Digital Detail – Computational Approaches for Multi Performative Building Skins

THESIS

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By

Shiras Chakkungal Mohammed

Graduate Program in Architectural Studies

The Ohio State University

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Master's Examination Committee:

Associate Professor Ashley Schafer, Advisor

Associate Professor Alexandros Tsamis

Associate Professor John McMorrough
Abstract

The paper explores the notion of a digital detail for the design and the fabrication of a multi performative building skin. The per formative aspects of the building skins are inquired using a taxonomy which classifies the envelope according to the materials, the structural system, the passive thermal strategies, the transparency and the construction techniques. The research proves the need for a rational computational approach, a digital detail that integrates the materiality, the performance and the fabrication techniques. The method employs an algorithmic process that synthesizes the information from a double curved surface to construct an emergent, a performative and an intricate detail. The process uses a recursive computing technique to generate the variations, which makes it difficult to decide a discrete moment where the transformation happens from structure to transparency or vice versa. The material and tectonic implications of the process are addressed in a smaller scale, using a material that simulates the fabrication and construction technique.
Dedication

This document is dedicated to my parents.
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Vita

1998..................D. Arch, State Board of Technical Education, Kerala, India

2004..................B. Arch, Calicut University, India

2008 - Present..............Graduate Study in Architecture - Digital Fabrication,

The Ohio State University

Fields of Study

Major Field: Architectural Studies
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1. Introduction

Of all conceptual paradigms of architecture, performance is the one which seeks to evaluate the efficiency of its ambitions. Opposed to architecture for the sake of architecture, it investigates the feed-back loops between architecture and the systems it is embedded in. Isolated questions of form, process, fabrication etc. cease to be apriori conditions of architecture. Performance does not ask how a form looks like, but what it enables. It does not focus on what process was used to make a design, but on what the process was able to generate in the design. Thus performance shifts the focus of interest from essence to effect. The question is not what something is, but what it does.- Andreas Ruby (1)

Digital design and fabrication have opened a completely different world to architects, which helps them to materialize a complex form with varying functional parts, non standard geometry and intricate detail. Digital techniques have equipped the designers to fabricate the monocoques for any voluptuous shape through a design process informed by performance, fabrication and material properties.

Figure 1. Digital Detail
2 Background Research

2.1 Skin Vs Technology

Architecture depends on its time. It is the crystallization of its inner structure, the slow unfolding of its form. That is the reason why technology and architecture are so closely related. Our real hope is that they will grow together, that someday the one will be the expression of the other - Mies van der Rohe (2)

In the 19th century, the industrial revolution had changed the world. The industrial revolution had significantly affected the architecture, the technology and the materials of construction. The industrial process achieved efficiency through the standardization of products that resulted in the mass customization of building units. The daring structures were optimized to obtain the objectives based on the purpose and the engineering needs. Industrial buildings and factories were the first to built using the innovative construction techniques. The full potential of the technology is explored through the prefabrication of building components in a controlled and specific environment in the production plants. The industrial process assured the qualitative and engineering properties of the buildings and its components.
The most important building is the Cristal palace designed by Joseph Paxton, constructed for the world fair in London in 1851. Every aspect of the structure was developed in accordance with the requirements of the task, the conditions imposed by the scale, the span, the costs, the prefabrication and the assembly times. The design reflects the versatile use of industrial materials and triumph of what could be achieved with available technology and resources.

The technical advance in construction and engineering after industrial revolution has eventually led to the advent of modern architecture. Le Corbusier is one of the architectural ideologist during the modernist era have further rationalized the construction and building through his concept called Dom-ino system. This model proposed a free floor plan consisting of concrete slabs supported by reinforced concrete columns and a stairway providing access to different levels.
The innovative ideas proposed by Le Corbusier paved the way for the invention of curtain wall, which facilitated the experiment on facade and roof. The Modern buildings have two different autonomous systems, an envelope with the freedom to construct a curvilinear surface and a structural system for purely technical reason. The later part of the 19th century, witnessed an increase in the number of modern projects with free form and curvilinear outer skins. The technical requirements of traditional facades like load bearing structure, rectilinear shape and limited openness are challenged through the fluidity and continuity in structures designed by Frederick J Kiesler, Eero Saarinen and John Utzon.
John Utzon’s Sydney Opera House is one of the most significant architectural presidents, which used computer for the design and the construction. The curvature of the main roof has challenged the architect and engineers in each stage of the project. The original shape proposed by architect was optimized by introducing bending stress in the curvature of the outer shell. The fabrication and construction is made possible through the available computer facilities at that time. The exact geometry of the roof, glass facade and external tilling were produced from precise computer models. The cutting, molding and fabrication of components are done manually even though the pieces were non standard. The entire fabrication process resembles construction methods used by digital architects.
The Guggenheim Museum, Bilbao designed by Frank Gehry is the one which used digital technology in all the aspects from design to construction. This building is considered as the one of the precedents which revolutionized the construction process through digital fabrication techniques. There were previous examples of sculptures which used the structural techniques in a similar way to achieve the form. In the Statue of Liberty the overall shape is made out of a skin with 2 systems- a primary structural frame to carry the load, a secondary structural system in between and an outer layer that conveys the artistic gesture.

