ABSTRACT
The research presented aims at extending the framework in which contemporary architectural form and formal features are discussed. In the recent years we—the computational design community—have gained a plethora of methods for form genesis and highly articulate configurations. Still, there is a lack of assessing and discussing formal and configurational qualities. The rigor of these generative methods and the ambition to drive them along performative criteria (material, structure, environment, occupation, ergonomics, fabrication) mostly formulates a rational argument around quantitative measures very often turning digital design into a question of resolution as Bob Sheil did recently in *Architectural Design*.¹

In the experiment the process of form genesis was eliminated and substituted by selecting a historic form, rich in features, namely the baroque sculpture Maria Immaculata by Matthias Steinl, 1688 (Figure 1). A high-resolution 3D scan of the sculpture was geometrically analyzed for local principal curvature. In the following eight digital methods were chosen by eight individuals to reinterpret the original sculpture. This was done by highlighting selected aspects of the geometric analysis, resulting in a series of eight sculptures—Digital Bodies—sharing the underlying morphology with the original baroque sculpture. The only rational criteria implied were 3D-printability and structural integrity under dead-load so printed sculptures could stand on a plinth without additional support.

After laying out the different methods and pointing at the formal intensities of Digital Bodies, the paper concludes with suggesting a draft version of categories, an initial framework, for the discussion of form in contemporary architectural design.
BACKGROUND

The development of digital design practice has seen great advances over the last fifteen to twenty years in terms of concepts, methods, and technology which included: animation software, parametric modeling, scripting culture, digital morphogenesis, material computation, robotic fabrication, and evolutionary and agent based design. The discourse associated with these developments was mostly focused on the generative/performative aspect or plain technical. This tendency becomes apparent when looking at the conferences which supported this development (Digital Tectonics 2002; SmartGeometry since 2001; Fabricate since 2009).

Historically an important aspect of aesthetic discourse was the question of proportions. This can be seen in classic architecture with Alberti or in Modernism with Corbusier’s Modulor. Second aspects of the aesthetic discourse cover typology and composition. This holds true in classic architecture as well as in Postmodernism. A third aspect is that of architectural detail in form of articulation, ornamentation and tectonics as pointed out by Semper or Frampton.

If form was part of the recent architectural discourse it was either charged metaphysically in Digital Morphogenesis (Achim Menges) or semiotically as symbols and semantic system (Patrik Schumacher). There was an attempt by Preston Scott Cohen initiated in Contested Symmetries to develop a rigorous form-focused view on computational practice, where he established amongst other concepts the notion of the Terminal Lines and exercised its capacity.

But there is a shift happening; a discourse on aesthetics in digital practice is emerging. Lars Spuybroek develops his very own reading of John Ruskin in The Sympathy of Things and calls for a new view on empathy theory where not only the object is experienced by a viewer but where all objects feel for each other and gestalt is a result of this sympathetic entanglement. Not so far from Spuybroeks thesis is Peter Trummers effort to shift discourse and design practice towards an ontological approach of aggregate objects. He builds links to current ontological philosophy by Graham Harman.

On the other hand, there is a body of work accumulating in practice, which suggests a highly developed aesthetic judgment on computational form. This is, for example, obvious in the work of Zaha Hadid Architects with its wide range of projects from objects to master-plans. It is also obviously present in the very focused work by theverymany, which operates on the evolution of one particular typology-computation-manufacturing framework and distinct aesthetic judgment. Interestingly, none of these practices disclose or discuss any of their aesthetic judgment. Even in the Autopoises of Architecture Patrik Schumacher does not give any qualitative hints on the development of computational form. In that sense it is not any different to pre-digital formal exploration like in the work of Santiago Calatrava, which was equally closed-off in terms of a formal discourse. The main difference though is that today’s digital design community agent do not act in isolation on almost any level—except the aesthetic one. Designers who primarily address the aesthetic dimension as Michael Hansmeyer does with the Digital Grotesque are still an exception.

Other design disciplines have a better framework for formal judgment and are more articulate about it; Hartmut Esslinger in industrial design Chris Bangle in car design, or Erik Spiekermann in font design. There are two main differences to architectural design practice. Firstly, these other design disciplines act directly upon the object at a 1:1 scale and thus name and judge things directly. Digital design practice in architecture helps to overcome the issue of scalar translations but is still lacking a culture of debate on form. Secondly, these other design disciplines mostly deal with typologies (the letters in an alphabet, the body or head-light of a car) where the discourse of form is already inherent in the object as a type that developed over time. Architectural design has made great efforts to overcome these typologies of building types as well as building elements. Now since some ground was gained on that front, it might be time to reintroduce aesthetics or at least an explicit discourse on form.

The research presented here is an attempt to introduce an aesthetic perspective in computational design to a Masters degree design studio by drawing a comparative study between eight design artifacts. It also hopes to be relevant as a trigger for a new discourse in the wider community.

