: Branko Kolarevic, Ali M. Malkawi, *Performative Architecture: Beyond Instrumentality*, Routledge, 2005.

perience, a number of similar teaching experiments were carried out under the academic supervision of Krystyna Januszkiewicz and Mateusz Zwierzycki, at the newly established Students' Research Laboratory at the Faculty of Architecture of Poznan University of Technology[3].

1. TASK DESCRIPTION

The task was to design a self-supporting wall, the purpose of which might be modulation of climate in architectural or garden interiors, separating usable space in order to provide shade and privacy, or as a free-standing decorative element. A free choice with regard to material and shape was allowed, encouraging the selection of materials which are easy in modeling, affordable and widely available. The task was focused more on the research process itself, its methodology, rather than on a search for a technologically advanced building material. The idea was to study a relationship between the geometric characteristics of a shape and physical characteristics of a material, and to prepare their parametric record to generate a digital geometric model, which in the CAD/CAM system is necessary for the formation (fabrication) using CNC robots.

2. TEST PROCEDURE

The first stage of the research included learning about the method of freeform surface modeling using NURBS-based tools. Experiments consisted in spreading digital surface on the profiles in search of the most convenient shape, i.e such that its spatial configuration ensures stability to the wall. Such surfaces were modeled, whose arrangement of the folds and the center of gravity would ensure the maintenance of balance without placing unnecessary supports. Mostly freeform surfaces with complex geometry were obtained.

During the second phase of the research, works were carried out aiming at dividing the digital surface into its constituent parts. At the same time, physical properties of the selected material were examined in terms of bending, cutting, and assembly, as well as its aesthetic values were evaluated. Draft physical models of the project sequence were built by hand. At this stage of the research, the methods of tessellation and contouring of curved surfaces were learned in order to divide them into flat elements, as well as the dynamic relaxation method as a way to optimize a system of similar elements, the method to boost their spatial self-organization.

Each time a protocol with records of the properties was drawn, and the obtained numerical parameters were published in the research logbook, together with the photographic documentation. In some cases, the studies proved that the properties of the material did not allow for a selected shape of the wall. Then, a modification was required, and even a change of the material. The aesthetic values could also be an obstacle. There is a correlation between the shape and the material, which means that there are shapes that in one material look better, and worse in others. The same goes for colors. While selecting a different material, we already bear in mind its desired properties.

In the third phase, when the results were already satisfactory and the protocols comprised all the necessary information and parameters, experimenting began with translating these data into a record that a computer could understand. Rhino Grasshopper application proved to be helpful here, created for parametric design. It allows for easy preparation of the script and creating individual boxes and connecting wires. Using this application, it was possible to generate 3D models needed for the design representation and for the creation of a prototype and of the final product.

It should be noted that the result of the shape and material analyses are digital models, which are structural models, where the relationship of the material parts with the whole form can be modulated parametrically.

2.1. Knots and weaves

Interest in woven structures, although having a long tradition in building and primitive art, it became enforced in architecture only thanks to Gottfried Semper (1803-1879) and Kenneth Frampton (born in 1930). They turned attention more to their structural aspect than just a source of decorative motifs. In the era of digital technology, woven structures entered the computer space as one of the ways of structuring the surface of a complex geometry.

The research work *U Knit* covers the study of a shape and structure of the free surface in response to possibilities of forming a corrugated PVC tube (cable protector). The study focused here on finding a weave that would provide the desired stability and aesthet-

[2] see: Michael Hensel, Achim Menges, *Material and Digital Design Synthesis*, AD, Vol. 76, No. 2, 2006, pp. 82-86 also: Michael Hensel, Achim Menges, *Morpho-ecologies*, AA Publications, London, 2006.

[3] For a more detailed description of these experiments see: Adam M. Szymski, *Free surface and material. Parametric design at the Students' Research Laboratory at the Faculty of Architecture of Poznan University of Technology*, AV 3/2013, pp. 52-57 and AV 4/2013 pp. 52-56.

ic quality. Different types of knots and weaves were analyzed, found in knitted fabrics made by hand and by knitting machines. A physical research model was created, which allowed for an assessment and conclusions. As a result, own kind of knotted weave was developed, which met the expectations of the designers. The collected parameters allowed for the preparation of a digital geometric model using Rhino Grasshopper application. It turned out that the *U Knit* fabric made of PVC tube is so rigid and flexible at the same time, that it can be used in the formation of multipurpose corrugated surfaces. The recycled material can also be used, ensuring its repeated use. Thanks to its resistance to adverse weather conditions, it may also be located outside the facility, be a functional element, or just a decorative, masking, separating or protective one. It can also be manufactured as a customized product (*mass customization*) in accordance with the demands of the customer.

