SURFACE REALITY:
GEOMETRY, CRAFT and SHAPE OF THE INVISIBLE WORLD.

Peter James John McPherson
ID: 1056759

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ABSTRACT

This research project investigates how the computer and Computer Aided Design software has influenced architecture in the past twenty years; from the influence the digital has had on design thinking to the production of buildings not before thought possible. A study of the principles of computer operation helps to establish a position for a proposal as to how digital tools might best be utilised by architects from an ideological and methodological perspective.

A study into geometric principles works in parallel with a historical survey to gain an appreciation of the differences between dominant contemporary architectural theory and the projects being carried out by practising architects.

Geometry is the constant throughout the study and the understanding of geometric principles and digital operations is critical to establishing a position with which to develop a methodology for exploring the design proposal for an events centre on Halsey Wharf in Auckland, New Zealand.

The goal of this research is to inform the practise of architecture with the benefits of particular geometric solutions in order to offer an approach to engage directly with the shaping of architecture in a digital environment.
DECLARATION OF WORK

I confirm that this thesis represents my own work, including text and images, unless otherwise stated.

Peter James John McPherson
ID: 1056759

Master of Architecture
Department of Architecture
Unitec New Zealand
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# TABLE OF CONTENTS

Abstract \hspace{1cm} iii

1 Introduction  
1.1 Research Question  \hspace{1cm} 11  
1.2 Introduction  \hspace{1cm} 13

2 Theoretical Background  
2.1 Greg Lynn and Folding in Architecture  \hspace{1cm} 17  
2.2 Calculus  \hspace{1cm} 19  
2.3 Conservatism  \hspace{1cm} 21  
2.4 Digital Tools  \hspace{1cm} 27  
\hspace{1cm} \hspace{1cm} 2.4.1 CAD + BIM  \hspace{1cm} 29  
\hspace{1cm} \hspace{1cm} 2.4.2 Computational Design  \hspace{1cm} 31  
\hspace{1cm} \hspace{1cm} 2.4.3 Design or Drafting?  \hspace{1cm} 33  
\hspace{1cm} \hspace{1cm} 2.4.4 Intelligence  \hspace{1cm} 35  
\hspace{1cm} \hspace{1cm} 2.4.5 Simplicity  \hspace{1cm} 39  
2.5 Foster, Gehry and the Sydney Opera House \hspace{1cm} 43

3 Geometry  \hspace{1cm} 53  
3.1 Peter Schröder  \hspace{1cm} 55  
3.2 Mesh Subdivision  \hspace{1cm} 57  
3.3 Planar Quadrilateral Meshes  \hspace{1cm} 61  
3.4 Curves  \hspace{1cm} 63  
3.5 Surface Types  \hspace{1cm} 67

4 Design Proposal  
4.1 Project Outline  \hspace{1cm} 81  
4.2 Brief - Viaduct Events Centre  \hspace{1cm} 83  
4.3 Project Development  \hspace{1cm} 87  
4.4 Process  \hspace{1cm} 93  
4.5 The Proposal  \hspace{1cm} 107

5 Reflection  \hspace{1cm} 123

6 References  
6.1 Bibliography  \hspace{1cm} 137
1. INTRODUCTION

1.1 RESEARCH QUESTION

How can an understanding of planar quadrilateral meshes inform an architectural design methodology with respect to doubly-curved surfaces?
Where previously geometric possibilities were limited by the ability to conceive and communicate a design with two-dimensional representation systems, digital tools offer the potential to move from design to fabrication to assembly for seemingly any shape one can imagine.
1.2 INTRODUCTION

The computer has come to completely dominate the architectural office. The computer and the digital tools it powers have brought a wealth of calculating potential far beyond what the human mind can easily comprehend. These tools enable designers to explore geometric possibilities far in advance of the traditional methods of the pencil, triangle and flexi-curve.

This research attempts to understand the link between architecture and geometry at a time when these digital tools present to designers a near limitless number of geometric possibilities. Building proposals of any shape can be conceived, engineered and communicated for construction. Some of the leading architects in the world engage with these fantastical shapes yet proposals for free-form architectural responses are rare except in these high profile instances.

History informs us of the fundamental link between architecture and geometry. The earliest example of free-form buildings could be considered the wood and willow dome-like shelters built 400,000 years ago. Concrete, and later reinforced concrete, gave designers the ability to construct and the freedom to design sculptural forms such as Eero Saarinen’s TWA Terminal (1956-1962) and Le Corbusier’s Notre Dame du Haut (1950-1955). Later, digital tools provided the instrument for Frank Gehry to build the Fish for the 1992 Barcelona Olympics. Where previously geometric possibilities were limited by the ability to conceive and communicate a design with two-dimensional representation systems, digital tools offer the potential to move from design to fabrication to assembly for seemingly any shape one can imagine.

However, this isn’t quite the case. Digital tools haven’t led to a revolution in the shapes of buildings we see in our cities every day. There appears even a conservatism to the shapes of new buildings given the potential the computer presents. What are the limitations to free-form shapes being proposed in architecture? How can we understand the shapes on our computer screens to take what exists, in Norman Foster’s words, in “the silent, invisible electronic world” and bring it into “physical reality”.

1. Cristiano Ceccato, Advances in Architectural Geometry 2010, (Dordrecht: Springer, 2010), Foreword. “Modern geometric computing provides a variety of tools for the efficient design, analysis, and manufacturing of complex shapes.”


2. THEORETICAL BACKGROUND
2.1 GREG LYNN and FOLDING IN ARCHITECTURE

In 1993 Greg Lynn published what is widely regarded as a seminal publication on digital architecture, *Folding in Architecture*. While digital tools, computers, and their application in design could first be seen in Ivan Sutherland’s development of Sketchpad in 1963, with its full graphical user interface and widely considered the ancestor of modern CAD software, Lynn’s publication came at a time which, in Lynn’s own words, “captured a moment before the discovery of a new kind of drafting machine, a much more vital machine than the compasses, adjustable triangles and rubber spline curves with which most of the projects were conceived”.

Here Lynn is referring to the “moment before” the advent of affordable computing power that led to the widespread adoption of graphical software as a real alternative to traditional ink and trace. This is important to note as it suggests that the subsequent digital explorations in shape and form were not due to critical thinking relating to the computer itself but rather based upon the theoretical implications presented by Peter Eisenmann and his formulation of Gilles Delueze’s at that stage little known text, *Le pli*. As a consequence, we note that the work contained within *Folding in Architecture* is based upon some other agenda and is not so concerned with what the “new kind of drafting machine” itself offered. The machine was merely the vehicle to explore Deluezean concepts with. In Greg Lynn’s words:

*So we see how an original quest for formal continuity in architecture, born in part as a reaction against the Deconstructivist cult of the fracture, ran into the computer revolution of the mid-nineties and turned into a theory of mathematical continuity. By a quirk of history, a philosophical text by Gilles Deleuze accompanied, fertilized and at times catalysed each of the different stages of this process. Without this pre-existing pursuit of continuity in architectural forms and processes, of which the causes must be found in cultural and societal desires, computers in the nineties would most likely not have inspired any new geometry of forms. Likewise, without computers this cultural demand for continuity in the making of forms would soon have petered out and disappeared from our visual landscape.*

4. From the publisher, Wiley: This seminal book from *Architectural Design* was originally published in 1993, at a time of crucial change and on the eve of the digital revolution. It brought together a series of essays that many believe created the favourable environment in which computer-based design could thrive. Considered one of the most influential architecture publications of the 1990s, this book ranks as a classic and in itself is a crucial chapter of history.


The desire for formal continuity in architecture has since been explored for two decades. The explorations in the 1990’s of Deleuze particularly focussed upon Gottfried Wilhelm Leibniz’s monads and work on differential calculus and provided the platform for the smooth forms that dominate the digital architecture scene today. The fold was combined with ideas of the infinitesimal and variable rates of change (from calculus) and the fractured, sharp and angular aesthetic started on the drafting table began to smooth in appearance. The desire to explore shapes that required more complex mathematical definition, that is curves, was made possible by the computational power of the digital tools available. However the theory underpinning this remained with ideas pre-dating the existence of the computer.

