THE INTELLIGENCE OF ORNAMENTS: *Exploring ornamental ways of Affordable Non-Standard Building Envelopes*

HEIMO SCHIMEK, MILENA STAVRIC & ALBERT WILTSCHE

Institute of Architecture and Media, University of Technology, Graz, Austria
{schimek, mstavric, wiltsche}@tugraz.at

Abstract. The purpose of this research is to explore ornamental patterns which can be used to enhance materials characteristics in low-cost building envelopes. We use standard building materials (sheets of cross-laminated timber) and develop a parametric design framework for the assembly. Existing rules of ornamental geometry are applied to a parametric controlled structural model so as to endow the building parts both with stability and aesthetics. The concepts of mass customization and “File to factory” support the digital fabrication of a non-repetitive pattern in façade construction and lead to reduced construction costs and building time.

Keywords. Ornament, symmetry, parametric design, building shell, affordable non-standard architecture, mass customization.

1. Introduction

Ornamentation is the source of inspiration for this research we try to develop a framework in which ornamental patterns can be used intelligently i.e. that enhances the characteristics of a building material. Another motif is to establish a concept for the design of architectural features which can be easily handled despite a high degree of complexity being inherent in its geometry. The aesthetical concepts of ornamentation shall be translated into parameters which guide the design work. For resource efficiency and ecological reasons cross-laminated timber is used as jointing patterns as construction material in the project.

2. Ornaments in Architecture

Through the history of architecture the role and denotation of ornament was shaped by cultural, intellectual and technical development. The decreasing and increasing use of ornaments in architecture were linked to their use as superficial, mostly two-dimensional and symmetrical elements on the façade. The development from Speiser‘s exploration of ornament as a matter of symmetry (Speiser, 1927) to Shubnikov‘s analysis of the symmetry method for revealing the invariants of transformation (Shubnikov & Koptsik, 1974) to Semper‘s theory of ornament (Fröhlich, 1991) and Loos‘s opposition to it (Loos, 1997), to Moussavi‘s classification of the ornament based on depth material or effect (Moussavi, 2007) indicates the complexity of the different approaches to the subject-matter of ornamentation.

The continued use and development of ornaments indicates there is a specific psychological base for using ornamentation. We will try to explore the causally determined connection between ornament, symmetry-perception-beauty and ornaments and as the theoretical basis for the use of ornament in our project.

In psychology the aesthetic value of ornaments is related to symmetry. Experimental psychology has proved that people can recognize symmetric forms in less than in a twentieth of a second. The eye is very fast in the detection of vertical symmetry. Locher and Nadine (1993) have proved that after the recognition of symmetry the eye start seeking only the superfluous elements of the composition while the other part of composition is accepted. Symmetry is further related to our perception and perception is related to our sense of beauty. According to Hekkert (2006) design is considered beautiful or pleasing when a great effect is attained with a minimum of means and when our senses perceive this hidden structure.

Cognitive psychology and Gestalt psychology can explain our aesthetic positively reaction to ornaments. The brain tries to make a group of elements and to find a law of composition. According to Shubnikov & Koptsik (1972) the aesthetic effects resulting from the symmetry (or other law of composition) of an object lie in the psychic process associated with the discovery of its laws. According to Leder (2002) most people consider aesthetic what is plausible.

The beauty of ornamental pattern can be found in the rhythmical repetition of motifs with conspicuous dominants and a distinctively emphasised arsis. Ornaments underlie the architectural effects of buildings and are also vital for effects in the urban landscape. Developed in all historical epochs and in all cultural areas the ornament was always a unique manifestation of figurative experience in many primitive cultures, performing not only decorative but also a pronounced magic and symbolic function. As the ornament developed it went from natural motifs to stylization and further to strictly geometric shapes. It is often very hard to trace the singular geometric motifs and to decide if we are dealing with an intrinsic stylization of figural motifs or if they are primarily conceived as an abstract form.

The aesthetic effect of ornaments on buildings has been explored in various ways in history.

Ornaments on buildings were used in traditional society as an instrument of differentiation. The structural and functional requirements of a building, according to Semper (Fröhlich, 1991), were subordinated to the semiotic and artistic goals of ornamentations. In the twentieth century with Modernism the ornament lost its social function and became unnecessary. For Loos (1991) the modern society needs not to emphasize individuality through the buildings but on the contrary to suppress it. Modernism tried by means of style to adjust changes in culture. The relationship between the interior and the exterior of buildings had changed. Modernism used transparency to replace ornament to achieve a conductive representation of architectural elements of space, structure and program. In this “transparent” paradigm the function of architecture was visible and readable in the urban setting.