2.2. Grids – Net Wall

Can a simple garden grid made of plastic, with rigid knots, be a building block for a surface of a complex geometry? One of the research teams sought for the answer to this question. In a step-by-step study of the material and shape, the focus was on the issues of translucency of the proposed wall, depending on the number of overlapping layers of a grid. Having determined the boundary conditions when bending the material, corrugation of the grid began. The intention was to prepare a wall from one piece of the material. First, studies of the form were performed on pieces of cardboard, to draw up a protocol of the process therefrom, which was used to write an appropriate algorithm. Based on the collected parameters on the shape and material, first, 3D geometric model was generated using Rhino Grasshopper application, visualizations were drawn up in the Rhino program, taking into account the color of the material and its texture. The result was a self-supporting corrugated wall with a continuous surface, consisting of two layers of the garden grid, which may be made of a single piece of material. Due to its aesthetic values and the material used, the best environment for this type of form would be natural parkland and recreational facilities.

2.3. Tetrahedron Wall

Regular tetrahedron is composed of four congruent (the same) equilateral triangles. At each vertex, three equilateral triangles (3 edges) meet, which is written as (3,3,3). Tetrahedron has four vertices, six edges and four walls – it is the smallest and the most stable structural element which is easy in the topological notation. It is the tetrahedron, which is supposed to embody the principles of building, which Buckminster Fuller (1895-1983) found in Nature. Fuller's topological geometry based on the tetrahedron revolutionized the engineering thinking in the mid-twentieth century[4]. It broke the Cartesian-Newtonian view, which assumed that there were primary structures as well as the forces and mechanisms that caused their interaction. He proved that every structure should be understood as a manifestation of its relevant processes. These processes form a network of relationships that are dynamic by nature. How, then, to use the tetrahedron as a tectonic element structuring free surface?

The research work *Tetrahedron Wall* comprises a study of the shape and material for a free surface, in response to the possibilities of forming aluminum sheet of the thickness of 0.3 mm, used in the printing industry. Based on the regular tetrahedron, the study focused on finding spatial elements, which as constituents would provide the desired shape and stability, as well as aesthetic quality to the proposed wall. First, properties of the material were analyzed, its rigidity, crush resistance and aesthetic values of the surface. Then, the behavior of small metal strips was studied (corrugation, bending, folding) and the results were mapped in the language of geometry. A method of combining tetrahedral elements was sought, so that the performance of the structure corresponded to the characteristics of the shape of the previously modeled free surface. Also, a physical model of certain sequences of the design was made, which allowed for the evaluation and conclusions. As a result, an overlapping method of combining tetrahedrons was developed, which enabled the mapping of the shape of the modeled surface.

Collected parameters regarding the geometry made it possible to draw up a digital model using Rhino Grasshopper application. The resultant parametric model provided the dimensions needed to create the prototype, which is cutting out and assembling a certain number of tetrahedrons, diverse in terms of size, and arranging them in the correct order.

It turned out that the structure called *Tetrahedron Wall* made of a 0.3 mm thick sheet is sufficiently rigid and flexible at the same time, so that it can be used in the formation of the corrugated multipurpose surfaces. The recycled material can also be used, ensuring its repeated use. Thanks to its resistance to adverse weather conditions, the corrugated wall may

[4] see: Buckminster Fuller, E. J. Applewhite, *Synergetics: Explorations in the Geometry of Thinking*, Macmillan, New York, 1975 and Buckminster Fuller, E. J. Applewhite *Synergetics2: Explorations in the Geometry of Thinking*, Macmillan, New York, 1979.

also be located outside, as an element separating the space and used for microclimate modulation.

3. TENSEGRITY WALL

Tensegrity (tension and integrity) structures are meant to be the spatial systems, in which the mutual stabilization of the elements under tension and compression occurs. Spatial systems then consist of rigid components (typically rods, but also the three-dimensional elements) interconnected by means of flabby elements (taut ropes, thin rods, etc.). Rigid elements can not come into contact. The invention of such a design system is attributed to B. Fuller (1895-1983) and K. Snelson (born in 1927), who in the first half of the twentieth century experimented with spatial interaction of forces in building construction[5].