The theoretical underpinnings of the work from the early 1990’s is claimed to be due to the cultural and societal desire to break with Post Modernism and Deconstructivism. The theories of folding and pliable architecture occurred at the instant where affordable computers came to bear and meant that complex formal explorations could occur, ultimately leading the fold to evolve into the blob. The investigation of the blob though relied upon the text of Deleuze to “fertilize” this exploration and one wonders if this obscured other potential benefits that the computer may have afforded architectural design at the time. As it stands, it appears the situation that the computer was used as a means rather than an end. This is interesting as initially, Antoine Picon notes, the computer was “expected to reinforce the predominance of structure and tectonic in architecture because of the new possibilities it offered to pass almost seamlessly from the first sketches to detailed technical solutions”8. This concept is particularly relevant today as the idea that what is produced digitally may be directly translated to fabrication is one at the forefront of advanced architectural practise and, even though the idea had been mooted, these early exploration appear to have little sympathy for it.

2.2 CALCULUS

The issue of calculus in architecture is of interest to this study as we find it being used as the basis of justification for curved shapes. Antoine Picon argues that in Renaissance times mathematics could be said to have empowered the architect, enabling the architect to work within some limits of geometry and arithmetic to produce architecture of power or restraint. However, when architects began searching for foundations in the 19th Century, those such as Eugene-Emmanuel Viollet-le-Duc looked to the biological sciences rather than mathematics. Mathematics was merely seen as a useful tool rather than part of fundamental design techniques. This estrangement of mathematics from architecture tends to exist today even though the advent of the computer means that we have never before used so many mathematical objects due to the tools that digital software provides us.

Additional to this is the way that calculus has changed the design process for architects. It can be said that the laws of approximation of mathematics in architecture that pre-dated calculus allowed the architect to work within a system of sorts. The skill of an architect was in applying a proportional system to best suit a situation to derive the most pleasing result, both aesthetically and functionally. Matters were visual and about the composition and shape of the building. The introduction of calculus and biology to architecture resulted in a different relationship between mathematics and the architect. Whereas previously we could say that an architect’s use of mathematics tended towards some average that could be manipulated, calculus changed this. Mathematics is now about “setting some limits to a phenomena, then modelling them with laws of behaviour”10. Picon goes so far as to say that, “Design was no longer involved”11 when discussing the role of calculus in architectural design. No longer is it possible to tinker with proportions but the designer is beholden entirely to the shape resultant from the input equation.

The issue of calculus and Leibniz is then one that I believe is critical in importance when considering a direction for digital architecture today. In the search of new shapes through defining changing form, calculus was taken to not describe an object, but their laws of change – the infinite, infinitesimal variations12 and it is the process for describing or generating the shape that takes priority.

10. Ibid., 33.
11. Ibid., 33.
As discussed previously this description would appear to infer that the final shape of a building is of lesser consequence in relation to the process. To my mind this raises a critical point as to the shape of the objects and whether indeed the formal exploration is actually about the shape of the building or is simply about astonishment and doing something different.

For example, if one analyses the work of Peter Eisenman in *Folding in Architecture*, they will note the projects are not in fact moving and changing works as the author desired but schemes that are frozen in time. Nor do they formally represent folds but instead fractured forms that break. It is an example of where design cannot be taken to be a formal exercise with regards to shape but is instead a process where the formal outcome is but a single moment in time determined entirely by some predefined laws of behaviour. We might determine that the failure to wholly engage with issues of shape are a legacy of preceding Post Modern and Deconstructivist theories. We could suggest that the literary investigation of the term calculus was a limitation to this work when regarded in the digital sense and so the digital aspect was naively or under-represented.

What we see in the early investigations and experiments with digital tools is what one typically witnesses when a new technology arrives. Chris Luebkeman discusses this issue in Branko Kolarevic’s *Architecture in the Digital Age*. Luebkeman talks of the initial adoption of a technology being imitation followed by injudicious exploration. The third stage of the adoption of a new technology is the appropriate application of said technology. While the curved shapes produced during the explorations of the 1990’s indeed pushed formal boundaries it might be fair to suggest that for many architects digital technology has never moved far from the conservative imitation of the previous technology, ink and trace.

The early outrageous explorations didn’t take us far as towards the ‘appropriate application’ of the technology that Luebkeman calls for but they did give us a foundation to begin exploring from. In (re)defining the necessity for the combination of heterogeneous elements, as opposed to the violent clashes sought by Deconstructivism, we now can explore what these elements for combination might best be, in order to meet the challenges that face architecture today.

13. Ibid., 15.


15. I say here ‘redefining’ as it could be argued that Master Craftsmen and Renaissance architects had a fundamental understanding of the combination of building science and architectural concerns. It is sometimes said that these concerns are again ones that are being explored today.
2.3 CONSERVATISM

If we consider the architectural propositions of the nineties described above as being ones of outrageous exploration, then what we witness today in many architectural offices can certainly be said to be an environment of conservatism. The computer is employed as a drafting machine and rarely is the tool utilised beyond the description of simple rectilinear shapes. It is merely imitating previous technologies. If we compare the majority of buildings designed and constructed today one sees very little change in formal appearance to those buildings built sixty years ago. I believe this point to be important given the legacy of early digital explorations and the ability the computer gives us to explore, visualise and communicate curvilinear shapes. It seems unusual that the computer isn’t being used more by architects to explore complex spatial and formal ideas. Computers are rarely used in the design process beyond the three-dimensional representation of buildings for visualisation purposes. The potential to engage with the computer as a design tool beyond what is currently in common practise is obvious so what leads to its conservative use?
“An architect who is not a master these techniques finds himself in the painful situation of the man who wishes to compose although he plays no instrument, is unable to write music, and knows nothing of the art of counterpoint.”

Pier Luigi Nervi
Bill Mitchell discusses the issue of conservatism as being linked to a lack of understanding of the tools available with digital software. I would equate this to the act of drawing in such that, if one is unable to draw a particular shape it is extremely unlikely that one will design with it. Mitchell states that it is the issue of mathematics that architects struggle with when engaging with the computer\textsuperscript{16}. Without a fundamental understanding of how computation works architects will struggle to escape the conservative application of digital tools. Perhaps one can reflect on Pier Luigi Nervi’s pertinent comment in discussing the student that considers building as form without any knowledge of structures, and hold it comparable to the architect utilising digital tools to explore building as form without knowledge of mathematics or geometry;

\textit{An architect who is not a master these techniques finds himself in the painful situation of the man who wishes to compose although he plays no instrument, is unable to write music, and knows nothing of the art of counterpoint.}\textsuperscript{17}

\footnotesize{Pier Luigi Nervi}


If a lack of understanding of digital tools can be considered one reason for conservatism another issue is the argument that cost is too high for curved buildings to be a viable option to even begin with. In a conversation with Greg Lynn, Frank Gehry talks spiritedly against this idea\textsuperscript{18}. To illustrate his point he uses the example of Beekman Tower (2006-2010) at 8 Spruce Street in New York City (image opposite). Gehry discusses the opinions at the time this building was being designed that “bubbly shit” was not possible due to the recession and that instead architects should be looking towards the “budget-conscious sort of box” to provide their clients with value. The design of Beekman Tower involved a rigorous process that included both architect and façade manufacturer in the design stage. This meant that there was “no mystery to the design” when it came to costing the project and yielded an outcome where construction bids to build the curvaceous twisting form came in at the same price as a simple flat curtain wall system. This relationship additionally resulted in there being only around 250 requests for information (rfi) throughout construction, whereas a building of similar size would normally result in around 1500 rfi’s.

To pick up on Gehry’s comment regarding the “budget-conscious sort of box”, it is suggestive of a sense amongst architects there being some virtue in adopting a conservative approach to shape making and applying value to the design through incorporating particular materials. This is in contrast to Gehry’s approach of maximising the formal potential of a material. Instead of engaging with complex spatial or formal exploration, the qualitative aspect of architecture is reduced to a narrative\textsuperscript{19}. The conservative formal language is justified based on a story, as opposed to the pursuit of a rich formal language based upon understanding physical material qualities and the craft of building with them. The approach pioneered by Gehry and his associates requires a design team demanding in their approach in order to achieve such exceptional formal results within a standard budget. It also requires the design team to be able to maximise all tools available to them, from hand sketches to physical models and digital models to fabricated scale mock-ups.


\textsuperscript{19} Ibid., 126.
The idea that architects might be able to explore greater spatial variety due to the computational power of the computer is a rich one and something worth understanding further, particularly given the claims that the computer opens up new geometric possibilities in architecture\(^\text{20}\). Understanding more about the possibilities and application of digital tools for architecture will help the architect move beyond the conservative use of the computer.