In 1970‘s Venturi and Brown (1966) formulated the critique of Modernism for the purpose of replacing transparency with décor. For them décor gives a building a new meaning in the eyes of the public and helps to integrate them in the urban setting.

Furthermore Deconstructivism, as a development in postmodern architecture, uses the geometry of collage as a style instead of transparency and decor. The finished visual appearance of deconstructivist buildings is characterised by a stimulating unpredictability and a controlled chaos.

Whether the ornament is used as a contingent - matter of décor and communication or a necessity like an effect or sensation - it is necessary and inseparable from the object.

Particularly new technologies in architecture have a huge influence on the further processing of the ornament as a non-standard element and new systems of production have opened up possibilities for their differentiation and customization.

In contemporary architecture we can find examples of contemporary ornaments like laser-cut sheets (Christian Dior Ginza Store, Kumiko Inui), glass tubes (Louis Vuitton Roppongi Hills Store, Jun Aoki), perforated screens (Centre du Monde Arabe,Jean Nouvel), color-coding effect (Laban Dance Center, Herzog & de Meuron) or silk screened images (Eberswalde Library, Herzog de Meuron, Thomas Ruff).

In our research we propose a screen-3d-ornament based on complex symmetry. In our proposed geometry, symmetry and order is the framework for creative design. Figure 1 shows one of the possibilities of form of infinite plane ornament.

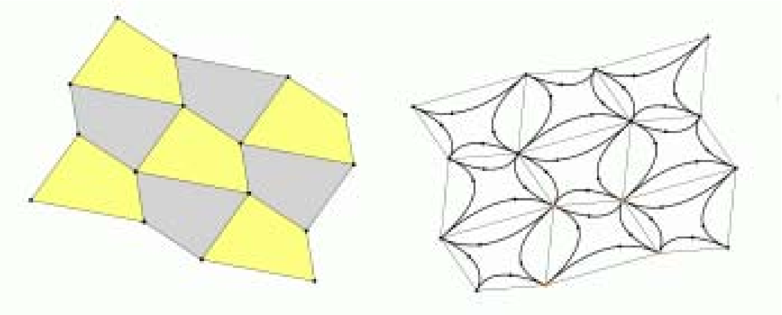

Figure 1. Part of the infinite space ornament with a whole series of regularities; symmetry + dissymmetry = harmony.

From the overwhelming pool of possible ornamental patterns we choose four-sided planes with symmetry of network pattern (Shubnikov & Koptsik, 1972). The ornamental pattern in our project has a maximum of four panels joining in each corner. This leads to a particular formal language given by a number of rules and constraints. The 2D-ornament becomes three dimensional by moving vertex points out of the plane into the space.

3. Materiality and Parameter Design

3.1. SUSTAINABLE STANDARD BUILDING MATERIAL

The province of Styria is a rich source of timber which has an excellent reputation as a sustainable and regenerative material. Both for that reason plus the fact that timber can be perfectly processed with a large variety of tools including CNC milling machines we are working with timber constructions (boards) with large and heavy members. Hence that means dealing with high forces which require geometrically exact and often complex joints, which we wanted to push to a high degree of automation in the design process.

In a first stage we are using glued extruded polystyrol foam panels as building material to prove the theoretical concept in a cost efficient way. Once our theory has been verified we will work with KLH solid cross-laminated timber boards with various thicknesses (100 – 250 mm) using high performance glue for the connections. The starting material for the production of KLH solid timber boards is the side-wood, as it is known, from trunk edge zones of Austrian spruce. Cross-laminated timber is produced from spruce strips that are crosswise stacked on top of each other. Depending on application or static requirements, 3, 5, 7 or more layers are stacked on top of each other, up to a maximum thickness of 600 mm.

3.2. CONSTRUCTIVE PARAMETRIC DESIGN

Our objective was to generate a digital parametric model for a geometrically non-standard structure based on 2D-ornament which develops into a 3D form by dragging vertex points out of the planimetry.

Rules of the default ornament – four irregular rectangles intersect at a time and vertex point manipulation in space need not lead to non-planar faces - raised the following questions: How can we translate the chosen ornament into parameters? How can continuity be guaranteed when altering the geometry? The problem was that a material of a certain thickness has to be perfectly mitred so that all of the four panels intersect in exactly one straight line. At the same time the control model has to restrict the panel size to a given size.