While building such a system, one of the research groups reached for simple translucent film for their wall to become an optical barrier. In a step-by-step study of the material and shape, the focus was on the issues of translucency of the designed wall, depending on the number of overlapping layers of film. Initially, the wall was to be built of "pillows" filled with water of various colors, but welding of the film and maintaining the stability of the wall turned out to be a problem. Apparently, the simplest idea would be to design a wall from one piece of the material. To improve its rigidity, experiments were carried out with wooden slats of a small cross section. Therefrom the idea was born of using the tensegrity system as a structural backbone on which material having a low coefficient of rigidity could be stretched. Having adopted such a way of thinking, first a physical model of the tensegrity module was developed, the variable size of which would allow to obtain the desired shape of the previously modeled free surface. Wooden bars and a plain string were used. Based on the collected parameters regarding the shape and material, as well as the record of the activities, a 3D geometric model was generated using Rhino Grasshopper application. The visualization was prepared in the Rhinoceros program, taking into account the color of the material and its texture. The result was a self-supporting corrugated wall of continuous surface, made up of spatial modules of different sizes covered with this film. Due to its aesthetic values and the material used, the best environment for this type of form would be natural parkland and recreational facilities.

CONCLUSIONS

By combining digital and analog design methods, a new approach to architectural design was developed. It is based on the study results of a material in terms of its formation possibilities. These results, translated into the language of geometry, introduced into the Rhino Grasshopper program, allowed to prepare digital material formations. 3D digital models were obtained, which were structural models at the same time. These are models in which the relationship between the material part and the whole form can be modulated parametrically. During the design and research experiments, a certain confrontation took place between the current "analog" design experiments (students) and the reality of modern computer tools in the formation of spatial structures. After all, attempts for tectonic considerations in the architectural design to become independent of the digital techniques is not a new concept in architecture.

However, the currently present extension of the CAD/CAM capabilities in modeling, fabrication and object implementation, resulted in focusing attention to those structural aspects of the design, which should translate into the form already at the beginning of the design process. This forces an architect, a builder and a contractor to come closer at the initial stage of the project. At the same time, it implies changes in architectural education and a need to improve the design tools.

REFERENCES

1. **Kolarevic B., Malkawi A.M. (2005)**, *Performative Architecture: Beyond Instrumentality*, Routledge.
2. **Hensel M., Menges A. (2006)**, *Material and Digital Design Synthesis*, AD, Vol. 76, No. 2.
3. **Hensel M., Menges A. (2006)**, *Morpho-ecologies*, AA Publications, London, 2006. pp. 82-86.
4. **Szymski, A.M. (2013)**, *Free surface and material. Parametric design at the Students' Research Laboratory at the Faculty of Architecture of Poznan University of Technology*, AV 3/2013, pp. 52-57 and AV 4/2013 pp. 52-56.
5. **Fuller B., Applewhite E.J. (1975)**, *Synergetics: Explorations in the Geometry of Thinking*, Macmillan, New York.
6. **Fuller B., Applewhite E.J. (1979)**, *Synergetics2: Explorations in the Geometry of Thinking*, Macmillan, New York.
7. **Fuller B. (1961)**, *Tensegrity*, Portfolio and Art News Annual, No. 4, pp. 21-26.

[5] see: Buckminster Fuller, *Tensegrity*, Portfolio and Art News Annual, No. 4, 1961, pp. 21-26.

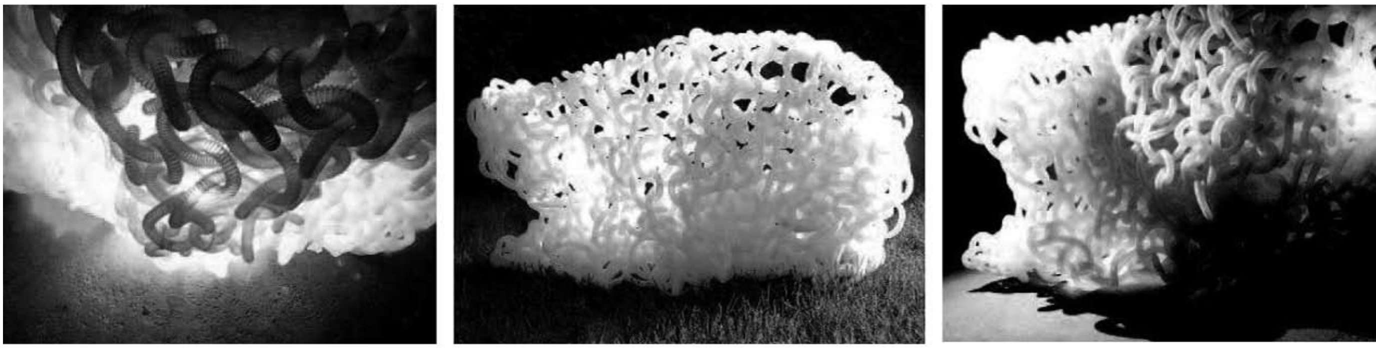

Fig.1. M. Korzec, D. Piechocińska, Sz. Nowakowski, *Knots*, 2013
Course Liders: Krystyna Januszkiewicz, Mateusz Zwierzycki, Faculty of Architecture (Research Laboratory of Parametric Design), Poznan University of Technology, Poland