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20. Helmut Pottmann et al, *Architectural Geometry,* (Exton, Pa: Bentley Institute Press, 2007), I. “Whereas the variety of shapes that could be treated by traditional geometric methods has been rather limited, modern computing technologies have led to a real geometry revolution”.

Image far right of 8 Spruce Street, Frank Gehry, 2010.
2.4 DIGITAL TOOLS

Digital tools available to designers today are varied and plentiful and as such, their purpose also varies greatly. Let us begin by describing not the computer but the types of software that architects commonly use to understand the implementation of computers in architecture.
2.4.1 CAD + BIM

For a long while I, maybe naively, considered CAD to stand for Computer Aided Design. However, in most instances, the ‘D’ stands for Drafting and it is most apparent that Computer Aided Drafting has come to dominate in all architectural offices across the world. The computer has proved to be a very efficient pen, triangle and curve, eliminating drawing boards from architecture offices. Yet this is where the advantages of the digital tool stops in most cases. The computer is exploited for its efficiency at drawing a series of disconnected lines and nothing more. This seems a strange situation given that what is considered the ancestor of modern CAD software, Ivan Sutherland’s Sketchpad (1963), placed parametric change at the heart of its system.

We are starting to witness a shift in the mainstream practise of architects towards what is called Building Information Modelling, or BIM. In this case, it is not a series of two-dimensional disconnected lines that come to represent a building but a virtual three-dimensional model of the building. This model comprises actual building elements; no longer do architects draw series of disconnected lines but instead walls, floors, roofs, windows and doors. And each of these elements can be embedded with all kinds of information. This information is extremely valuable when it comes to quantifying what comprises the buildings (for example areas, volumes, count of materials) and like Computer Aided Drafting, provides further efficiencies in the description of a building. Additionally, architects and engineers can co-ordinate their models to combine the architectural model with structural and mechanical systems providing a comprehensive understanding of the building before construction has begun. There is the potential for this model to be used to predict the energy usage of the building and be used for post-occupancy activities such as maintenance. Extending beyond three-dimensional representation and considering the modelling of behaviours such as these is an important aspect of BIM.

BIM can be referred to as a parametric model. This is because parameters and behaviours are embedded within elements or, because relationships between elements are established. Some building elements exist in relationship to other elements, such as a door in a wall, and if you adjust one then the other adjusts in kind. If you change something in the model, such as the composition of parts of a wall, then the parameters update.
Whilst we might associate parametric design as being part of the cutting edge of digital design it is extremely rare to find BIM be described as a design tool.

While being very good tools for architects to use in everyday practise, neither of the two practises described above have a strong impact upon the design of a building or how an architect might conceive of the design of a building. It is true that even after 20 years of use of digital tools in architects’ offices much design work is undertaken with pencils, paper and physical models.

However, all this is not to say that we don’t see further explorations utilising digital tools that extend upon the curved forms that we were beginning to see in the mid-1990’s. At what might be deemed the fringes of advanced design practise one can see all manner of wildly curving and twisting shapes in the architectural context. The twenty-first century has seen digital design tools enter the era of the algorithm through generative and parametric design.
2.4.2 COMPUTATIONAL DESIGN

There are a number of areas of digital design that might be tending to be classed in the area of Computational Design yet all maintain separate headings. Three common areas in this field are Algorithmic Design, Generative Design and Parametric Design. Definitions for each of these are difficult to find a consensus on yet generally we might consider them thus:

Algorithmic Design.  

An algorithm is, “a procedure for solving a mathematical problem (as in finding the greatest common divisor) in a finite number of steps that frequently involves repetition of an operation”21. If we think about this in the sense of design then we might consider a design being arrived at by a step by step approach that achieves some outcome. It’s important to note that algorithmic thinking isn’t necessarily restricted to computational processes yet the computer may aid in processing outcomes more quickly.

Generative Design.  

Generative design typically involves the use of algorithms to achieve some outcome through a repetitive process or, iterations. This involves the definition of a rule (often based on some phenomena) that can be tested and modified with further outcomes possible. The feedback loop is important here for outcomes to be considered generative. Typically generative outcomes may be considered either self-organisational or evolutionary. Once again these processes aren’t restricted to digital design. Pier Luigi Nervi’s hanging cloth models or Antonio Gaudi’s hanging chain or plaster models represent analogue methods for generating a form in an interactive manner.

Parametric Design.

Parametric design is perhaps one of the more difficult terms to define. Generative design is considered to utilise parameters and we might define BIM as a form of parametric modelling, that is, the building elements contain some type of parameter. Essentially we may consider parametric design as elements that have an association of some sort to a property or some other element or elements.

The tools or software available for computational design is usually from fields outside of the architectural discipline. One of the most famous examples is CATIA²², which Frank Gehry employed to construct the Fish sculpture in Barcelona, Catalonia, Spain for the 1992 Olympics. CATIA was initially developed for the design and manufacture of aircraft by French manufacture Avions Marcel Dassault in 1977. Since 1992 Gehry has adapted the technology to be more specific to architecture and released the software, Digital Project. There is other software available and used by architects such as those from the industrial design field like Autodesk Alias or McNeel & Associates Rhinoceros, or the visual effects industry where Autodesk Maya and 3dsMax are used. More recently visual programming languages are being adopted where Grasshopper, Bentley Systems Generative Components and Autodesk’s Dynamo are providing architects the tools to create ever more complex formal designs.

²² CATIA – Computer Aided Three-Dimensional Interactive Application.
2.4.3 DESIGN or DRAFTING?

Generally, even if only in a conservative way, architects can be considered to incorporate computers into the practise of design and, it is maybe unsurprising that it is the area of visualisation where computers are readily employed in this manner. Being able to view a design from any and every angle is an extremely powerful tool for an architect as they work through a design. Ideas can be tested and critiqued based upon what they look like and adjustments made to the digital model, usually in real-time\textsuperscript{23}. The computational power of the computer is harnessed to draw and re-draw the multitude of lines that would traditionally be laboriously constructed by hand. Additionally, a series of perspectival images can be prepared in addition to the tradition plans, elevations and sections, making evaluation of the design for an eye untrained in architectural conventions more accessible. In fact, an entire industry dedicated to the virtual realisation of unbuilt projects is testament to the value placed upon being able to see a building before it is built. This process is becoming more prevalent as three-dimensional models become standard for documenting a building via BIM practises.

We see here how the value of the computer is prioritised by architects around its ability to visualise works. An architect uses the computer to see a work and communicate it to others. Aside from issues of conservatism discussed previously, perhaps another reason that the early digital works within Folding in Architecture haven’t made an impact upon mainstream architecture is that visual matters were not a priority. Impressive and new shapes were introduced to the architectural discourse but with no way to evaluate them in a visual sense. The priority was upon the process, not the outcome. In most architectural work the process is varied, complex and often highly personal and, the digital tool needs to support this, not supersede it in generating outcomes that cannot be questioned. Understanding this will enable architects to move beyond using the computer to simply draft and instead open up opportunities to explore design.

\textsuperscript{23} Real-time; the display is updated instantaneously so that the view of the object is communicated back to the user with little to no delay.
“The computer is a finite machine” and, “all that computers can do is to follow simple rules quickly and reliably. A piece of software may contain thousands of rules and this gives an illusion of intelligence”

Chris Williams
2.4.4 INTELLIGENCE

In the previous chapter I introduced the idea that many things influence an architect as they design. The issue of what the building looks like however is always a principal consideration and Buckminster Fuller’s statement, “When I am working on a problem, I never think about beauty. I think only how to solve the problem. But when I have finished, if the solution is not beautiful, I know it is wrong”, is a position I think many architects can relate to. To my mind this is especially important to remember given how digital tools are currently utilised. In embracing new technologies one should perhaps heed Sulan Kolatan’s words of the danger of, “an extreme reliance upon technology. We ought to be careful about trusting a new technology to create perfect solutions on its own”24. Having looked at various ways that the computer is used in the architectural field I feel that in order to focus design practises specifically about shape and form one should better understand the computer that powers the software, how the computer works and some limitations of the tool. This in order to understand what the computer might best offer a designer to be able to pursue engaged formal exploration.

We looked earlier at ideas pervading architecture in the 1990’s. These ideas placed calculus and the idea of ‘rates of change’ at the centre of architectural thought. From here architecture explored the infinitesimally smooth and architecture of heterogeneity. These computational explorations appeared to place emphasis back upon mathematics and spatial ideas after a period of Post-Modern representation and Derridean Deconstructivist linguistic pursuits but they didn’t explore specific potentials of the computer. Calculus was the vehicle to introduce curved shapes to the architectural discourse and yes, the tools we engage with on a computer utilise calculus, but the way we interact with a computer is based upon the algorithm.