EXPERIMENT SET-UP

The experiment was run in a Master degree design studio. It aimed at creating a variety of formal proposals based on the same source geometry and establishing a framework for discussing the results in a formal—aesthetic context. Participants were asked to calibrate the intensity of their chosen computational method and keep a balance between the distinct expression of the method and the source form. The figurative aspects of the source became less important while the overall notion of the original morphology was still maintained within the articulated method.

The selection of methods is not by any means exhaustive and somehow reflects across section of contemporary methods as it was down to the individual to choose and steer formal development.
MESH ACQUISITION AND GEOMETRIC ANALYSIS

The scan was taken with an Artec EVA® scanner resulting in a mesh of two million vertices. Texture information was scanned along with 3D vertex information but eliminated for the purpose of the exercise. The main interest in the mesh was its richness in formal features such as folds, directions, movement, taut and slack areas, as well as the difference in depicted material like: flesh, hair, cloth. The mesh was down sampled to 20,000 vertices to be fit for real-time parametric design in Rhinoceros® Grasshopper (GH). As every software suite GH comes with its very own aesthetic bias: Rhinoceros® is a NURBS modeler with basic mesh tools, GH an acyclic dependency graph interface with scriptable nodes, this suite has become popular in recent years in architectural design. Although very versatile there are two aspects that give it a certain bias. One is obviously the smoothness of NURBS in Rhinoceros® and the other the rigidity of lists in GH. Two steps where introduced to challenge this bias. Firstly, the 3D scanned of the baroque sculpture is a form foreign to the generative methods available. Secondly, mesh geometry was used as the point of departure that is not natural to GH. After all, the aim was to explore a spectrum of computational design aesthetics where processes and methods are linked. This is a deliberately different approach than mesh sculpting applied as in Z-Brush®.

In order to conduct the experiment, a mesh analysis tool was developed as GH Python component: meshCurvature. The component approximates the local curvature of any given mesh based on angular difference relative to the size of adjacent mesh faces. The readouts include: principal curvature direction and values, mean curvature as well as Gaussian curvature (Figure 3).

The aim was to identify different formal features such as folds in the fabric, main body parts, facial features or extremities by associating them with a certain curvature range.

METHODS

#1: Here a further down-sampled subset of mesh faces was substituted with closed spline curves. The subset selection filter was set to threshold of Gaussian curvature, excluding areas of positive synclastic curvature (Figure 4). Areas of small mesh faces become solid as the uniform thickness of the curves start to merge into a continuous solid layer. It naturally emphasis areas of tight negative curvature. It excludes the tight crease lines thus making the form less dynamic.
#2: In this approach an octree algorithm was employed on a subset of the mesh vertices. The subset was filtered by lower minimum curvature values (Figure 5).

The result shows a stable frame. It blurs the boundary of the original sculptures surface. This aggregation of objects make it very hard to recognize any previous notion of surface and continuity, still areas of different densities and intensities are visible.

#3: This method uses selective edge thickening via smooth iso-surfaces. The selection filters out the areas of lower minimum curvature values. The smoothing on the iso-surface mesh is done using Catmull-Clark subdivision (Figure 6).

This leads to a result where the tightly curved areas are forming smooth solid areas. Other areas get more and more porous. The original figure is still quite visible through a layer of thick texture.

#4: The method uses a local vertex displacement along the mesh normals and a smoothing algorithm to even out abrupt changes. The selection of vertices to displace is done on a sub-set of maximum curvature values (Figure 7).

The technique blurs the boundary between a continuous surface and an aggregation of elements. It creates new moments of self-intersection showing up as sharp elongated discontinuities, which are in contrast to the sharp singularities of the stretched out peaks. They also form a set of folds and creases much smaller than the fabric folds of the original sculpture.

#5: Here a manual selection method is chosen which traces the line where the fabric of the sculpture peels off the underlying body. This is a recognition easily done by the human eye but hard to translate in computer vision. The line is then materialized by “spikes” that point into the direction of the
negative direction of the local mesh normal. They are scaled to a degree where they intersect globally and form an overall stable framework (Figure 8).

This seemingly simple spatial array of similar elements creates a rich variety of local situations by intersections and alignments. Stretches of smooth changes are contrasted by sudden changes in direction and scale of elements.

#6: Here the entire volume of the sculpture has been filled with a homogeneous network which then was thickened using an equal potential filed method (Figure 9). This allows to look at the form volumetric aspect of the form showing nothing of the actual outer boundary. This structure itself is oscillating between an aggregation of elements and an extremely intricate distribution of smooth curvature changes.

#7: Here spheres are applied in areas of small minimum curvature. The radius of the sphere is inverse proportional to the local minimum curvature radius (Figure 10). This results in almost string like arrays of sphere following tight folds and creases in the form. The bigger spheres highlight local curvature peaks.

