IJAC 4-1_final 4/4/06 12:20 pm Page 33

The Digital Ornament using CAAD/CAAM Technologies

Russell Loveridge and Kai Strehlke

The Digital Ornament using CAAD/CAAM Technologies

Russell Loveridge and Kai Strehlke

New digital technologies are challenging the traditions of the architectural design methodology, the relationship between context and design, and the dependency on skilled workmanship for the fabrication of beautiful and complex architecture. Intellectually, applications of digital technologies are also allowing for the reinvestigation, reinterpretation, and redevelopment of historical concepts, theories, and skills[1]. Our focus of ornament in this paper is presented as a constrained architectural testing ground, a reduced issue that still addresses the primary issues of geometry, aesthetics, individualism, and the transferal of design to materiality. Our work on digital ornament combines the traditionally intuitive skills of geometric & graphic manipulations with easily edited input (variables and digital images), control through parametric programming, and automated output (CNC manufacturing). The combination of these processes allows for efficient diversity and uniqueness of design, while also compensating for the increasing cost and declining availability of skilled artisans for the physical fabrication. The presented projects in teaching, research, and professional activities demonstrate our ongoing experiments with new technologies of programmed surface modeling and computer numerically controlled manufacturing (CNC manufacturing). This work has been incorporated in real world projects, both in the revitalization historic buildings, and in new applications of ornament in contemporary architecture.

Keywords: 3D modeling, parametric design, image processing, design education, CAM

1. Introduction

Architectural ornament, the art of decorative patterning, is commonly perceived as an historical characteristic of architecture, which declined in the beginning of the 20th century. The lecture of Adolf Loos in 1908 "Ornament and Crime" [2] can certainly be seen as a crucial contribution in the architectural discussion about the exclusion of ornament. This modernist emphasis on unadorned form, combined with the upcoming international style and the replacement of craftsmanship by the rise of mass production yielded a systematic elimination of ornament. The resulting relationship between architects and the public has become sometimes confusing. Architects are expected to employ current engineering, materials, and technologies, in the creation of "beautiful" design, however the general public most often reveres the ornamented characteristics of historical architecture. New and improved are not always considered "good architecture" to the common man.

A frequent critique of modernist or standardized architecture is that it is "boring", or it lacks character. By contrast historical, religious, and cultural architecture embellished with ornamentation, express character and can reveal the relationship between advances in technology and materiality and the resulting evolution of that society. Above all the ornamental narrative is visible, impressive, and appreciated by the public.

The ability to efficiently create an expressive architecture, one that has "character", is now however more often limited by economics than by design or style. By developing more efficient concepts and methods for design and by rationalizing the entire process of design-fabrication-construction, we are working towards a more efficient, and therefore flexible architectural process. Fostering this rational and creative approach to ornament and architecture requires a combination of new concepts of design and new technologies, with an acceptance and acknowledgement of the successes of the architectural past.

> "From the maker's standpoint, the revival of ornament means a new approach to accustom materials and techniques: a new level of control, a repertory of patterns to learn, a new understanding of the relation between the functional and decorative form." [3]

2. The re-introduction of ornament

Applications of digital technologies into the traditional realm of architecture have thus far focused mostly on developing large-scale geometry solutions, and project representation. In our work, we are examining the use of digital technologies, and specifically the application of programming in computer aided architectural design (CAAD) and computer aided architectural manufacturing (CAAM) to work at the aesthetic, detail, and tactile scales of architecture. Different processes have been developed to create components using different types of data or digital input, however, in each case the working method focuses on the complete production cycle, from the generation of the digital geometry to its final manufacturing. This complete work process is important in our methodology as each of the stages is interdependent.

Recent increases in the availability of Computer Numerically Controlled (CNC) manufacturing technology, and the subsequent and decrease in cost has made it possible for architects to consider using CAM in every-day architectural projects. The advantage to using CAM when combined with programmed and generated digital geometry is the ability to efficiently generate and fabricate variations as output.

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.

Digitally generated ornament has a somewhat ironic relationship to the concepts of mass customization and CAAM production. Ornament and its role in architecture declined dramatically in the late 1800s through the standardization of building components. This was firstly due to the mechanization of the industrial revolution, and then subsequently, and more directly to the (afore mentioned) rise of the resulting modernist style. This reduction of ornament in architecture can be directly attributed to the intensification of machines in fabrication. It is therefore paradoxical that a return to ornament may be possible through the use of CAAD/CAAM technology.