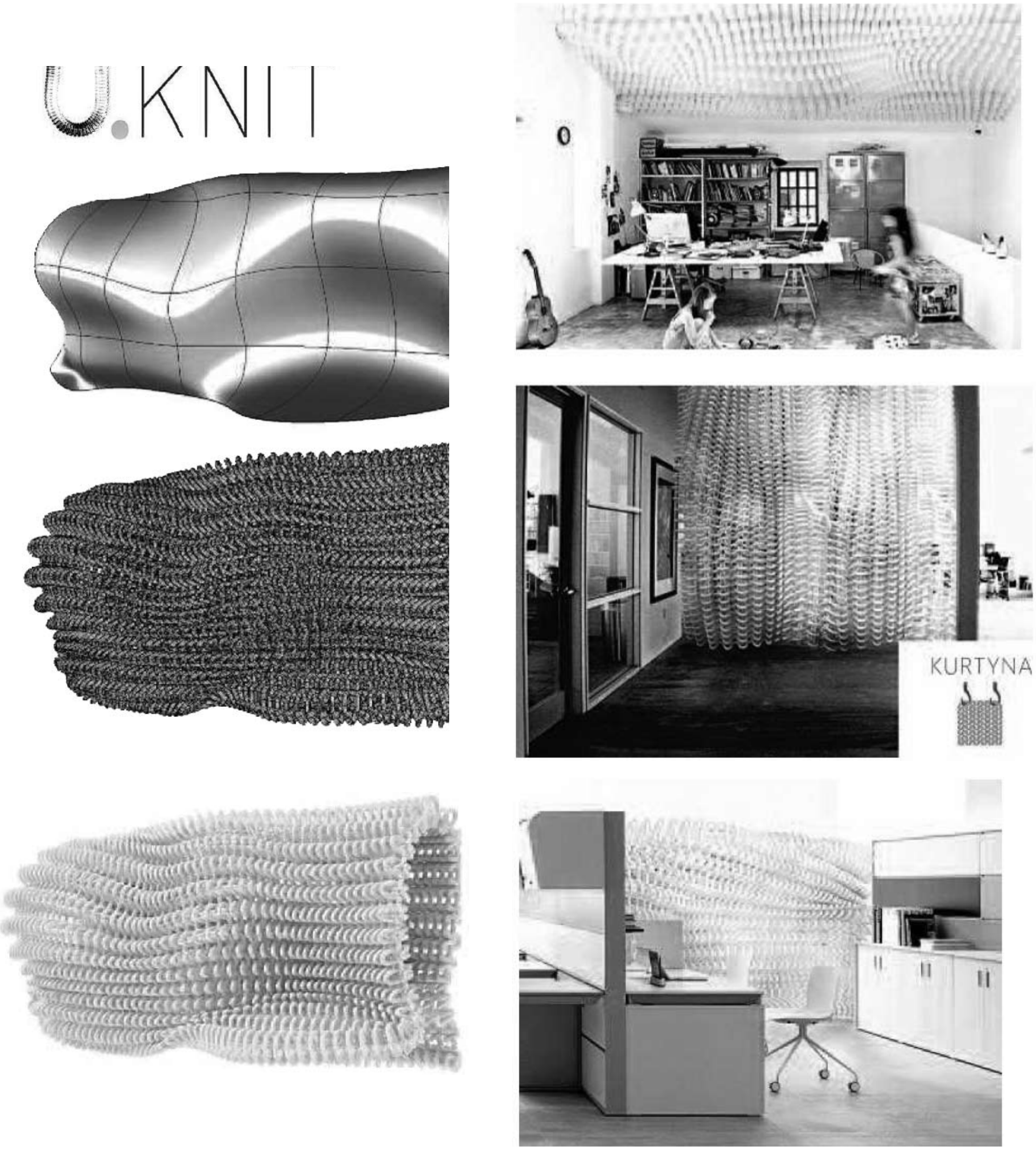

Fig. 2. M. Korzec, D. Piechocińska, Sz. Nowakowski, *Knots*, 2013
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