In the Guggenheim Museum, Frank Ghery was interested more in the visual qualities of the outer layer with a continuous, a smooth and a varying form. He subdivided the envelope into a three autonomous...
system—primary structural system, a secondary structural member that takes the shape and the outer layer of cladding.

*Happy accidents and automatic process are certainly the precursors of fine grain, detailed, continuous compositions. The later demands a fusion that is not possible without a theory of synthesis and unity that maintains detail as a discrete moment that participates intensively on the new kind of whole—Greg Lynn (3)*

![Figure 6 Lab Architecture, Federation Square](image)

The recent designs by architects are concentrating more in the use of digital tools as a mean to integrate different performative qualities on a complex structural skin, which can be produced with non standard parts. The Federation Square, Melbourne designed by Lab Architecture is a building with highly complex variations in the skin,
which used the digital techniques to achieve the visual effects in terms relative transparency of materials, individuality of facades, patterns and lighting requirements.

Figure 7. Toyo Ito, Serpentine pavilion

The Serpentine Pavillion by Toyo Ito and Cecil Balmond integrates variations in terms of structure and transparency in a single system. The BMW Munich designed Reiser and Umemoto shows a transformation in structural skin, the variation is achieved as a kind in the overall. The structural system consist of three kind a one way frame, two way frame, and a space frame. It is difficult to decide moment where the system change from one to other - *a received structural definition – was only a moment of purity within a continuum of change* - Jesse Reiser (4)
2.2 Skin Vs Computation

The design and production of building skins with geometric complexities and varying surface strategies are directly related to the computational methods employed in the digital process. Bernard Cache argues that the objects are no longer designed but calculated, which shows the potential for the computational approach towards design and production of varying non standard components and multiple functions. This is a novel computational approach towards the fabrication of furniture and panels. This method is able to generate infinite variations in the visual and surface qualities through the procedural methods in Micro station. The mass customization of non standard products are done using a standard industrial material, with the application of computer numerically controlled machines.

The Embryological house designed by Greg Lynn is an innovative idea in the realm of domestic architecture. He proposed a series of houses for individual clients that can be customized and tailored - a non standard architecture “a strategy for the invention of domestic spaces that engages contemporary issues of variation, customization and continuity, flexible manufacturing and assembly” - Greg Lynn). (5)

The two major computational approaches in the digital design and fabrication are parametric design process and algorithmic design process. The buildings are made up of parts, through the detailing of respective components for practical and technical reasons. Each detail should be different unless it repeats with exact size, orientation materials and other technical requirements. The detail in a digital design is dynamic, the intricacy is no more treated as an isolated fetishzed
instance, in an intricate network, there are no details per se. Detail is everywhere, ubiquitously distributed and continuously variegated in collaboration with formal and spatial effects. Greg Lynn (6)

The parametric tool is a process based holistic method in which a change to the part will result in the reconfiguration of overall system. The logic is that the whole is always a sum of the integration of its interactive parts. The association between the elements and components of a structure, allows the designer to control the form in an interactive way. The interactions of the elements to the whole can either be the result of a single parameter or multiples.

The most practical implication of the parametric design is that the whole structural system can be subdivide into components, parts from the components, the G codes for machining and specific bar codes to aid the assembly of discrete units. The parametric methods are effectively applied to achieve performative optimization in the contemporary buildings. The Water Loo Terminal, London by Nicholas Grimshaw is an example for the application of parametric techniques to regulate and control the fabrication of the varying structural beams along the skin.