Through experiments we investigated how to establish a method within the digital workflow what is closely related to an architects way to design - intuitive and with a high degree of freedom (influence the geometry directly rather than use dimensionally driven design) to handle a non-standard form. Non-standard means joining planar boards with non-orthogonal angles resulting in the mitering of each edge with arbitrary angles. With geometric and constructive rules and constraints implemented in the digital model we achieved to produce adaptations to geometry and construction automatically. The architect is no longer handicapped by constantly thinking of the constructive consequences by changes of the design. In the background the model generates the data later used for digital reproduction.

It has become obvious that generating the parametric model takes the most time within the design process. Geometrical problems have to be solved through defining appropriate constraints and rules, more pragmatic considerations concerned the panel size what had to be limited to standard dimensions. Additional constraints were given through the tools – we work with a standard 3-axis-router and there is no way to perform undercuts with that kind of miller, consequently we are abusing" a 3-axis CNC-miller as a 4 axis machine which had to result in constraints of the angles of the undercuts. How can 3-axis do a 4 axis job? For that we used a custom made milling cutter and a custom scripted G-code to run the machine what will be explained later in this paper.

A project where the concept of Architectural parametric design has been employed very successfully is the Hessing Cockpit building within the alliance of an acoustic barrier in Utrecht, Holland (Figure 2).

Figure 2. Oosterhuis, Hessing Cockpit Building, Utrecht 2005.

Sander Boer and Kas Oosterhuis proposed one parameterized universal detail for the whole structure – One building, One detail (S. Boer, 2005). Boer/Oosterhuis provided a control model to the contractors which allowed them to build all constructive details on top of this control structure. The concept was proved to be possible by the realization of the project.

3.3. RULES AND CONSTRAINTS

We employed the MCAD-software tool SolidWorks not only because of its feature based design abilities of parametrically changing the model but also to have a common interface to directly communicate with the CAM module and a potential client or contractor and vice versa. Since every party is using the same parameterized digital model communication performs smoothly almost without any loss of data.

Usually SolidWorks is used as a Bottom-Up design tool where individually designed parts are assembled into a collective model. In our approach we integrate single part files in the assembly file containing a underlying control model (Figure 3). This method is commonly known as Top-Down process. A feature based control model enables us to easily control geometry on a highly complex level. Inside the assembly we can take advantage of the full power of the assemblies modeling features. Design alterations are achieved through changes of the geometry by dragging vertex points of the construction grid in space to adjust the form which instantly influences the subcomponents (panels) attached to the governing geometry as variations of a single part.

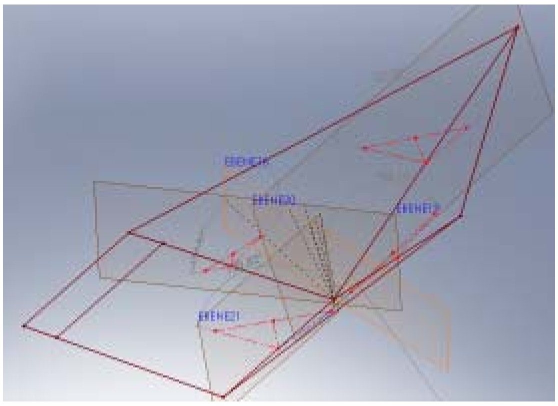

Figure 3. Section of Control model with symmetry cutting planes (Ebene18-21).

This enables us to reach a high level of automation of the design process. Changes of the geometry immediately trigger necessary adaptations to the details that are the base for manufacturing in the sense a mass customization process. However we established the following parameters (dependencies, rules and constraints):

In the assembly file

• panel size restriction
dependent on standard panel size (600x1200 mm) → geometrical based rules + dimensionally driven restriction through equations in Visual Basic ("D1@Skizze1" = IIF("D1@Skizze1"> length(width) value, value, "D1@Skizze1")
• Restriction of angles between panels
given through the limitation of machine capacity → dimensionally driven restriction through equations in Visual Basic ("D2@Skizze1" = IIF("D2@Skizze1">angle value, value, "D2@Skizze1")
• Secure planarity of 4-edged faces
when vertex points are moved → geometrical based rules and constraints
• Symmetrical planes
depending on the inclination angle between neighboring faces (eventually used as cutting planes for panels) → geometrical based rules and constraints (figure 4)

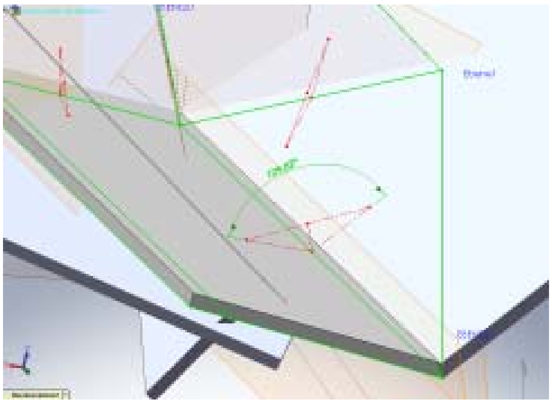

Figure 4. Mitering of boards using cutting planes.