3. Digital generation of surfaces

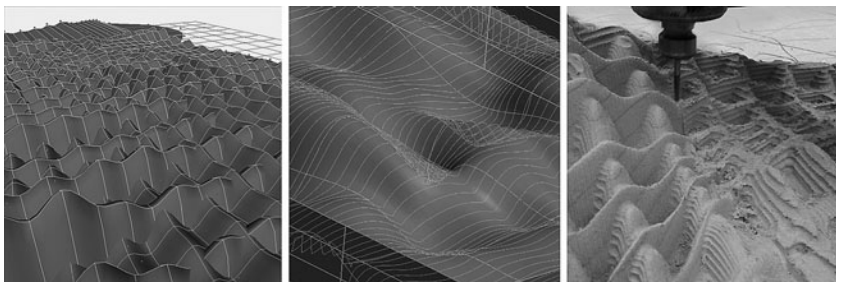
We have developed three primary methods for the creation of digital surfaces. These different methods allow for varying levels of complexity, both in terms of the skill required to create a surface, and in the intricacy of the final product. Complexity, in a design project, is defined as the balance between added design and added construction content, or more precisely:

> "the number of required design decisions relative to the scale of the project" [4].

To achieve a high level of efficiency in a project, it is desirable to minimize the amount of design labor, while maximizing the flexibility and effectiveness of the fabrication processes. To obtain higher degrees of subtlety and flexibility, either more design work must be invested, or another method must be found to increase the efficiency of labor in the design process. Conversely different levels of complexity make early allowances for a logical user learning curve, and distinct differentiation in the ease of use. The three methods of surface creation presented here use progressively more complex CAAD programming to generate progressively more controlled, and complex output.

3.1. 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. NURBS surfaces can be manipulated or transformed using the digital tools available in CAAD and animation software. The use of NURBS surfaces allows for a high degree of manipulability while bringing a direct analogy to the "sculpting" of a surface 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 and order of cutting tools, cutting path algorithms, and their parameters.

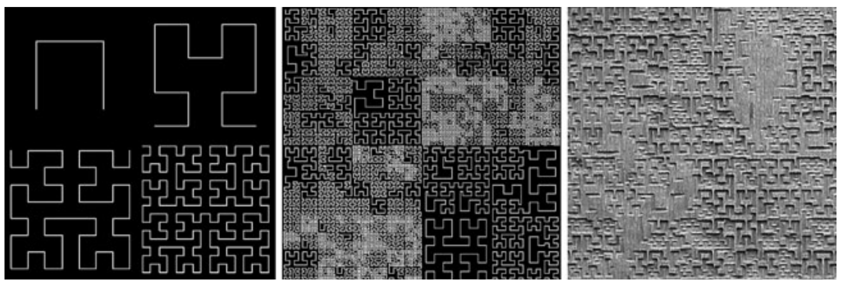
The desired surface quality is also an important issue to be considered. The choice of cutting tools and machining parameters will greatly influence the aesthetic quality of the surface. By controlling these parameters it is possible to accentuate and amplify textures that are a result of the machining 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.

3.2. Programmed surfaces

The second approach uses programming to generate surface topologies and ornament. This method takes advantage of the computer as a numerical machine, 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.



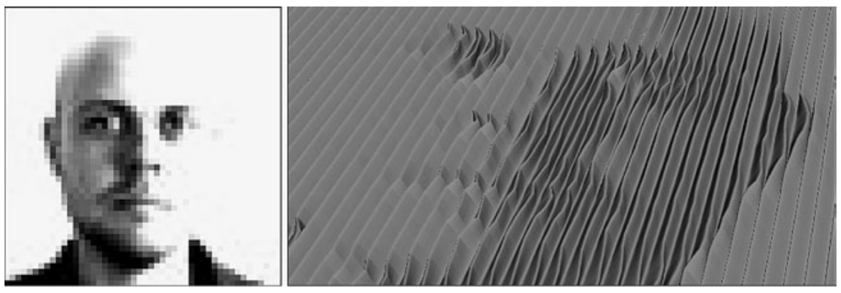
◀ Figure 2. Surface scripting with Hilbert curve

The Hilbert curve (David Hilbert, 1903) [5] 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 plane filling curves make them ideally suited to computer generated and manufactured ornamentation.

