The Redefinition of Ornament

Using Programming and CNC Manufacturing

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Abstract: Architectural ornament, the art of decorative patterning, is commonly perceived as an historical characteristic which declined in the beginning of the 20th century. The lecture of Adolf Loos in 1908 “Ornament and Crime” can certainly be seen as a crucial contribution in the architectural discussion about the exclusion of ornament. Although the modernist emphasis on unadorned form, the upcoming international style and the replacement of craftsmanship by the rise of mass production yielded to a systematic elimination of ornament, we are experiencing its revival in contemporary architecture through experiments using digital technologies. This paper describes our ongoing research and teaching activities in the field of architectural ornamentation, surface modeling and texturing, as well as the related CNC manufacturing processes.

1 INTRODUCTION

In our work, different course environments and research projects have been developed which deal with the production of ornament Using Computer Aided Architectural Design (CAAD) & Computer Aided Architectural Manufacturing (CAAM). In each case the working method focuses on the complete production cycle, from the generation of the digital ornament to its final production. This complete work process is important in our methodology as each of the stages is interdependent.

Digitally generated ornament equates well with the concepts of mass customization and CAAM production in architecture. Ornament declined dramatically in the late 1800s through the standardization of building components, due at first to the industrial revolution, and then subsequently to the rise of the modernist style. This reduction of ornament in architecture can be directly attributed to the intensification of machines in fabrication. It is therefore ironic that a return to ornament may be possible through the use of CAAD/CAAM technology. The creation of varied ornament, especially when it is programmed, is a good test for mass customization from an architectural perspective.

The fundamental principle upon which this work was undertaken is the importance of working at the 1:1 scale. The result of any manufacturing method will leave traces of how it was made. If these traces are to be exploited for an aesthetic value then it is important that these "artifacts" be viewed and evaluated at their true scale. Within the university context this goal of working at 1:1 obviously cannot be applied on complete buildings, but only on building components, assemblies, or objects at the furniture scale. This immediacy of scale and fabrication is another reason why we are dealing with the issue of ornament.

This paper is structured in three chapters. The first chapter discusses different approaches to the generation of digital ornament, the second outlines the procedures used in the production process, and the final chapter illustrates the processes with examples from courses and research and actual projects.

2 DIGITAL GENERATION OF SURFACES

In both research and teaching we have developed three ways to create digital surfaces. Different methods allow for varying levels of complexity, both in terms of the skill required to create a surface, and in the intricacy of the final product. Levels of complexity are especially important in the context of teaching. It is essential that students can understand and control the processes in a way that facilitates an expressive and creative output, and likewise more advanced levels of complexity are required for subtle manipulations and sophisticated generation concepts.

2.1 Modeled Surfaces

Modeling of surfaces in 3D CAD software is the easiest approach to creating an ornamented surface topology, and for architecture students also the most intuitive. This work typically begins with manipulation and transformation of a NURBS surface using the digital tools available in the software of the students choice. This process is a direct analogy to "sculpting" a surface into the desired form for output. Although this seems straightforward, it is already important at this digital stage to know and understand which fabrication process will be used for the project output.

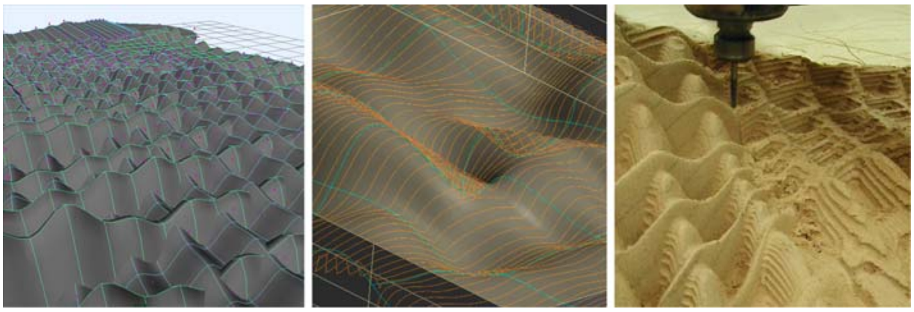

Figure 1 Surface modeling and production

Several different types of computer numerically controlled (CNC) machines are available, however most work is done on a 3-axis CNC milling machine. In 3-axis milling it is important to understand the constraints of the mill and how they affect the possible geometry of the piece (ex: undercutting). Other considerations include the selection & order of cutting tools, cutting path algorithms, and their parameters.