In the part file

- Solid model of the standard panel + variations (configurations) – parent-child principle. The configurations (children) of the parent panels are inserted in the assembly file using simple geometrical constraints congruent, co-linear on the control model (Figure 5)

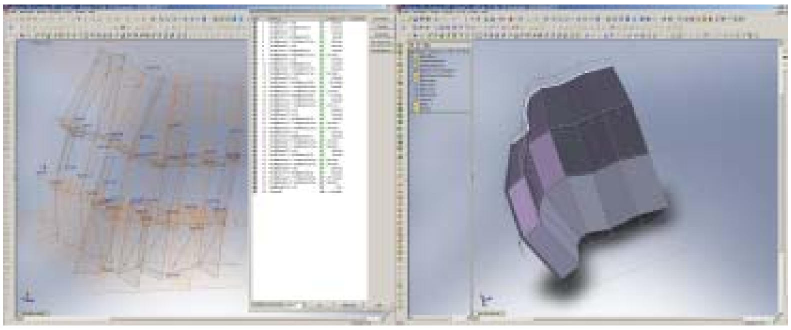

Figure 5. 3D sketch and virtual model in the assembly file.

3.4. DATA OUTPUT

We export geometric panel data from SolidWorks to a milling software tool which we programmed in Visual C++ to generate the G-code for the CNC-router. To support the physical assembly of the panels a variant parts list is generated and linked to consecutively numbered plan representation of each panel. Object orientated programming and class structures (hierarchies, members, inheritance, etc.) within C++ assist thereby the framework of our intelligent panels. Each “panel class” knows its position in space, its dimensions and its neighbors and so represents the intelligent ornament in a minor key.

In a first trial assembly we mounted about 20 boards which worked pretty well. Since the digital model delivers very accurate data only experiments with the KLH timber will eventually reveal how far we can push the precision tolerances to the limit in the physical assembly.

4. Tooling

We employ a standard 3-axis milling cutter to machine our panels because we want to produce our complex forms in a simple manner and with standard equipment. Moreover students should be enabled to handle with the machine within a workshop after short instructions.

Technical data available are a work space of about 2000 x 1000 mm, maximum spindle speed 20000 rpm and maximum feed rate of 2000 mm/min. In this type of machining the tool can move simultaneously in the direction of the x, y- and z-axes.

This limits the degrees of freedom compared to a 4- or 5-axis cutter. With a standard machine we can reach every point on the upper side of our boards. But it is impossible to mill objects with undercuts (Figure 6).

The untreated boards we use are on the scale of 1250x600x50 mm. For a perfect fit of the boards we have to mitre each board on all sides with arbitrary angles including undercuts.

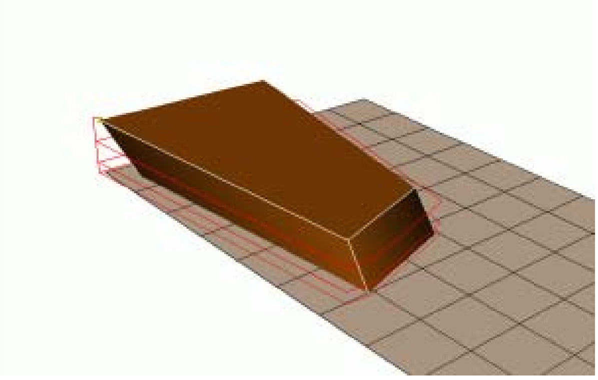

Figure 6. An undercut shape (arrow marked) cannot be milled with a standard 3-axis milling machine.

To achieve this we thought in the first stage to manufacture the pieces in two steps. First step is to mill the upper side and then turn the pieces upside down to perform the undercuts. This turned out to be almost impossible because we could not fix the panel in an exact position after the turnaround. Even if you use laser controlled machines there will always be an imprecision.

Eventually we decided to use a special cutting tool, namely a disk shaped cutter (Figure 7). It is customized from a regular buzz saw blade with a curved cutting edge at the outside of each of the twelve saw teeth.