What we may understand better today is what the computer in its own right can offer to the designer. Whereas previously the curved forms being portrayed had their origins in a linguistic theory, increased computational power and access to software means that anybody is now able to define a wilfully arbitrary curved object. Merely having a pseudo-theoretical basis for exploring curved forms no longer seems enough given as we see very few built examples.

So perhaps we need to better comprehend the computer as a tool in its own right to make better use of it within our architectural design process. What then is it that underlies the computer and how we interact with it?

“The computer is a finite machine” and, “all that computers can do is to follow simple rules quickly and reliably. A piece of software may contain thousands of rules and this gives an illusion of intelligence.” The basis for any computational activity is the algorithm. An algorithm can be described as a step-by-step procedure for calculations. Whenever we interact with the computer we are asking it to follow a set of processes in order to reach an outcome. These computational outcomes are the result of an algorithmic logic. Therefore, to design something within the digital environment, one needs to be aware of this logic. Extending from this, one can also postulate that the computer is not in fact intelligent but merely a machine that is very good at performing calculations. A human on the other hand is intelligent but with relatively little computational power. We might begin to argue then that computer aided design needs to align the advantages of the calculating power of the computer to the intelligence of the human operator rather than expecting the computer to produce Kolatan’s perfect solutions on its own. As Steve Jobs famously remarked, “what a computer is to me is it’s the most remarkable tool that we’ve ever come up with, and it’s the equivalent of a bicycle for our minds.” The computer is a tool, one that allows us to process large amounts of data and architects should be using this power to extend their own intellect.

It is undoubtedly controversial to suggest that the computer has no intelligence. After all, there are many investigations happening in the area of artificial intelligence that certainly hope towards this not being the case and, a simple argument for computers being intelligent might be that all we need to do is understand the human brain in its entirety and then reproduce it perfectly with the outcome being an obviously intelligent replica. Or, if that sounds unfair, then by Alan Turing’s Turing Test to establish artificial intelligence (AI), whereby Turing stated that if an interviewer is unable to ascertain through questioning which of a pair of responses are human or machine then it does not matter how the responses are elicited and thus the machine can be considered intelligent.


27. Ibid., 79.

28. From a documentary Memory & Imagination: New Pathways to the Library of Congress, link last accessed 25 July 2014. http://www.mlfilms.com/productions/m_and_i Video: http://www.youtube.com/watch?v=6kalMB8jDnY . Steve Jobs makes this statement after first discussing humans as ‘tool builders’, “I think one of the things that really separates us from the high primates is that we’re tool builders. I read a study that measured the efficiency of locomotion for various species on the planet. The condor used the least energy to move a kilometer. And, humans came in with a rather unimpressive showing, about a third of the way down the list. It was not too proud a showing for the crown of creation. So, that didn’t look so good. But, then somebody at Scientific American had the insight to test the efficiency of locomotion for a man on a bicycle. And, a man on a bicycle, a human on a bicycle, blew the condor away, completely off the top of the charts”.

29. Steve Jobs makes this statement after first discussing humans as ‘tool builders’, “I think one of the things that really separates us from the high primates is that we’re tool builders. I read a study that measured the efficiency of locomotion for various species on the planet. The condor used the least energy to move a kilometer. And, humans came in with a rather unimpressive showing, about a third of the way down the list. It was not too proud a showing for the crown of creation. So, that didn’t look so good. But, then somebody at Scientific American had the insight to test the efficiency of locomotion for a man on a bicycle. And, a man on a bicycle, a human on a bicycle, blew the condor away, completely off the top of the charts”.
However, as stated above, the intelligence demonstrated by a computer is an illusion based upon the ability to recall information. We have a number of examples to point to that suggest that no matter how hard we try, the computer will offer no more than the ability to give feedback based upon a set of given instructions.

A simple example of this might be the mobile ‘smart’ phone. You can talk to the phone and have it set appointments or find you somewhere close to eat yet none of these activities suggest that the object in your hand is intelligent, it is responding to a set of inputs and you aren’t able to have a meaningful conversation with it. Moreover, we can compare the computational capacity that we currently have had for some time and compare it to that of a bumblebee. While of similar processing capacities, we do not see computers forming social structures, fending off threats or reproducing. We can also consider the intelligence required for a human to walk, to co-ordinate the enormous number of impulses to balance as a step is taken while processing the surrounding environment and compare to the exploits of robots, even those as advanced as in the DARPA Robotics Challenge, where this form of analysis demonstrated by a human is beyond even these most sophisticated and powerful of machines. In each of these situations we note that the computer processes a set of instructions and provides a result based upon the inputs. Animals and humans however are able to make analysis and adjustment based on unknown variables.

A considered philosophical response to the issue of artificial intelligence can be seen in the philosopher John Searle’s Chinese Room situation. This example explains why a computer cannot be considered to think. In the scenario, one is to imagine themselves as an English only speaker locked in a room. In that room are baskets of Chinese symbols and some rules so that you can manipulate the Chinese symbols. These rules determine the purely formal manipulation of the symbols, their syntax as opposed to semantics. You then imagine that Chinese symbols are passed into the room, ‘questions’, and you are able to pass back ‘answers’, having been provided further rules to pass Chinese symbols back out of the room. The responses sent back are unidentifiable to the native Chinese speaker as being by somebody that doesn’t understand Chinese and hence imagines that the person in the room knows and understands Chinese.
However Searle asserts that the responses are merely the result of following a series of instructions, or programme, and that the respondent cannot possibly learn Chinese from simply manipulating the formal symbols. Searle goes on to restate that, “a computer has a syntax, but no semantics” and that to have a form of mental state involves more than having a bunch of formal symbols. Searle goes on to make four conclusions as to why computers cannot have minds and therefore no intelligence.

If then we are to conclude that the computer is incapable of intelligence, I would like to set aside in this study the area of so-called bottom up digital design processes. These generative techniques suppose a set of abstract phenomena as defined by the author and compute a result based upon the algorithmic description of said phenomena within the computer. Not being trained in computer science or able to accurately reproduce biological algorithms I would prefer to focus the study on the properties of what a building might look like and investigate ways to engage the computer to deal with visual matters. After all, visual matters are to-date where the majority of my architectural work and education has focussed and to repeat Antoine Picon once more, the situation of setting limits to design can be considered such that “design is no longer involved” in the sense that the designer is not directly engaging with and adjusting the shape of a building.


30. Ibid., 28-41.

2.4.5 SIMPLEXITY

The digital tools available to architects today are becoming ever more powerful and intuitive to the operator. This follows a general trend of ease of use of digital devices witnessed in the way a small child, monkey or even cat can use a tablet device. There doesn’t need to be a reasoned or intellectual engagement with the digital device for the user to access simple, top level functionality to achieve some output. We might say that this is also true of much of the software available to designers. The tools available, even at the top level, allow an individual with relatively little architectural training or digital understanding to create all manner of curved digital shapes. Modern engineering analysis tools and construction techniques would also mean that many of these shapes would be able to come to full realisation (even if at huge financial expense).

So then, what value is there in these digital tools with relation to design? What are the “tools for the efficient design, analysis, and manufacturing of complex shapes” 32 that Ceccato talks of and how might architects start to incorporate these tools into design thinking?

Mark Burry is an advocate of digital tools and their positive impact upon the understanding of design. He is the lead architect on Antonio Gaudi’s Sagrada Familia and began work on this project at a time before digital tools were commonplace. Burry talks positively of the way digital tools have aided in the understanding of Gaudi’s models and drawings and the speed enhancements that they have brought to the project. For Burry, scripting is one of the most powerful tools an architect can understand to make benefit of the digital tool. By understanding the language that drives the computer one can better appropriate the tool for one’s own needs. This means however that the architect needs to be trained to be more than a mere user of the software.

Yet does this mean that an architect need solely focus upon being a computer scientist? I would argue no, yet architects do need a greater awareness as to how the tools that they use function at a deeper level in order to utilise the computer to extend their design ability. Mark Burry tells a story of his introduction to scripting in 1992 to help in the production of drawings for the Sagrada Familia.

“now that there is massive computer power and software cheaply available, most scripting has become nothing more than an onanistic self indulgence in a cozy graphics environment. Endless repetition and variation on elaborate geometrical schema with no apparent social, environmental and technical purpose whatsoever.”