Algorithmic process is a computational approach in digital design using algorithms, in which the complex geometry and optimum solutions are generated through a finite set of instructions. The idea is to break down the whole system into subsystems that could be controlled, differentiated and constructed using a rule based system. The algorithm provides the power of recursion to generate a complex geometry through continuous interaction in a defined manner, which has immense calculating power. The basic conditions are set in the
beginning and the iterations are easier through a predefined code. The rules that govern the discrete components are the same in the overall system.

Algorithms embedded with recursive logic can invoke repetitive loop to find the minimum and maximum values in a set of data. In a digital detail the set of values for the construction of geometry is obtained through a Gaussian analysis. The mean curvature of the trajectory is read in each UV point using an iterative logic and bought down to the scale which varies from 0 to 1. The topological relations are volatile, considers as a trajectory which controls the generative potential. The approach can either be deterministic or non-deterministic depending on how the threshold for different variations is given in the loop. That means the threshold can be given manually to achieve a determinant and optimum in the performative iteration. This method can be further explored in a different way to produce an indeterminate, performative and complex output from a threshold taken from a range of random numbers between 0 and 1. The persistence of the generated components are precise through formal rules, which controls the output that can happens in the feasible range of materials and individual parts. Each component can be accessed individually for fabrication and the material tolerance.

According to Greg Lynn the intricacy of a digital detail can be divided into two types: aggregations and assemblage. Assemblages are non-modular constructions where each and every part is unique in shape and dimension but are derived from an overall composition of a whole. Aggregations are instances where modular components are complexly connected to produce a
form that is not simply reducible to a single modular logic of assembly. -Greg Lynn (7)

The industrial fabrication of aggregates is done precisely through robotic production and construction techniques. The Resolution Wall, ETH Zürich, 2007, is an additive construction of digital wall, the variations are achieved through the arrangement of bricks with different standard size. The variations in structure and appearance are obtained through procedural methods in simulation software. The variation of a kind, structural optimizations and effects are produced using modular units that can be mass produced.

The assemblage is an intricate detail of varying geometry and performative structural parts that could be achieved either through algorithmic or parametric process. The digital tools ensures the changes in the performance through the variation of geometry, than can be materialized through a specific fabrication technique. The best example for the algorithmic potential in the realm of architecture is the Serpentine Pavillion designed by Toyo Ito and Cecil Balmond. The complexity is achieved by recursive repetition of a simple rule from which stems the structures geometry and detail. Within this complexity modularity and repetition are preserved and hierarchies order and govern process of fabrication and construction Cecil Balmond (8)

2.4 Skin Vs Performance

The performative aspects of buildings and its skins are always in the forefront of critical discourse, in a century that faces the scarcity of
resources. Architectural precedents are the best examples to learn from the history, in order to find the research potential for a digital detail which considers the computational approach towards multi performative skin. The scientific classification and analysis of the skin can done in a systematic way. In order to access the available data from a general pool of works happening around the world, the set of architectural works published in the AD for last twelve years is studied. The wide range of classification has forced the taxonomy to be separated in terms of performivity and materiality. The respective taxonomies are used as a base datum to find the suitable areas, to decide the gap which does not integrates the performative strategies and construction techniques.

The first taxonomy is a classification based on the comparison of four basic materials used in the construction against how these materials are used in a structure. The horizontal divisions include the four basic materials used in the construction industry. The vertical divisions in the taxonomy are based on how the other materials are used in the structure as: - a single material, a combination of two different materials and a composite

This second taxonomy is a comparative graph based on the performative aspects of the building skins against the construction technique. The performance of an envelope is analyzed according to the load bearing aspects of a structural system, the thermal strategies and the transparency against the construction techniques. This is taxonomy is complex and interesting corresponding to its cross over and analysis.
Figure 8 Taxonomy 1
Figure 9 Taxonomy 2
The most interesting thing with taxonomy is that the overall representation itself will function like a graphical diagram, so the analysis and interpretations are evident.