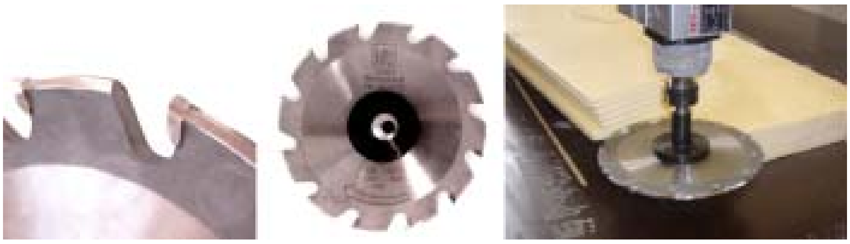

Figure 7. A disk shaped tool made of a regular saw blade.

Therewith we can mill limited regions in a certain area round the undercut (Figure 8). The limitation is given by the radius of the disk tool. Our disc shaped tool has a radius of 90mm and a cutting length of 6mm.

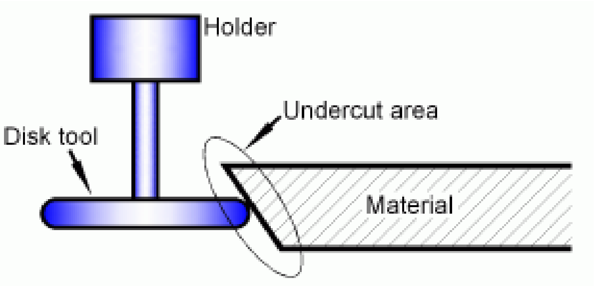

Figure 8. A disk shaped tool can mill undercut areas in a certain area.

In only one production step we are now able to manufacture all the mitres. We operate horizontal (waterline) milling in constant z-levels. In order to accelerate the work flow we first perform a roughing job with a standard milling tool. This job mill cuts the contour of the panel very quickly. Afterwards we can remove most of the unused material and the disk tool can move unobstructed. Due to the large radius of the disc tool we save time because much more material can be removed at once compared to a regular cutter.

Since standard milling software is not useful for our task it was necessary to produce our own software tool to control the cutter. We wrote a program in C++ to import data from the designing software (SolidWorks) to produce G-Code files and a visual interface to monitor the flow of work. G-Code files are text files to activate CNC-machines.

Figure 9 illustrates the tool paths together with a panel.

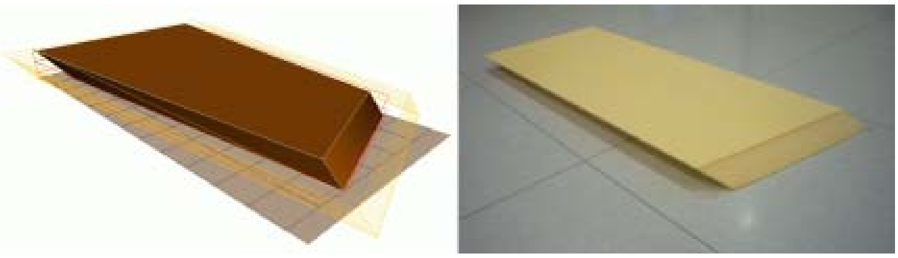

Figure 9. The panel and its tool paths.

Working time to mill one panel is about 25 minutes - if we expect an average quality. The roughing tool needs 2 – 3 minutes and the disk tool about 20 minutes. Better quality results in a higher number of tool paths which increases machining time.

One drawback is the waved shape of the milled faces (Figure 10). But as we join the panels right there no “visual damage” occurs.

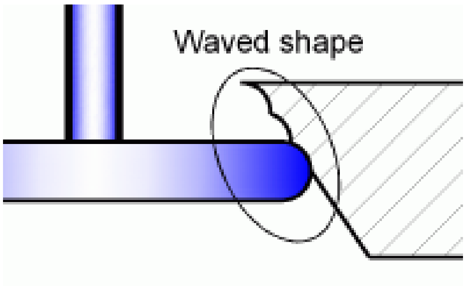

Figure 10. The disk tool mills “waved shaped” faces.

But overall it turned to be very time and cost efficient to “abuse” a 3-axis milling machine with a customized cutter for the production of a non-standard structure.

5. Conclusion

In our paper we presented a theoretical and practical concept and tools for the design of complex architectural features with standard building materials. After completion of the digital control model in SolidWorks incorporating all rules and constraints the model became very rigid which unintentionally constrained the open formability of the model. Nevertheless all parameters performed perfectly so that the targeted automation in the design process (CAD phase) was fully achieved. The milling process with the polystyrol test material showed enough accuracy for the joining. Further research will be the enhancement of the parameter structure what shall eventually lead to a higher degree of freedom in design.

Furthermore research will incorporate KLH as a partner to explore how our concept work with self-supporting space structures with cross-laminated timber.

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