John Frazer
Burry had been drafting in AutoCAD™ a series of curves and points, calculating and labelling each as he went, an entirely laborious exercise and one taking no advantage of the available computational power within the ‘black box’. Once he had learnt to script this process however, the computer was able to compute each curve in seconds as opposed to the best part of an hour it was taking him to do so manually. This is a perfect example of utilising the computer to augment a human’s intelligence, Steve Job’s bicycle for the mind.

There is a danger when it comes to scripting however, something that Burry discusses in his book, Scripting Cultures. Burry talks of how it is easy to achieve complex formal effects with a series of simple scripts that simply repeat a number of times. Burry puts forward the statement of John Frazer as further evidence of this position, “now that there is massive computer power and software cheaply available, most scripting has become nothing more than an onanistic self indulgence in a cozy graphics environment”.

This is something that we see commonplace in examples of digital architecture, where this complexity is deemed a worthy outcome by virtue of the belief that an outcome is complex simply by producing a complicated spatial or formal proposition. But there is little to no consideration as to the basis for this form making and so it becomes difficult to assess in any meaningful way. Contrary to this approach we may argue that it is much more difficult to understand a complex concept or set or rules and execute a simple routine to achieve some desired effect, as in Burry’s example from the Sagrada Familia. It is at this point one might be considered in control of the digital tool rather than being led by it. This being something we might call ‘Simplexity’.

“Simplexity is a term in system science which describes the emergence of simplicity out of intricate and complex sets of rules.”

Sawako Kaijima and Michalatos Panagiotis

Burry talks further on his experience in scripting. Whereas he had previously seen scripting as something that had to be done for a designer heading towards the 21st century, the experience of turning a repetitive, time-consuming and mundane task into one of rapid production changed his relationship with the computer.

34. Ibid., 52.
35. Ibid., 92.
Now with an understanding of how the computer might work for him, Burry felt able to transcend the limitations of the software and use it with the same authority as a pen and compass. We see above that Burry was originally employing the computer as he would a pencil and paper. Only when he appropriated the tool specifically to his intended purpose was he able to see the computational advantages that the computer offers.

The idea of understanding the toolkit available in modern architectural software is one that Robert Aish discusses with passion. Aish is a long time user and designer of digital software and a founding member of the Smart Geometry Group. He has served as lead software designer for architectural software produced by both Bentley Systems and Autodesk. Aish discusses the existence of a powerful and general geometry toolkit that exists below the top level tools that most architects engage with.

Through understanding how to access these tools an architect can begin to build their own semantics for design, as opposed to being limited to the grammar offered by the basic set of top level commands. A grammar that Aish argues is pushing a conservative semantics for much of architectural design. The idea of “a tremendously conservative situation” is a product of architects not having a fundamental understanding of mathematics and computation. Without this architects are not seeing the full benefits of digital tools and are “trapped irrevocably in this cycle of conservatism that I think one can observe in a lot of work”.

The computational power of the computer then is not being fully harnessed by architects and the computer exists in the main either as simply a very efficient drawing board or, where architects do utilise advanced software tools, we note that it often accompanies a preoccupation with the unchecked proliferation of unbuildable shapes. These shapes we need to start understanding more fully and consider further their foundations. If we take Jim Glymph’s position that, “architecture needs to return to a more direct association between material, craft, the physical reality of the building and its own design process” we may discover a starting point for Chris Luebkeman’s “appropriate application” of the new technology.

36. Ibid., 30.
38. Ibid., 294.
39. Ibid., 294.
40. Ibid., 65.
Two very influential current practising architects are Norman Foster and Frank Gehry. These are two significant architects working at the forefront of digital design. Their work has developed over a number of years with various theoretical concerns and digital technologies have allowed each to build previously unworkable projects. Foster has an in-house Specialist Modelling Group (SMG) that is a multi-disciplinary group researching and investigating the use of digital tools and their application to digital design. This group provides custom tools beyond those accessible at the top level of the software package for architects within the office to use on design projects. Gehry goes even further and has developed his own software package, Digital Project, which other architects are now adopting. This software allows for the link between design and fabrication processes of architecture. These approaches are representative of those that we note Robert Aish discussing earlier, in that these architects are removing the constraints exhibited by the top level CAD tools and utilising the “very powerful and general geometry toolkit” underneath to invent their own semantics.
Looking at the work of these two architects one notes a very different aesthetic – you could not mistake either’s work for the others. While Foster’s work appears very rational and organised Gehry’s comes across as playful and whimsical. Could there be something that links the work of these two architects together? Through analysing buildings of the two architects we can begin to draw some parallels in the approach to design. And that approach begins with a tacit knowledge of how their buildings might be constructed.

Frank Gehry develops his buildings physically. From sketches he builds large models that are digitised for further analysis, development and ultimately to describe the building to those that will be building it. Gehry often uses strips of paper in his physical models to describe the surfaces of his buildings. We can describe these building surfaces as a developable or ruled surface. These types of surface can be built, like their modelled equivalents, out of a flat and or flexible material as they only curve in a single direction. For reasons of economy Gehry is conscious of how many surfaces in his designs are flat, of single curvature and doubly curved keeping the highly shaped pieces to five percent.

“Flat pieces cost one dollar; single curvature pieces cost two dollars; double curvature pieces cost ten dollars. The good thing about the computer is that it allows you to keep a close control over the geometry and the budget. It was not just speculation; it was real.”

Frank O Gehry

44. See section 3.5 ‘Surface Types’.


46. Ibid., 71.
The process used by Gehry to model his buildings is interesting and it is here that we can see a parallel with Foster. The understanding and awareness of the physical construction of a building is similar to Foster’s buildings, in particular a series of buildings designed and built from 1987 to 2004 that explored the ‘torus patch’. In these buildings, the torus was sliced to give canopies for the Canary Wharf underground station and the roof of Copenhagen Zoo’s Elephant House as well as being combined, revolved and translated to give shape to buildings such as 30 St Mary Axe, Albion Apartments, Chesa Futura and the Sage Theatre. In each case the underlying geometry allowed for economic construction of the buildings from flat building materials and, like Gehry, providing apparently curved buildings within reasonable economic constraints.

There is a clear difference when we look at the work of these two architects however. Foster continues to celebrate technology and structure in his buildings as in what was deemed the High Tech style of his earlier work. One is able to clearly articulate the outline of the exterior of a Foster building and see a relationship to the interior volumes, which continues an early design direction of Foster to integrate the skin, structure and services of a building, notably seen in the Sainsbury Centre for Visual Arts, Norwich, UK (1974 – 1978). Gehry on the other hand seemingly works skin and structure separately and perhaps is a reflection of the Deconstructivist style. In much of Gehry’s work the interior and exterior often bear little resemblance to one-another and between these two worlds the structure is hidden away. Bruce Lindsey describes this process as, “skin in”; the system is “skin, a space for connection, and a space for the structure”. Lately we might perceive a shift in Gehry’s work, back to what one might have read in his early work where the structure is pulled out and put on display. For example, in the Walt Disney Concert Hall (1999-2003) in Los Angeles we can see the outer panels being aligned with the underlying structure, strengthening the material, structure and fabrication relationship. Perhaps we can start to read this as an acknowledgement of the importance that geometry and structure play in Gehry’s work and the expression of a wider reading of it.


49. See section 3, ‘Geometry’ for further explanations.

Drawings of the Sydney Opera House. The drawing on the left depicts the reinforced concrete shell competition scheme (1957) with the drawing on the right from the Yellow Book (1962) portraying the ribbed precast shells. Image credit: NSW Government State Records.

We can describe the systems for design employed by Foster and Gehry as relational. In contrast to modernist systems, based upon a standardisation and separation of structure from walls, these two architects work with elements of the building that depend upon each other. While it is obvious to see the relationship between skin and structure in a Foster building it is no less important in a Gehry building. Here is maybe a link back to those digital explorations in the 1990’s where parts of a building are ‘folded’ together in order to realise a new aesthetic. This describing of a relationship of parts is not new nor is it unique to Norman Foster, Frank Gehry. We can see the origins of this approach to architecture in a much earlier building.