#8: Here linear members of constant diameter are laid out in the direction of the local maximum curvature. These members are extended by a length proportional to the local Gaussian curvature to either side. This provides sufficient overall intersections to form a stable frame. Members with no intersections to others are excluded (Figure 11). Due to the inherent directionality of this method and the application rules we see areas of strong alignment between members where the minimum-curvature is relative high in relation to the maximum curvature. This happens along major fold lines in the fabric.

FRAMEWORK FOR DISCUSSING FORM

The versatility of mesh modeling has proven to be a good choice for achieving a wide spectrum of results. This allowed us to look at the selected sculpture by reading out geometric properties and feeding them into an array of generative modeling techniques. Valuable strategies applied to all techniques were the filtering and smoothing of analysis data as well as the accentuation, amplifications and damping of local selections in the dataset.

Four main categories were established to draft a framework for discussing these forms in particular and generative design in general. It puts a focus on different qualities–intensities and their internal relations.
FORM AS DISTRIBUTION OF CURVATURE
#3, #4, #8

This geometric perspective allows discussion of form in terms of continuity and its derivatives such as the rate of curvature change. It includes the notion of principal curvature and the derivatives mean- and Gaussian curvature.

To make these local geometric properties more meaningful in a discussion on overall form they could be best used as navigational devices to “travel” on that form i.e.: find a place on the form with the smallest minimum curvature and travel along the direction of the maximum curvature. How does the curvature change in the way of travel in terms of slope (relative up-down) and steer (relative left-right).

On a global level one can map out a histogram of a set of sampling points of the form. The values in the histogram shown would be local minimum and maximum curvature. These histograms give a an overall reading of the distribution of different curvatures, resulting in different characteristics whether showing human hand, a piece of soft folded fabric or a smooth geometric object such as torus. This is set to be the new research thread, which will be further explored.

FORM AS RECOGNIZABLE FEATURES
#1, #3, #5

What we see as “features” is really happening in areas of geometric discontinuity or singularities. These features show up as crease-lines, peaks, kinks, edges, holes. What make these entities a feature is that they exhibit a formal characteristic in themselves. The curvature changes along a crease-line could be distinctly different from the surrounding form. Thus each feature could be discussed independently from its surrounding or host.

On a global level the relative number, extend and clustering of features plays an important role in the characteristic of a configuration and form. When looking at form by features we are reading learned patterns and meaning into them, seeing seemingly familiar objects. This is well covered and addressed in gestalt theory. There is a danger that we do not analyze what we see but analyze what we have learned to see.

FORM AS AGGREGATION OF ELEMENTS
#2, #7, #8

This is the perspective were architects are most familiar with - the assembly of objects into a larger whole. It does not matter whether these elements are of uniform nature like bricks or
individually crafted like voussoirs. This aspect of part-to-whole relationship has been embraced by computational design and digital fabrication and it is often argued that form or gestalt is an emergent property.

The lesson we have learned in recent years in computational practice is that there is a practical distinction between composition and organization. To what extent that procedural distinction is also an aesthetic one remains still unresolved.

**FORM AS DIFFERENTIATED TEXTURE #1, #3, #4**

At this level form is experienced through the articulation of texture. These textures could be of two-dimensional nature like animal coat patterns or three-dimensional ones, like folds and wrinkles. J.D. Murray has proven how animal coat patterns are directly linked to the growth process and form of the animal’s body. Thus, even when looking at the flattened skin one understands the initial form of the body. Similarly with a piece of cloth loosely draped over an object, the physical properties of the fabric and gravity reveal a notion of the underlying form by the distribution and articulation of folds.

**SUMMARY**

It is obvious that these four categories cascade and could not be seen in isolation but by making these distinctions they could help to get a better hold of what we talk about when we assess from. Eight proposals over a shared source geometry is far from exhaustive but make for a tight comparative study. It is necessary to explore this further ideally by crowd sourcing design variants. The set-up in a small design studio could only be the very first mapping attempt.

This study also makes it more clear why other design disciplines seemed to have a better handle on their respective formal discourse, i.e. in font- or car design: they mostly operate on a clearly defined domain, the line-figure of letters and the their aggregation as text; the surface-body of a car and its decomposition into a few panels. Architecture on the other hand has the ability to constantly move between categories making it even more important to hold on to a framework.

**FURTHER RESEARCH**

Firstly, this draft framework should be used to discuss a selection of seminal build projects which employed computational methods for design and fabrication. It should also be exposed to a similar selection of speculative or unrealized projects.
Secondly, this framework should be extended in its criteria such as the intensity of effects and resolution so aesthetic design moves could be communicated along the seemingly more rational performative criteria.

Thirdly, a method of how this framework could be conveyed most easily in practice and academia should be explored.

NOTES
7. SAC. 2012 Trummer, Peter “The Aggregated Figure & Its Unfolding Ground(s)” https://www.youtube.com/watch?v=who2vV2mKac

REFERENCES

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