3.3. Image derived surfaces

The third method uses digital images as the initial 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 (or other pictorial muse for ornament) as input.

In the book "the Language of Ornament", James Trilling [3] states that "ornament comes from ornament". Historically, styles and ornament were catalogued, and these were used as the basis for generating most other new ornamented works. The carpenter would begin with a style from a catalogue, and as he worked might make changes and variations, which in turn could be then catalogues as a variation on the style. This is an analogy to the concept of "versioning" [6], the creation of a parametrically variable ornament. The use of these ancient catalogues, and specifically the logical descriptions and images contained within, can be used as a starting point for digitally generated ornament. As the skill of creating ornament has been in decline (at least in the western world) for the last century new techniques for creating ornament may be required. The use of digital fabrication technology, which can be programmed to "sculpt" ornament using similar (albeit simulated) techniques of carving, is a possible and efficient alternative. With image derived surface CAAD it is then possible to use historic catalogues or digital images of existing real (physical) ornament, as the genetic code for the digital process.



► Figure 3. Translation of image into an undulated NURBS topology

It is important to note that the processes developed here are not about digitally reproducing an exact copy of the original geometry from the object in the image. The processes are rather about using the pictorial impression of an original to translate a 2d representation into a new 3d surface topology. The goal is to produce a surface which is a representative "visual" reproduction of the image, and not a duplication of the geometry. This process is composed of 2 steps: the digital interpretation of an image, and the translation of this image data into a producible surface.

Digital interpretation of images

The goal of the image interpretation process is to extract a three-dimensional topology from a two-dimensional image of ornamentation. Photogrametry can calculate and reproduce the exact surface geometry; however, this process is computationally complex and requires multiple images. Likewise, laser or lidar scanning can survey and measure a given object or surface to an incredible degree of precision, however it too requires specialized equipment, skilled operators, and a large degree of postprocessing. What is of more concern in our process is not the precise geometry, but an accurate optical appearance of the ornament.

Digital photo-interpretation is a series of procedures which are run using the data of a digital image to develop a surface topology that delivers an similar optical impression. The basis for our photo-interpretation programming comes from an understanding of the physiological and psychological components of image recognition. 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. (This is, for example, why we can interpret and understand an aerial photograph of the ground, even though we are not typically used to viewing the countryside from several kilometers in the air.)

Advances in technology, and exposure to new and different forms of media have radically changed the way that most people interpret images today. In early cinema, film patrons were scared out of the movie theater because of projected images of an oncoming train. In the classic adaptation of King Kong [7], the movie about a giant ape loose in New York, the special effects were clearly out of scale and proportion, yet as the effect was new at the time the audience's interpretation of the film was to accept the scenography. With contemporary digital media, and an audience that has been exposed to more contemporary imaging, new styles of images or visual representation are valid. As the awareness and perception of viewers change the styles and media can also evolve.

◀ Figure 4. Images that are now understandable due to visual experience

When a viewer is interpreting a surface topology, the process is similar to the deconstruction of a digital image. The viewer (unconsciously) interprets changes in light, contrast, and reconstructs 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 and its pixel values 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.

Generation of ornament

From the analysis of the pixel values, the contrasting blocks, pattern recognition, and from the controlling parameters of the program, a specific data set is generated. 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 generating a surface from the data it is important to rationalize the geometry of the surface to avoid irregular incidents that can result from too much "noise" in the data. Noise in the form of rollovers, blebs, and loops can occur if there is an extreme change in the frequency or value of a point within a greater series. Although the surface may be continuous, the resulting g-code translation may be problematic.

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 [8] that fulfill this criteria ideally.

4. Manipulating the process

In addition to creating ornament directly from images, we as designers are then interested in how we can manipulate and affect the process efficiently. Because the generative process is derived directly from images we have a unique opportunity for manipulation using photo-editing software. Programs such as Photoshop, or Corel provide this process with an incredibly robust GUI –or interface, to directly affect the generated surfaces. With a knowledge of how the interpretation program is working, the user can directly manipulate three-dimensional parameters using the standard set of images adjustments. An example of this is the simple adjustment of contrast, if the degree of black (Kvalue) determines the depth of cutting, then by increasing the contrast of an image there will be more deep cutting and less mid-range detail. Likewise, by adding or decreasing the noise of the image (a filter in photoshop) the surface texture can be increased or decreased.