Geometry and structure play a fundamental role in the realisation of one of the twentieth century’s great buildings, the Sydney Opera House (1957-1973). In 1957 Jorn Utzon produced a competition winning scheme of organic looking shells sitting atop a podium. The project at this stage was envisaged as a single skin, reinforced concrete shell, similar to other reinforced concrete buildings like Le Corbusier’s Notre Dame de Haut (1950-1955) and Eero Saarinen’s TWA Terminal (1956-1962). These curvaceous monolithic structures were made possible in the nineteenth century to the mid-twentieth century through industrialisation and the development of iron, steel and reinforced concrete and peaked in their use in the 1960’s. In the years that followed the engineers tasked with realising the structure for the Sydney Opera House, Ove Arup and Partners, struggled time and again with achieving a solution that aligned structural and aesthetic sensibilities. The parabolic shell solution simply wasn’t achievable due to either the weight of the structure or the cost.

The resolution for the shells presented itself in mid-1961 after a series of at least a dozen explorations including schemes with parabolas, ellipsoids and circular ribs. The solution involved using spherical geometry so that all shells could be formed from the same arc. This rationalised solution allowed for the re-use of moulds for structural ribs resulting in benefits in cost while also expediting construction with less waste when compared to a reinforced shell system.
geometrical construction showing the shells of the major hall (eleva...
There are interesting things to note here. The first point is the significantly altered shape of the building. The low smooth shells of the competition scheme were replaced by taller arches finished in the now distinctive striped panelling. The lack of geometric knowledge at the outset resulted in a building proposition unable to be realised. This leads to the second point, which is the significant impact geometry was to bear upon Utzon’s subsequent work, as seen in the National Assembly Building in Kuwait (1971-1983). What I find extremely interesting is that while admitting to a limited understanding of mathematics, Utzon was still able to understand and solve structural architectural solutions geometrically. This suggests that numerical mathematics might not be an absolute entry criteria to gaining advantage from digital tools but, geometric mathematics very possibly is.

The Sydney Opera House “made it clear that complex freeform shapes needed sophisticated techniques of geometric description and integration of structural and fabrication principles to make them buildable”55. The traditionally held relationship of the architect designing the formal concept for a building and then working with an engineer to find a suitable engineering solution in the nature of ‘form, structure, material’ was reversed in the relationship developed between Utzon and engineers Jack Zunz and Ove Arup. Peter Rice in, An Engineer Imagines (1994), identifies this collaboration as one where, in order to find the final solution, the process was flipped to become ‘material, structure, form’; the final solution for the geometry for the Sydney Opera House comes from the covering tiles that influenced the design of the rib structure and the overall form of the roof 56.

In the example of the Sydney Opera House we see once again, as with Foster and Gehry, an understanding of the physical properties of a material leading to exceptional structural and formal solutions. This linking of the material craft in architecture with shape making is one of the key elements of interest for this thesis. It is the link between geometry, structure and shape that I am most interested in developing with this project.
3. GEOMETRY

Given that the study of geometry is critical to this project it is necessary to understand how geometry is represented in the computer. Principally, shapes in digital space are described with points, lines or curves and surfaces. Curves and surfaces are the basic elements by which we can explore architecture. We may consider curves as the profiles that are used to define a surface. In their 724 page book, *Architectural Geometry*, Helmut Pottmann, Andreas Asperl, Michael Hofer and Axel Kilian explain the mathematics of curves and surfaces in far more depth and detail than I could ever hope to in this study. From their work however, it is useful to identify some specific properties for defining surfaces and, types of surfaces useful for this architectural project. Before doing so, I would like to discuss further the way that shapes are represented on a digital display to further explain the approach for considering the project to be comprised a series of flat panels.
“we must elevate to first-class citizens the discrete facets of the structure – the mesh, in the case of the computer – as the building blocks of our designs”

Peter Schröder
3.1 PETER SCHRÖDER

It is useful to discuss the representation of the shapes we define on the computer screen as it is important to understand the technology and there is also the potential that it could also form a basis for an approach to a formal design language. We have already discussed computer software being used to explore ideas of the infinitesimally smooth (Greg Lynn et al.), however the shapes that we see on the computer screen are not actually smooth at all. They are comprised of many faceted pieces to give the illusion of smoothness. This is interesting if we consider a building that will be made from physical materials. In most instances the building will comprise straight members of steel and glass due in large part to established construction practises and issues of economy; curved materials are expensive and specialised. Like a pixelated digital image, our buildings are formed of finite pieces that achieve seamlessness and the smooth aesthetic as we move away from them. In understanding the digital medium in this way, Peter Schröder suggests that the “mathematics of the smooth curve should still guide us, but we must elevate to first-class citizens the discrete facets of the structure – the mesh, in the case of the computer – as the building blocks of our designs”.

The mesh is a way in which one may consider a surface, as represented by its component parts. A mesh can be defined as “a collection of points (vertices) arranged into basic elements called faces. The faces are bounded by polygons and the polygons fit together along common edges and roughly describe the shape of a smooth surface”\(^{58}\). The development of a mesh as an architectural and structural solution can be seen as an early example in the double-curved shaped roofs of the Sydney Opera House discussed earlier.

Schröder’s argument reinforces earlier research in this study and contributes to an ideological position for meshes to be considered as a fundamental aspect of digital architectural design. If we look at the physical properties of the materials that we use then we see that it is most likely that rigid flat elements will be necessary. Issues related to cost are significant where curved components increase costs to unrealistic levels. Concerns of the environment and quantity of material used should also be a consideration and the efficient application of particular types of mesh is important to understand. We have the argument above by Schröder, highlighting the significance of the mesh for digital design thinking.

If we combine the factors studied so far there is a compelling argument to investigate appropriate surface conditions for a mesh that works with these ideas.

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3.2 MESH SUBDIVISION

With the use of a mesh to form the basis for the exploration of building shapes established, we should understand how a surface might be broken down into mesh elements for construction, given curves and surfaces are a principle means of describing shapes with computer software. A mesh is derived from a surface where typically the surface is divided into triangles, quadrilaterals or sometimes hexagonals and occasionally some other pattern such as a voronoi. I will focus on the first two as they are the more common mesh solutions.

The most basic and common technique to derive a mesh from a surface is to divide it into triangles. This is the most efficient method due to convenience. It is a basic approach and triangles easily represent all surfaces. The three points of a triangle exist in a flat plane so the panels are always planar and there is an inherent structural stability when utilising triangular meshes.

Figure showing the same surface represented as a triangular and quadrilateral mesh.
Figure showing images of the Smithsonian Institution roof, Foster+Partners, 2007. Image credit: Nigel Young, Foster+Partners.

Triangular meshes are commonly seen in architecture as a ‘thin’ skin across a building. Examples of this include the glazed roof by Norman Foster over the Great Court at the British Museum (1994-2000) and the glazed roof over the DZ Bank atrium (1995-2001) by Frank Gehry. It is uncommon to see triangular meshes being used to provide thickness to building elements. This is because triangular meshes are not well suited to offsets. When offsetting a mesh we look for a common node axis. The issue with a triangular mesh is that the offset parallel mesh is a scaled copy with respect to some centre resulting in approximate solutions that uniformly distribute the error throughout the nodes of the mesh. The consequence of which is complicated, inefficient and costly construction. Offsets are important to consider in architecture as the buildings we construct are not like digital surfaces without thickness.

Yet if we consider that the surface will comprise quadrilaterals we initially discover that there are issues with planarity. Yes, we could divide any surface into quadrilaterals but this would usually result in the need for curved elements. If we look at the example of Foster’s roof at the Smithsonian Institute, Washington DC, USA (2004-2007) we see clearly that flat quadrilaterals are unable to define any surface.

While more intellectually challenging to the designer, there are a number of advantages with quadrilateral meshes over simply triangulating the surface and the benefits offer interesting areas for architectural exploration.

The benefits of planar quadrilateral over triangular meshes are notable in architectural terms. Firstly, a quadrilateral mesh has greater surface area and less structural members. This results in greater areas of glass or cladding panels which points to less weight overall for the quadrilateral system. Cost per-area, quadrilateral panels are cheaper than triangular. Since fewer members meet at each intersection (four vs six) the node junction for the quadrilateral system is less complex. In addition, it is not possible to generate torsion free nodes for triangular meshes which are preferable for construction. Offsets with planar quadrilateral meshes offer greater architectural potential compared to triangular meshes.

60. I say ‘thin’ as the building element is a single thickness, like a two-dimensional surface in digital space.


62. Ibid., 676.
3.3 PLANAR QUADRILATERAL MESSES

If we think of curved buildings with regards to physical material qualities, construction practises and structure, we can consider geometric principles that might be employed to conceptualise and design such structures. Instead of starting a design within the digital environment without any constraints, we consider the material, its physical qualities and the geometric solutions that work with those properties and explore such geometric potentials to respond to an architectural brief.