The desired surface quality is also an important issue to be considered. The choice of cutting tools and machining parameters will greatly influence the aesthetic quality of the surface. By controlling these parameters it is possible to accentuate and amplify textures that are a result of the machining process. If these textures were to be modeled digitally it would result in massive data files which are tedious to use in production. The resulting designed object is therefore a product of the entire process; the integration of the design with the production, and the output parameters.

2.2 Programmed Surfaces

The second approach uses programming to generate surface topologies and ornament. This method takes advantage of the computer as a numerical environment, and is a novel approach to the idea of contemporary ornament. The working approach to a project, including its requirements for input, output, and the type of geometry, all together determine which programming language and CAAD software package will be used.

The chosen software environment for teaching is MAYA, or specifically MEL (Maya Embedded Language). MAYA is an excellent teaching tool due to the interactive nature between the GUI and the MEL scripting editor. Typical programming techniques such as simple loops, parametric scripts, shape grammars, and genetic algorithms allow for different methods of surface generation.

Programming allows us to employ different mathematical concepts of geometry and topology in the description of surfaces. Considering the machining process, one will notice that the cutter of a mill is essentially sculpting a surface by following a line, or an organized series of lines. In several projects lines have been used as recursive geometric descriptions of a surface.

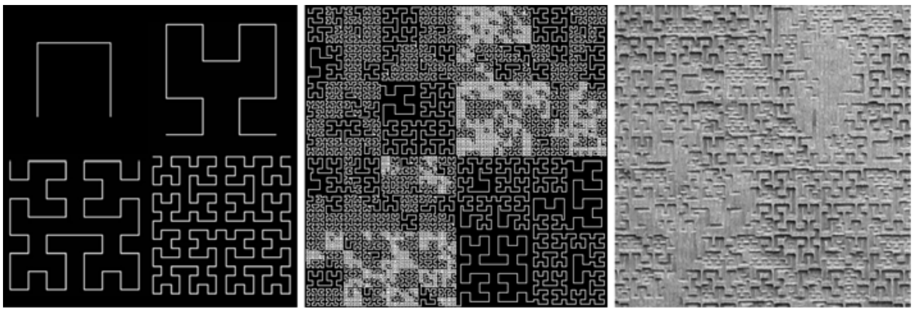

Figure 2 Surface scripting with Hilbert curve

The Hilbert curve (David Hilbert 1903) is an example of a plane filling curve; a fractal algorithm which fills a given area with a recursive line pattern. The interesting characteristic is that a single line describes a surface, yet it has inherent possibilities for controlled complexity. The Hilbert curve never intersects with itself, but also generates an interesting overall pattern. These features of space filling curves make them ideally suited to computer generated and manufactured ornamentation.

2.3 Image Derived Surfaces

The third method uses digital images as the preliminary data, which a program then analyses and translates into a digital topology or structure. This method has two significant advantages; first it allows us to work in an intuitive way with the images, using existing programs such as Photoshop, and secondly it allows us to use images of ornaments as input. In the book "The Language of Ornament", James Trilling states that "ornament comes from ornament". Historically, styles and ornament were catalogued, and these were used as the basis for most ornamented works. As the art-form of ornament has been in decline (at least in the western world) for the last century, it is then possible to use digital images of ornament (or other images), as if from an artisans catalogue, as the muse for the digital process.