◀ Figure 5. An original image versus two image based manipulations and their milled output

The flexibility of the image interpretation programming is that the programmer can "design" how a specific visual parameter can affect the 3d-topology. The benefit to the architect is that they may not be an expert in programming, however most architects can intuitively learn how to use image editing software.

5. 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.

5.1. 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.

5.2. 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 6. 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. The typical use for these machines is the production of engineered parts though exacting geometrical and functional specifications. 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. Our approach disregards the traditional practices of CNC machining, and focuses on developing patterns and ornamentation with an aesthetic which is partly geometrically defined, and partly emerging from the machining processes.

5.3. 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.

5.4. The design-fabrication cycle

There is an intrinsic correlation between these issues of design, output data, production parameters, machining processes, materials, and the desired qualities of the final product. Manipulating one or many of these parameters can influence the product and the balance between flexibility for creative design, and procedural rationalization. Repeated experimentation with the multitude of project parameters therefore brings experience and an intuitive understanding of their effect on the final product. Iterative experimentation is facilitated and accelerated due to the automated algorithmic processes, however interesting (and sometimes unexpected) byproduct can result through an "informed playing" with parameters. It is important to analyze, critique and reinvest results from each iteration into the overall process, to the end goal of both rationalization and creativity.

6. 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.

6.1. Window shields

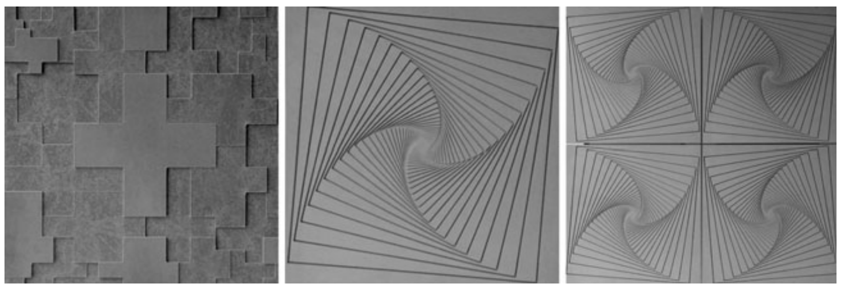
◀ Figure 7. Window shields project 2005

After a break-in in several apartments of an old apartment building – from its internal main staircase, preventative measures had to be found to increase security at this weak point. The design solution was to develop a secure window shield, where the conflicting requirements of security vs. light could also be fulfilled. In addition the shields would need to be fitted into the existing frame, and as the building is over 100 years old and had settled, the window openings were no longer square. A customized approach would be required for each of the four floors.

Inspired by the stair and balcony railings details; a series of four different patterns where uniquely designed from the measured data of the openings, and the image of the railings. The patterns were generated from high contrast images of the iron-work, and modified for the strength and stability of the chosen material: sheet steel. The data for the frames and patterns were then combined manually and laser cut into the steel plates to create new ornamented window shields.

Each window shield was then manipulated to be stable and secure, while maximizing the opening for light. This ornamental approach created shields which are based on the historical architectural style of the building, and fit within it almost imperceptibly.

6.2. EternitOrnament



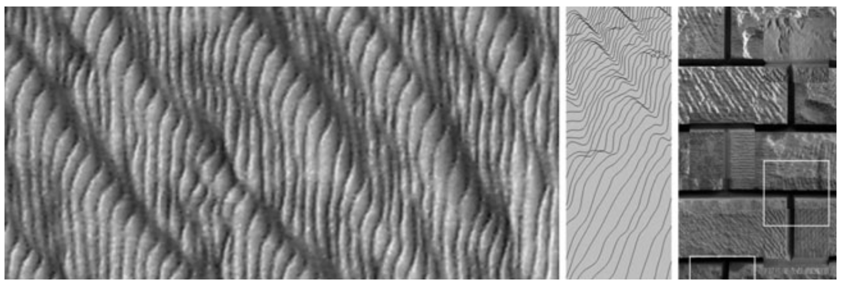
▶ Figure 8. Samples from EternitOrnament

The focus of the course EternitOrnament was to develop programmed ornament that could be manufactured in Eternit, a cellulose reinforced concrete panel material, 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.