It seems an absurd assumption that we begin designing a building without any sense of the material we will use or how it might be constructed yet one can note a number of examples where this is in fact the case, the Sydney Opera House being just one. If we consider a building as a series of elements, or faces, connected together then the way in which we consider these faces is important in an architectural sense. If we consider that the face is to have some restriction, say, to be planar, what are the limitations and possibilities for the various shapes we might define? Why planar? One assumption is that we see little free-form architecture due to issues of cost. Curved building components are more expensive than flat materials which are in most common use. It has been noted how Norman Foster and Frank Gehry employ flat materials in their apparently curved buildings. Often these materials are not just flat but also quadrilateral. Not every surface can be described as a planar quadrilateral mesh and we need to understand specific qualities of a surface that will result in planar quads. Benefits of planar quadrilateral meshes to architecture are discussed above but what additional constraints might planar quadrilateral meshes present over triangulation when considering the type of surface to design.

One can consider surfaces as belonging to various classes. These classes determine the types of mesh that can be derived. Examples of such classes are Conic Sections, Traditional Surface Classes, Freeform Surfaces, Quadrilateral Meshes, Sweeping and Skinning and Developable Surfaces. Let’s examine some types of surfaces that might be available to design with now that we have this restriction for planar quadrilaterals.

The following two sections give an overview of surface types and, or ways of defining a surface that have been found useful for this thesis in terms of defining planar quadrilateral meshes.
3.4 CURVES

Where numerical mathematics is used in this section it has been derived from Pottmann et al. and is used to highlight the difference in numerical and geometric mathematics. The geometric aspects are focused upon in order to provide principles for a designer to use in design exploration which can later be refined using associative models and numerical mathematics.

Before discussing surfaces it is useful to first discuss curves. Curves are used to define a surface and can be considered as comprising a string of points. Pottmann et al. describe a curve as a “connected one-dimensional series of points”[63]. Special types of curves are straight lines, circles, helixes and the conic sections. Curves can be classed as ‘planar’ or ‘spatial’. A helix is a true spatial curve as it does not fit into any plane. We find the helix used in architecture on columns and as staircases. It is the planar curves that are of greater interest to this study.

The conic sections are of particular interest and a conic can be described as a curve by the quadratic equation[64]:

\[ a \cdot x^2 + b \cdot x \cdot y + c \cdot y^2 + d \cdot x + e \cdot y + f = 0 \]

Equally we may understand them visually as demonstrated on the following page.

Conics shouldn’t be confused with a catenary which appear similar and can be best described as a rope or chain hanging under gravity. The mathematical description for a catenary is:

\[ Y = a \cdot \cosh(x/a) \]

Catenaries are useful to us for the creation of a minimal surface, which can be generated by sweeping a catenary around an axis. A minimal surface is defined as a surface of zero mean curvature and can be investigated using a wire boundary and soap film. These types of surfaces are common in the work of Antonio Gaudi, Felix Candela, Pier Luigi Nervi, Frei Otto and Heinz Isler. Often realised in reinforced concrete these shapes reached a peak of their use in the 1960’s.

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64. Ibid., 231.
Ellipse: $b^2x^2 + a^2y^2 - a^2b^2 = 0$

Hyperbola: $b^2x^2 - a^2y^2 - a^2b^2 = 0$

Parabola: $x^2 - 2py = 0$
Further types of curves are those that can be described as ‘freeform’. These include Bézier, B-spline and NURBS (non-uniform rational b-spline) curves. These curves are shaped by a number of control points that define a ‘control polygon’ and are more recent in their use than those curves described above. These curves can be found in tools developed from the 1950’s but have their origins in the lofting table of boat building as a weighted spline. The differences in these curve types is generally to do with the level of control offered by each. Control is offered by design handles; Bézier curves are controlled by ‘control points’ only, B-spline by ‘control points’ and ‘degree’ and NURBS by ‘control points’, ‘degree’ and ‘weights’. The ‘control point’ is used to define the curve. The ‘degree’ controls the proximity of the curve to the control points. For instance, Degree n = 1 is considered a ‘linear’ B-spline and consists straight lines between the control points and is otherwise known as the control polygon. As n increases the curve moves away from the control points. The ‘weight’ drags the curve towards or away from the control point which occurs locally to the individual control point. NURBS curves can be used to describe all of the conic sections.

If we are to consider the usefulness of these curves we may consider it thus; For a Bézier curve any change to a control point has an effect on the overall curve. Adding or subtracting control points makes a global change to the curve. The greater the number of control points in a Bézier curve the less the curve will represent the control polygon. B-spline curves adhere to the shape of the control polygon better than Bézier curves and can be controlled locally at each control point. NURBS add the effect of being able to adjust locally the weighting of the individual control points.
Figure demonstrating the discretization of a sphere surface to a polyhedral mesh.
3.5 SURFACE TYPES

From curves we can begin to define surfaces. Surfaces can be smooth or they can be defined as a ‘polyhedral’ surface. A polyhedral surface is one bounded by planar faces, something that this study is aiming to work towards. The most basic way to think of a polyhedral surface is a pyramid but also the Platonic solids; tetrahedron, cube, octahedron, icosahedron and dodecahedron. Geodesic spheres are a further example. A geodesic sphere can be thought about as taking a smooth spherical sphere and ‘discretizing’ it into a fixed number of elements, or faces. As the number of vertices increase the shape becomes smoother.

The concept of discretization is an important one. It is taking a smooth shape and reducing it to a lesser number of discrete parts. In terms of a building this is the process we take when translating a smooth surface into one that we can make buildable from flat elements.

In the following I investigate surface classes paying particular interest to those surfaces that result in planar quadrilaterals through the process of discretization.
Figure illustrating a curve rotated to achieve a smooth surface and a polyline rotated and a resulting polyhedral surface.
Let’s start with Traditional Surface Classes. These are based on what is termed ‘kinematic’ generation. An ‘extrusion surface’ is created by moving a curve along a straight line. A ‘rotational surface’ rotates a curve around a straight line or ‘axis’. A ‘ruled surface’ is generated by moving a straight line along a curve and a ‘translational surface’ moves a curve along another curve.

I touched on rotational surfaces earlier when discussing a series of buildings by Norman Foster. The building 30 St Mary Axe (1997-2004) is an example of a curve being revolved around a centre. The interesting thing about rotational surfaces is that a smooth curve can be approximated by a polyline. We can additionally discretize the rotation to create a polyhedral surface.
Figure showing the cylinder, cone and torus.
If we look at special cases of rotational surfaces we have cylinders, cones, spheres and tori. The first two cases are generated by rotating a straight line around a centre while the second two utilise a circle. If we rotate a circle around any of its diameters we achieve a sphere. If we move the rotational axis away, in the same plane as the circle, we generate the torus; spindle, horn or ring torus depending if the rotational axis is less than, equal to, or greater than the radius.

The Foster projects mentioned previously explore the properties of the torus, or toroid, patch, a part of the torus. This is useful in an architectural sense in that two circles define the shape and hence it is possible to extract planar quadrilateral meshes.
Figure demonstrating cutting plane through a cone to produce an ellipse and parabola.
The ability to generate a cone through a simple rotational translation of a line is useful to help understand the benefits of the conic sections, the ellipse, parabola and hyperbola.

When rotated the conic sections begin to provide interesting surfaces that have a history in architectural design; the ellipsoid, the hyperboloid and the paraboloid. The surfaces are now starting to become more complex than a simple spherical geometry but follow similar laws of logic and are useful when considering their construction. We start to see a greater range and level of control of complex surfaces with double curvature.
Figure showing translational surface with ‘generatrix’ and ‘directrix’.
The ruled surface is alluded to above in the description of the cylinder and cone. Ruled surfaces are of particular interest in architecture as they consist of a family of straight lines that can be unrolled onto a plane and thus can be constructed more easily. These surfaces are created by revolving a straight line in space. Ruled surfaces can also be created by sweeping a straight line along a profile curve. In most instances a ruled surface is singularly curved yet there are special cases such as the hyperbolic paraboloid (saddle) and one sheet hyperboloid (cooling tower) where the surface is doubly curved. A ruled surface can also be generated by moving a straight line along another curve, the ‘genratrix’. If the direction of the line stays constant we produce a simple extrusion surface however if we adjust the direction of the straight line as we move along the curve we create a ruled surface with a more complex shape. Ruled surfaces are implicit in the use of paper strips in the model making process utilised by Frank Gehry.