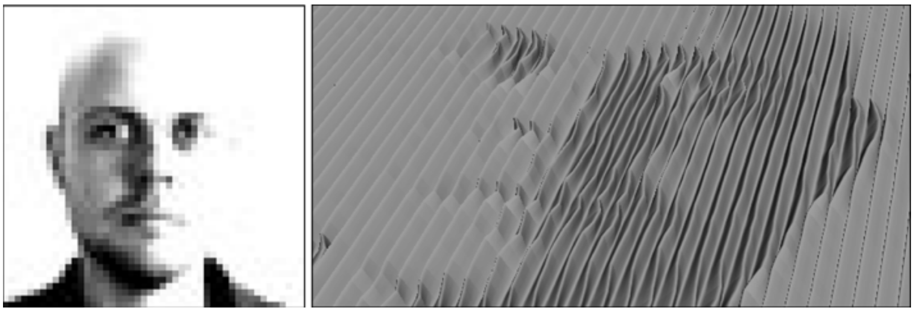

Figure 3 Translation of image into an undulated NURBS topology

It is important to note that this process is not about digitally reproducing an exact copy of the geometry from the image. It is rather about using the graphic impression of an original to translate a 2D representation into a new 3D surface topology. This process is composed of two steps: the digital interpretation of an image, and the translation of this image data into a producible surface.

2.3.1 Digital Interpretation of Images

The goal of this process is to extract a three-dimensional topology from a two-dimensional image of ornamentation. Photogrammetry can calculate and reproduce the exact surface geometry, however, this process is computationally complex and requires multiple images. What is of more concern in our process is not the precise geometry, but an accurate optical appearance of the ornament. Our methodology therefore uses concepts of photo-interpretation to develop a surface that delivers a similar optical impression. Image recognition is the process in which the brain interprets what is being seen by the eyes. If the image corresponds, or is closely related to a known condition from memory, the brain will interpret the image based on that known condition. When looking at an image of any surface topology, a viewer is therefore interpreting the relative pixel values, and reconstructing an impression of that 3D surface topology in their brain.

In our work we are making an analogous process within a digital process. By analyzing the image in three different ways we can extract different surface characteristics. At the smallest scale the texture of a surface is determined by large differentiation in the contrast of pixels within small areas, the “noise ratio”. On a smooth surface this noise ratio is small, and on a rough surface it is large. At a medium scale the overall gradient of pixels determines whether the surface is sloped, flat, high or low. Over the entire image simple optical recognition is looking for repeating patterns of contrast within a given threshold, effectively mapping out edges, tool traces, or other distinct features within the image. By combining the three processes of analysis and setting up logical rules for the relation between height and pixel brightness a topological system of vector lines or a surface can be directly generated.

2.3.2 Generation of Ornament

From the analysis of the image and from the parameters of the program we get a specific data set, this data set is then translated into a digital surface geometry. Knowing that the surfaces will be carved using a specific milling tool we can follow one of two approaches; either we can create a surface or series of surfaces, or we can create one or a set of lines to define the cutting pattern. When lines are used to define a surface there is a much greater aesthetic control over how the final surface will appear. As each line exactly defines the path of the cutter, the spacing and organization of the lines also therefore defines any “artifacting” or texturing. To define a surface topology the series of lines are spaced based upon the size of the cutting tool and the parameters of the machine. The most common method is to create a series of parallel lines and to deviate the cutting path in Z-height so as to define the topology. Other algorithms for defining a surface can also be used, such as progressive contour lining, spiral cutting, or block cutting. As mentioned previously, there are a number of mathematically defined recursive curves, such as the Hilbert, Peano, Wunderlich, and Moore’s curve that fulfill this criteria ideally.

3 THE CNC PRODUCTION PROCESS

Production using CAM is divided into two steps; the generation of Numerical Control (NC) machine code, and the manufacturing. In addition at this stage the material qualities in relation to the fabrication process will be an important issue.