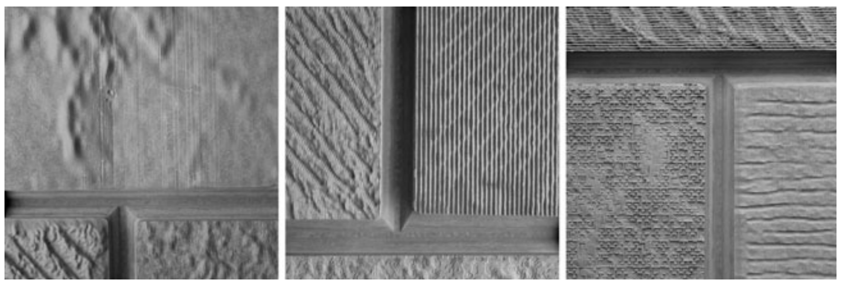
One student created a code for recursive geometries carved into Eternit cladding panels. By mirroring and rotating the pattern the overall wall attains an aesthetic akin to geometric Islamic tiling. A second student programmed variable sized water-jet cut openings in a paravant screen, which created 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" [9]

6.3. The Rustizierer

The experimental project 'Rustizierer' [10] 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 [11].



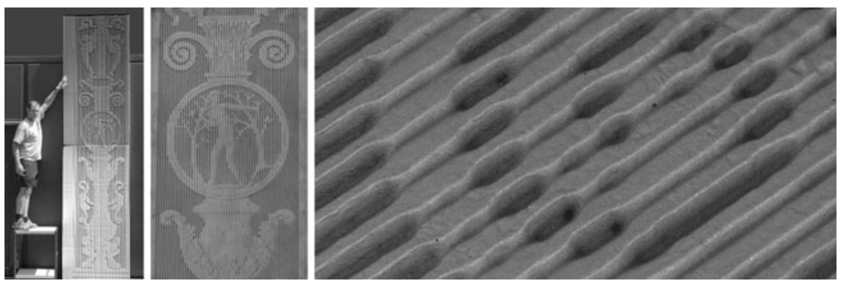
◀ Figure 9. The Rustizierer project 2003



◀ Figure 10. The Rustizierer, details of individual stones

6.4. 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 ornamented column façade aesthetic was required 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 creating castings 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 parameters which re-informed the subsequent production process. The resulting pieces and process received approval and praise from the Zurich Historical Board, and have been installed in the final renovations.



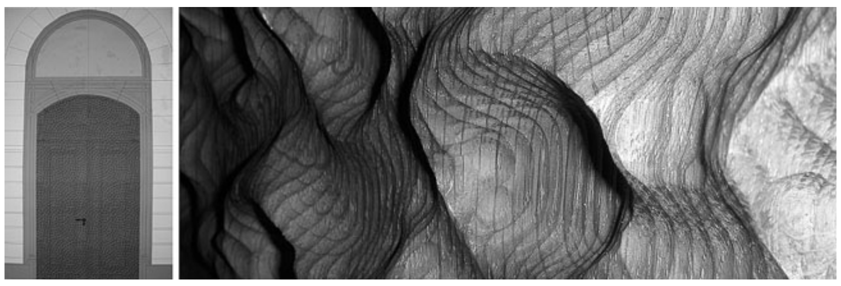
◀ Figure 11. Historical Building Facade project 2004

6.5. Swiss National Museum

Similar to the previous project, the Swiss National Museum in Zurich is undergoing a major renovation. In this process fire protection doors are to be incorporated in the main exhibition area, in openings where there have never been doors before. The previous renovation occurred about 100 years ago. At this time the Zurich school of design and craftsmanship was asked to develop floral ornaments for other doors which were designed and incorporated at that time. Christ & Gantenbein AG, the architects responsible for the present day renovations wanted to take up this theme and find a modern-day interpretation of floral ornament. The concept emerged to take photographs of plants and transform these images into three-dimensional ornaments. The chosen photographs were from Photographer Karl Blossfeld, who is recognized for having modernized the pictorial image of plants and biology. The theme for the project process therefore became the reinterpretation of plant based ornament through the overlaying of different technological translations.

Images of flower tissue, taken with a microscope, were chosen as the underlying structure for the ornament. The image provides the basic data to represent the complexity, harmony, patterns, repetition and variations found in nature. The aesthetic qualities of the complex natural structures were translated to a topology for fabrication. By varying the parameters the sharpness and texture of the design was controlled. The generated milling patterns are still an abstraction of both the actual 3d structure, and the image. The milled result is still analogous to the chiseling patterning of wood carving; similar to the 100 year old ornament. This is yet, another reason why we do not want a 1:1 photogrametric re-representation of the existing topology.