The argument by Neil Leach is added here to support my analysis, what we are beginning to witness is a 'structural turn' within architectural culture. It is clear that a significant number of progressive architects are seeking to step beyond a certain Postmodern sensibility which celebrates scenographic properties and surface effects, and focus instead on the structural integrity of building - Neil Leach (9)

The day lighting is an essential requirement in a building and the interplay of light and shadows through the structure is always interesting. The lighting conditions have an impact on the visual qualities, apparent mass of a structural system and the building itself. Louis Khan is one of the master architects, who utilized the advantage of a light inside the space in different ways to express his forms. He mentioned that the structure is the maker of light and the light of the vault is a choice out of structure. When you chose a vault, you are already choosing the light, when you choose the column; you are choosing a kind of light. (Louis Khan)

The digital design is a performative structural system in which the interior lighting conditions and the structural depth have its own variation throughout the form. The non standard parts are generated using an algorithmic process, which uses the values from a double curved topological surface. That means the topological data is volatile, so the overall performance is based on the surface curvature from UV points. But the rules regarding the components are consistent and each behaves in a certain manner and the overall will
be sum of the behavior of discrete parts. The percentage of variations is almost the same for a different surface, but it is difficult to decide a clear moment where the transformation happens from structure to transparency or vice versa.

2.5 Skin Vs Fabrication

In the past traditional architecture has engaged with production in a consistent and defined manner, through the components and part made out of standard size. But the established routine got changed, with the emergence of computer numerically controlled machines such as wood routers, water jet cutters, milling machines and laser cutters.

The fabrication of building skins with varying geometry is a direct related to the computing and digital fabrication. There is no single machine available that can fabricate the whole structure as ‘non assembly’ unless the prototype is printed in a smaller scale. There is a need to incorporate production strategies into the algorithmic design, during the initial stages of form finding. In most of the case the architects have to produce the component from the industrial materials that are available in standard sizes.

The digital techniques follow the logical rules in order to machine the process in from the set of available material and the design intentions to be followed. The constructive aspect in the ‘digital detail’ is implemented through an algorithm that reads the curvature value from the corresponding topological surface. The curvature of a double curved surface is analyzed using the Gaussian curvature –the product of principal curvatures in either directions of a point on a
surface. This method is used by Frank Ghery to achieve the surface qualities and fabrication requirements of his sculptural shapes. He is interested in the fabrication process that follows the smooth curve of surface panels and skins, with a material that follows the geometry. The analysis is used to find a material tolerance within the range, to find the feasible solutions in terms of fabrication and construction cost.

In a digital detail, the mean curvature obtained through Gaussian analysis is used to triangulate the surface, a geometric pattern with incredible control over the fabrication. He the aim is achieve the optimum in terms of material constraints, the size of structural members and the performative qualities

The different fabrication techniques available are two dimensional fabrication, subtractive fabrication, additive fabrication and formative fabrication.-Kolarvic (10) . The transformation the geometry to machine code is not simple; the whole process is time consuming and laborious .The each component and its parts should be aligned, unrolled and converted to curves that aligns with the world coordinate system. These parts should be optimized to meet the material and machine constraints to deal with the tolerance. The order and hierarchy of machining should be followed with extreme care and tagging if the information is layered, so as machine the process in stages to reach the final product.
3 Project Outline

3.1 Digital Detail

In the avant-garde contemporary architectural design, various digital generative and production processes are opening up new territories for conceptual, formal and tectonic exploration, articulating an architectural morphology focused on the emergent and adaptive properties of form - Kolarevic (11)

Digital Detail is a generative algorithmic process which integrates the performative aspects, the material properties, the tectonics and the construction process. The method is a rational process to generate the detail for a double curved surface using a rule based system in which the algorithm will analyze the surface curvature in order to produce material distribution in terms of structure and transparency. The structure is generated through the evaluation of the mean curvature using Gaussian analysis, the corresponding information at each U V point are scaled into a range between 0 to 1. These values are used either in a linear or exponential way to assign structural depth. The architectural detail is no more treated as isolated and discrete information in the process because the intricacy and overall coherence of the structural system is constructed out from a logic which interacts with the surface, a digital detail.

The main objective of the research is to explore different generative and construction alternatives for a multi performative building skin from a double curved surface. The objectives to experiment with digital techniques, to mass customize the variable purpose parts for any complex shape. The aim of the thesis is to evolve a Digital Detail – Computational Approaches for Multi Performative Building Skins
a, the first experiment is to subtract shapes out of a two dimensional surface,

b, the second experiment is to carve the volume from a three dimensional unit.