3.1 Generation of the NC Machine Code

To physically fabricate a surface its geometry first needs to be defined as NC code for the specific CNC machine. This is often the point at which the students think the design exercise is finished, however the parameters and choices made in creating the NC code also affect the final piece, and should be seen as important design decisions. The creation of NC code is typically done using traditional CAM software such as SurfCAM or MasterCAM. The geometry is imported into the CAM program where the parameters for the cutting paths, the cutting tools, and the specific machine are defined.

The CAM software then outputs an NC-code file which is originally based on an HPGL plotter code, where the main difference is in the inclusion of a controlled Z-height. Because this code is very simple, sometimes this process is omitted and the NC code is generated directly from our scripted programs.

3.2 Computer Controlled Manufacturing

The final step in the process is the fabrication of the ornament on a CNC machine. Each machine has capabilities and constraints, however, constraints can be overcome creatively, and often lead to new techniques and new aesthetic output.

We are working with both a mid-sized model laser cutter, and a large industrial gas assisted laser cutter, however they are restricted to 2D profile cutting or surface etching of a material. A water-jet cutting machine; conceptually identical to the laser cutter, can be used to work with materials that cannot be cut with the laser. In addition we have a 3D-printer, which is not used in the ornament courses. The small 3D-printer does not allow us to work at the 1:1 scale and we are constrained to the plaster powder based material associated with this technology.

Figure 4 CNC machining and different materials

In most projects a 3-axis milling machine is used. For the fabrication of surfaces, and specifically of ornaments, the mill is appropriate as it is analogous to a "sculpting machine". It is a simple, proven, inexpensive, and robust technology. The constraints of a 3-axis mill reside in the fact that it cannot do undercuts. This limitation, is seen as a positive influence (especially in the teaching) as it forces additional reflection on the fabrication process while in the digital design stages.

CNC milling technology is relatively old, and as a result is more commonly available in industry. Although we are using machines common to other manufacturing industries we are approaching the processes in an unorthodox manner, and as a result the outcome is often novel and atypical.

3.3 Materials

The final consideration in the overall process is the material. Fabrication is a process of controlled stressing of material producing vibrations, internal stresses, and fractures which can cause unexpected damage to the piece while being manufactured. Consequently, it is important that the choice of material is suited to both the design and the fabrication process. The laser cutting machines are limited to materials that will be cut with high intensity energy. The waterjet-cutter can cut most other materials, but will stress or fracture brittle materials.

The CNC mill will cut most materials with sufficient internal rigidity. Typical architectural materials such as foam, plastic, lumber, engineered wood products, and Eternit (fiber reinforced concrete panels) are used for most projects.

4 EXAMPLES IN PRACTICE AND RESEARCH

Experimentation and experience play a key role in the successful fabrication of a piece. Our projects investigate the role of CAAD/CAAM in architectural ornament.