For fabrication, the g-code was further optimized. A second "filtering" script was developed to optimize the CNC machines movements, eliminating loops, and reducing loss of directional momentum, while also minimizing the differences to the surface. The goal for efficient fabrication was achieved through effective programming, giving the client a maximum of "ornament per hour" [U. Hirschberg] [12]. It was through these efforts that the project was possible, and allowed for the vision of the architects to be realized within the given budget.



▶ Figure 12. Landesmuseum project 2005

7. Conclusions

Digitally generated ornament can be seen to exemplify the concepts of mass customization within the context of architectural design. Traditionally every single architectural project was regarded as a unique or customized project crossing all scales, from the overall building design down to detailing, and the aesthetic and tactile role of ornament. Parametric or generative design in architecture is achievable with current office level computers; CNC fabrication machines are becoming more common and less expensive. The combination of CAAD/CAAM technologies will continue to challenge the traditions of architecture and construction, and engage the architects that play an active role in the entire process. Mass customization and individualized in architecture is achievable at the large scale, but may be more effective to develop initially at the smaller, ornament, scale.

Contemporary forms of ornament can already be seen to be making a return. The pictorial or narrative surfaces of Herzog & deMeuron and Francis Soler [13] use large 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 public and critical response to these designs is favorable, and acknowledges it as a first step towards an updated cultural iconography. 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 development of programmed, interpretive, surface or form generation also has potential to change the working methodology of architects. Programmed CAAD enables a designer to create parametric geometry that is easily variable. By managing the input data type so that it is more intuitive to designers the process becomes more manipulable and user friendly to "graphic professionals". By changing from numeric input values to the use of images as raw data, designers can use familiar software and create topological effects that a product of both the programming, and the designers ability to edit, alter, or even create images. This is an expansion of the ability to work in 3d, and as design or as artist, opens up an entire new palate of digital tools for 3d design.

The architect through the use of these tools could play a more prominent role in the creation of architecture. By experimenting and understanding the technology, designers can manipulate the processes creatively to affect the results. Knowledge of the technique, as well as the technology, is integral to exploiting the "quirks" of the processes, and using the inherent qualities of each part of the process to reinforce the entire methodology.

The projects presented within this article 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 concepts as well as the software and processes of this research are continuously evolving, and are being applied in current real world projects. Although this research began with investigations at the small scale, the principles and programming were easily adapted to a larger building scale, specifically for customized building façade panels. The processes presented represent both a proof of concept for mass customization in architecture, and a contemporary approach to a traditional art.

References

1. Cache, B., *Earth Moves: The furnishing of Territories*, MIT Press, Cambridge, 1995.
2. Tournikiotis, P., *Adolf Loos*, Princeton Architectural Press, New York, 2003.
3. Trilling, J., *The Language of Ornament*, Thames and Hudson, London, 2001.
4. Mitchell, W.J., Constructing Complexity, in: Martens, B., Brown, A., eds., *Computer Aided Architectural Design Futures 2005*, Springer, Vienna, 2005.
5. Hilbert, D., Bernays, P., Toepell M., Grundlagen der Geometrie, Teubner, Germany, 2002.
6. Pasquarelli, S. H., *Versioning: Evolutionary Techniques in Architecture*, Wiley Academy, London, 2002.
7. http://www.imdb.com/title/tt0024216/ [15-11-2005]
8. http://www.cut-the-knot.org/do_you_know/dimension.shtml [18-11-2005]
9. http://www.ethlife.ethz.ch/articles/news/eternitpreis.html [18-11-2005]
10. Loveridge, R., Strehlke, K., in: Bindl, H., ed., The Rustizierer: A dimensional translation of antiquity into technology. *In TransLate: Trans vol 12*, GTA – ETH Press, Zurich, 52 -59.
11. http://www.museum-gestaltung.ch/ausstellungen/archiv.html [18-11-2005]
12. in conversation with U. Hirschberg
13. Imperiale, A., *New Flatness: Surface Tension in Digital Architecture,* Birkhäuser, Basel, 2000.

Russell Loveridge and Kai Strehlke,
Swiss Federal Institute of Technology Zurich, Department of Architecture, ETH Hoenggerberg, 8093 Zurich, Switzerland

loveridge@arch.ethz.ch
strehlke@arch.ethz.ch