4 Design and Fabrication

4.1: Skin A, Triangular Units-2 Dimensional – Iteration 1

Figure 10. Skin A, Iteration 1
The internal organization of the structure is generated using a rule based process which reads the mean curvature at UV points to control the material distribution and overall performivity. *Every point of a curvature is a structural possibility* – Cecil Balmond (8) This notion is used in an empirical way to explore the possibilities of emerging material qualities for a building skin in terms of structure and transparency.
Figure 13, Structural depth

Figure 14, Iteration 1- Part detail
Figure 15, Iteration 1 Part Detail

Figure 16, Iteration 1 Part Detail
4.2: **Skin A, Triangular Units** - 2 Dimensional Iteration 2

In the second experiment - the components are flipped and the subdivisions are one instead of two.
Figure 18 Iteration 2 - Variations

ALGORITHM FOR SUBDIVISION OF STRUCTURAL MEMBERS

\[
\text{Factor} = \frac{X - \text{min}}{\text{max} - \text{min}}; \quad \text{in} \quad 0 < X < 1
\]

Figure 19 Iteration 2, Algorithm

IF factor ≤ lower_limit THEN
factor = 0
ELSE IF factor ≥ high_limit THEN
factor = 1
ELSE
factor = (factor - lower_limit)/(high_limit - lower_limit)
ENDIF

thickness = factor * (max_thickness - min_thickness) + min_thickness

ALGORITHM FOR VARIATION OF STRUCTURAL DEPTH
Figure 20 Iteration 2, Structural Variations
4.3: Skin A, Triangular Units-2 Dimensional – Iteration 1 a

The mean curvature values are used in an exponential way to get the maximum variations in structural depth and the interactive variations to achieve lighting need.
Figure 24 Skin A, Iteration-1a, View

Figure 25 Skin A, Iteration-1a

Figure 26 Skin A, Iteration-1a
4.3: Skin A, Triangular Units-2 Dimensional – Iteration 2a

Figure 27 Skin A, Iteration- 2a

Figure 28 Skin A, Iteration- 2a
Figure 29  Skin A, Iteration- 2a

Figure 30 Skin A, Iteration- 2a
4.4: Skin B, Pyramidal Units-Subtractive – Iteration 1

Figure 31  Skin B, Pyramidal Units

Figure 32 ,Skin B, Pyramidal Units ,Iteration 1
Figure 33 Skin B, Pyramidal Units
Figure 34 Skin B, Pyramidal Units
5 Discussion

5.1 Performative Building Skins

Digital Detail is a generative algorithmic process which integrates the performative aspects, the material properties, the tectonics and the construction process. The method is a rational process to generate the detail for a double curved surface, using a rule based system in which the algorithm will analyze the surface curvature in order to produce material distribution in terms of structure and transparency.

5.2 Findings and explanations

The findings in the thesis are related to a natural outcome of an effort to solve the fabrication issues and answers to certain questions that came up in the reviews.

The overall transparency could be matched with the lighting and occupancy requirement in the rooms inside. The structural members can further optimized towards the material tolerance, joinery detail and other possible loading conditions.

The assembly achieved in the design is with the help mechanical joints, but materials like PVC can be joined using a solvent that activates the chemical bonding.

Algorithms allow the control over individual components or each piece, which enables the fabrication in precise manner. The scripting, enables the construction of every single piece in a different layer, to unroll the parts and to export the geometry to an AutoCAD format with specific filenames. The persistence of the generated components
is precise through formal rules, which controls the output within the feasible range of materials and individual parts.

The fabricated geometry of the second experiment using a form cutter is very efficient to construct a negative mould. So it is possible to make the entire structure or a bigger chunk through the molding process. The resulting structure will integrate the digital and analog process to revisit the ‘notion of non assembly’ in building construction.

5.3 Limitations and Further research

In order to obtain a better control over the design process, the performative aspects are considered only for the structure, the transparency and the fabrication requirements. The tolerances for machining, material thickness and joinery details were not added in an initial level of the exploration. The limitation imposed by a temporary supporting structure to build the structural skin had restricted the construction of the physical model in a bigger scale.

The further research should aim for an intelligence that overcomes the issues in a structure with discrete components. The components in the structure will be placed in relative positions without any mechanical joinery system. The double curved, performative structural system should fits into its position when applied with the required internal stress.
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Figure 3: Le Corbusier, Dom-ino system

Figure 4: John Utzon, Sydney Opera House

Figure 5: Frank Ghery, Guggenheim Museum
http://upload.wikimedia.org/wikipedia/commons/6/65/Guggenheim_museum_Bilbao.jpg

Figure 6: Federation Square
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Figure 7: Serpentine Pavillion
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