4.1 EternitOrnament

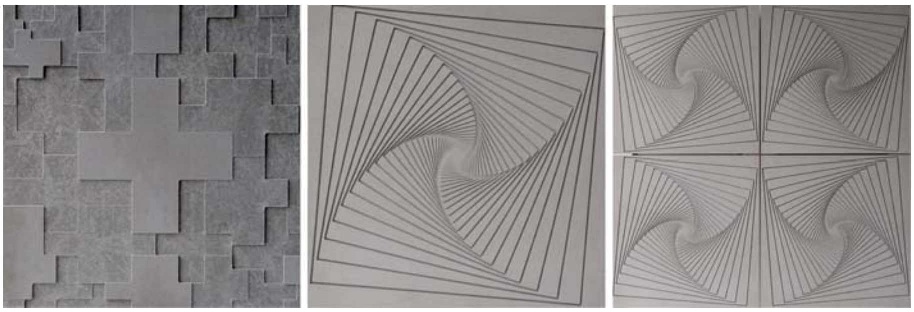

Figure 5 Samples from EternitOrnament

The focus of the course EternitOrnament was to develop programmed ornament that could be manufactured in Eternit so as to provide new expressive possibilities for the material. Students were encouraged to experiment with the various concepts of ornament from different cultures and histories in architecture. Different digital designs strategies emerged that were then augmented by variations in the manufacturing process. One student created a code for recursive geometries carved into Eternit cladding panels. By mirroring and rotating the pattern the overall wall attains an aesthetic akin to geometric Islamic tiling. A second student programmed variable sized water-jet cut openings in a paravant screen, which created ornamental patterns of shadow and light. The final products ranged from variations of wall cladding systems, to furniture, and signage. Many of the final products were included in the traveling exhibition "Eternit Architektur Preis03: Experiment Eternit".

4.2 The Rustizierer

The experimental project 'Rustizierer' is a reinterpretation of Gottfried Semper's rusticated and ornamented façades. The Rustizierer uses photo-interpretation of the original (manual) tool traces to translate the original stone-working patterns into algorithms. These algorithms were then used to generate the digital surfaces for fabrication using a CNC milling machine. The Rustizierer was part of the exhibition "Gottfried Semper, Architecture and Science" Museum für Gestaltung, in Zurich.

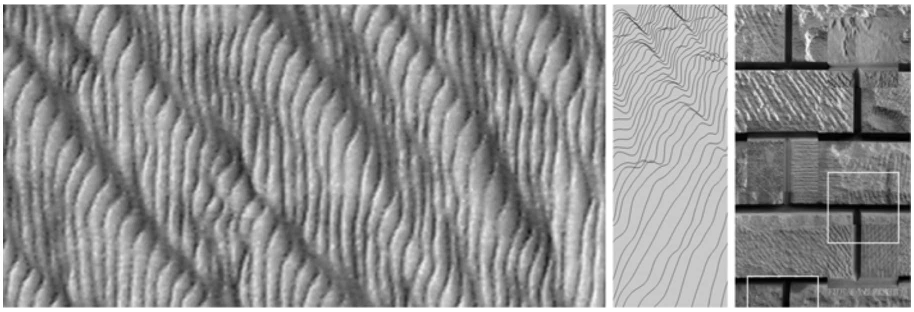

Figure 6 The Rustizierer project 2003

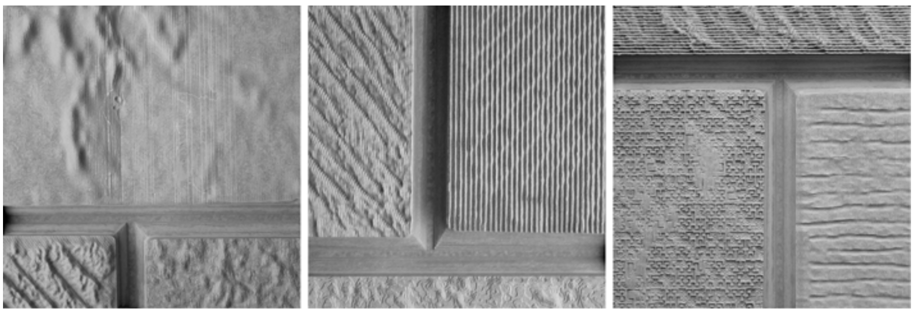

Figure 7 The Rustizierer, details of individual stones

4.3 Historical Building Facade

During the renovation of a historical building in central Zurich two exterior columns required structural work, and in the process the carved ornamented façades were required to be replaced. Due to its historical designation, the façade aesthetic had to be preserved. Our image based process was adapted to generate “wobbling” vertical vectors which vary in depth to recreate the appearance of the ornamental carving. The CNC-mill was used to fabricate a series of plates which were then used for casting in stainless steel. For the casting process it was important that the molten metal could easily “flow” over the complete surface. The foundry specified the minimum sizes for the profile of the ornamental grooves, these parameters were then used to retroactively define the entire design and subsequent production process. The resulting pieces and process received approval and praise from the Zurich Historical Board.

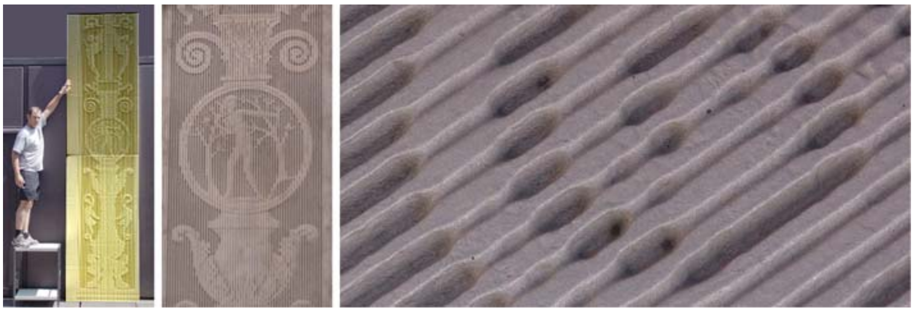

Figure 8 HBF project 2004

5 CONCLUSIONS

Digitally generated ornament is developed here to exemplify the concepts of mass customization within the context of architectural design. Mass customization and individualized fabrication are becoming more common. The inclusion of parametric design in architecture will continue to grow as the architectural role of the computer evolves. The combination of CAAD/CAAM technologies will continue to challenge the traditions of architecture, and engage the architects that play an active role in the entire process.

Contemporary forms of ornament can already be seen to be making a return. The pictorial or narrative surfaces of Herzog & deMeuron and Francis Soler use large appliqué images to enliven the surfaces of their buildings. The printed images remain two dimensional but they act with the same intent as Semper’s rustication and ornamentation, to enliven, communicate, and differentiate the façade. The possibilities for integrating the ornament directly into the design and materiality of the architecture can easily be seen as a next step in this development. By adding a third dimension to the ornament the architecture regains its active play of light, shadow, and optical effects, allowing for direct communication with the viewer in a highly specialized and controlled manner.

The projects presented within this paper seek to engage this advanced technology in both the design and fabrication of a historically significant part of architecture: Ornament. The availability of skilled workers, specifically in the historical restoration and preservation sector continues to diminish. The benefits of this work lie in the ability to generate ornament efficiently, and also to re-generate ornament and styles in some cases only preserved in archival images.

The merits of this research, as well as the software and processes are continuously evolving. This process presents a contemporary approach to a traditional art that has been successfully applied in the restoration of a historic building. The results thus far continue to be positive, and several further projects to push this research further are in progress.

REFERENCES

Cache, B. 1995. *Earth Moves: The furnishing of Territories*. Cambridge: MIT Press.

Deluez, G. 1988. *Le Pli: Leibniz et le Baroque*. Paris: Edition de Minuit.

Imperiale, A. 2000. *New Flatness: Surface Tension in Digital Architecture*. Basel: Birkhaüser.

Kolarevic, B. 2003. *Architecture in the Digital Age: Design and Manufacturing*. London: Spon Press.

Loveridge, R., and Strehlke, K. 2004. The Rustizierer: A dimensional translation of antiquity into technology. In *TransLate*: Trans vol 12. ed. H. Bindl: 52-59. Zurich: GTA Verlag - ETH Press.

Sharples, Holden, Pasquarelli. 2003. Versioning: Evolutionary Techniques in Architecture. *Architectural Design* 72(5). London: Wiley Academy.

Staub, N. 2003. Semper's stronghold of education. In *ETH Life* vol 080103. Zuerich: ETH press.

Strothotte, T. 1997. *Seeing Between the Pixels: Pictures in Interactive Systems*. Berlin: Springer.

Trilling, J. 2001. *The Language of Ornament.* London: Thames and Hudson.

Tufte, E.R. 1990. *Envisioning Information*. Connecticut: Graphic Press.