Translational surfaces are similar to the idea of extruding a curve to achieve some surface. This time we move, or translate, the curve along another curve. The first curve is known as the generatrix and this is translated along the ‘directrix’, as defined by Jim Glymph\textsuperscript{65}. This process will result in a surface consisting of planar quadrilateral mesh. Glymph determines the basic principle for a planar quadrangular mesh as maintaining a parallel set of vectors that connect to a sectional curve. This is similar in principle to the ruled surface above in that we can think about it as straight lines being used to connect a series of generatix curves.

Figure depicting various transformations of a curve into a surface; beginning with a straight polyline, moving to a curve; extruded surfaces with affine transformations; translated surfaces, ruled surfaces and finally a complex translational surface.
It is the visual geometric representations over the numerical mathematical descriptions that I find most useful as a designer trained in visual matters. While it is necessary to define a curve using formulas within software packages to create a relational or associative model, I first need to be able to see what it is that I want to create. The digital ‘parametric’ or ‘associative’ model then enabled me to investigate versions or iterations of this model visually. The limitation of this technique in a design sense however was that once relationships were established there was no way to explore options outside of the implied limits. The investigation needed to work towards a more flexible system for modelling.
4. DESIGN PROPOSAL
4.1 PROJECT OUTLINE

The project for this study is entirely hypothetical which has afforded freedoms a real project otherwise might not. Throughout the process of this thesis it became apparent to me that the most important issue was not specific project outcomes but instead the impact that the study has had upon my design thinking in general. I am satisfied with this as I had hoped that the course of study would provide reflection upon design practises that I have been using for a number of years and in particular highlight the greater relevance and application of digital technologies in my work. However, while I hopefully demonstrate the application of my developed methodology in a wider sense, there does need to be a design project to which it has been applied.

The proposal then is as follows.
4.2 BRIEF - VIADUCT EVENTS CENTRE

The type of structures that this study has been looking at lend themselves to being of an open, long-span type building. A freeform building might sit best in an open site where it can act as a focal point for other activity around it. There is such a location in Auckland in the newly developing Wynyard Quarter precinct. More exactly, the location of the recently completed Viaduct Events Centre on Halsey Wharf.

This is a fantastic site at the edge of Auckland’s central business district. It is close to the heart of the entertainment areas and has connections to the water on three sides as well as impressive views back to the city, the marina and out to the Waitematā Harbour. The area is a working portside with commercial boats coming in and out which require access to the west side of the wharf.

The brief for the design itself comes from the existing building. This project aims to work with those criteria, set out as follows:

A multi-purpose events centre;

Exhibition hall, meeting rooms, conference spaces, offices.

Public promenades to the east and west.

12 meter clear internal height.

Area ≈ 6400m²

The project will also engage with the following considerations:

Consideration of the overall site and potential engagement.

Legible overall form.

Defined entry.

The considerations above are due in part to possible criticisms that I have of the existing building.

Further, in the interest of this study the design proposal should also consider:

Double curved surfaces.

Offset surfaces.

Environmental considerations;

Daylight, minimise shading by building to the south, shading from the northern sun, wind protection (particularly to entry).

With these criteria established I’ll outline the development of the design.
Figure locating the site: Halsey Wharf, Auckland, New Zealand.
Figure illustrating digital analysis of wind across the site.
4.3 PROJECT DEVELOPMENT

It is important to understand the site from the outset of a project to recognise where the greatest potential might be. Multiple visits to the site were important to see how it is being used and what the environmental conditions are like. Digital tools can aid in gaining an understanding of the environment, particularly over a longer duration of time.

Combining the digital and first hand analysis highlighted the potential of the northern most tip of the site as being one with direct sunlight at all times. Further, the eastern edge of the site is well sheltered from winds year round. These two factors highlight the potential for some public activity in these zones and are suggestive that the building should not be placed in either position. The western edge of the wharf is heavily used for marine activity by large boats, as is the rest of the harbour edges to the west. The harbour to the east is more recreational with smaller craft using the water. There is a strong pedestrian connection running east-west at the southern edge of the site.

Views are excellent in all directions with particular focus south-east to the city, east to the marina, north to the harbour and west to what will become a large park. The wharf itself sees nearly no people using it due to a distinct lack of public activity.
Figure showing view north to Waitematā Harbour.
Figure showing view to east across the Viaduct Marina to Auckland CBD.
Figures showing various explorations using gravity driven cloth modelling and geometric processes.
4.4 PROCESS

I began the exploration of shape with parallel exercises. The first by looking at geometric shapes influenced by the hanging cloth models of Pier Luigi Nervi and Heinz Isler and more generally by exploring geometric shapes based upon the conics through translational surfaces (ellipses, hyperbolic and parabolic surfaces) along with instances of the torus patch. This was done within the existing building footprint as an initial exercise to understand the scale and potential for shapes within the constraints.

The hanging cloth, or gravity driven models were interesting in that they begin to define a curved shape based upon physical properties set for the material. The outcomes are in themselves pleasing to the eye as forces can be traced across the shape to the ground with shadows falling enjoyably across the surface. There are obvious restrictions with regards the initial state (a rectangle) but numerous outcomes could still be explored depending upon the anchor points constraining the surface to the ground. Shapes other than rectangles were explored later through more complex modelling methods that defined a variety of original mesh states.

A major benefit of this approach is the already proven outcome that the shapes become buildable due to their inherent structural stability that comes from the production of a minimal surface. However, they are not necessarily easily definable as a series of planar square panels and more importantly, they work within set limits of a phenomena, in this case gravity, which is something that I was seeking to avoid in this study.
Figure showing parabola with various levels of subdivision.
The second study investigated parametric, or associative, models based on some strict geometric principles. I also investigated transformation of surfaces by moving or scaling curves that defined the surface. This maintained the planarity of the quads and so proved a useful experiment that could be applied later. The most interesting part of this research in terms of the thesis overall however is demonstrated in the images opposite exploring a parabola.

I defined an associative model using Grasshopper and Rhino to first describe the parabola (see following page). This was used to create a translational surface. The definition was driven through a numerical mathematical formula and could result in a parabolic arch, a plane or a hyperbolic paraboloid (saddle). When I introduced a further definition to subdivide the surface I made an important discovery for myself. Even with just four faces defining the overall mesh the approximation of the parabola was already obvious. As further vertices were added the coarse mesh came to more closely represent the original parabolic surface.

Having found defining associative models early in the design process to be limiting and tedious, not to mention already requiring some idea as to what the outcome needed to be, this felt like a useful realisation in order to shift the design process towards looking for a method to utilise the computers potential to visualise shapes quickly. This led me to search for a technique to interact with simple coarse shapes from the outset and then apply a subdivision routine later once the general shape was determined.

Working in this manner would enable me to interact with the digital shapes directly, manipulating as few points as necessary with complex surfaces being the outcome.
Figure showing the Grasshopper associative model algorithm based on a parabolic translational surface.
Figure showing an architectural model with the mesh model and line model extracted from the underlying geometry.
The early experiments with the virtual hanging cloth models had developed a workflow with 3ds-Max for taking base geometries and manipulating them in a non-destructive manner. This concept of non-destructive modelling is important as it allows the designer to apply a variety of transformations and move between them as required. In the case of the modelling process I was seeking to establish this concept would allow me to move back and forth from the coarse geometry to the more refined shape.

Processing a coarse mesh is less processor intensive and returns results more rapidly. This is why meshes are used in modelling analysis and engineering process such as finite element analysis or for fluid dynamics or daylighting simulations. If we consider the human brains capacity to compute information in comparison to the computer, we can imagine the situation that the human brain can comprehend the coarse mesh (while having an idea about the refined shape) while the computer performs the heavy computation to actualise and visualise the refined mesh.

Throughout the design process I developed this method to ensure further amounts of data are able to be extracted from the model to move across software platforms with minimal rework of information.
Figure demonstrating physical modelling procedure from unrolled surface.
Explorations with this technique required the informed judgement of the initial geometry study. Without this background I would have again been back at step one, wilfully shaping digital forms. It became useful to test the process with physical models as well as the digital ones as, after all, the driving aspect of the project is the realisation of digital shapes in the physical world. What was additionally helpful at this juncture was that it was evident that the coarse models would be just as useful as the smooth ones in determining planarity, after all, “garbage in, garbage out”\(^66\). If the coarse model wasn’t working neither would a more refined model\(^67\). This made testing faster through building simpler models rather than their more complicated counterparts.

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Figure showing curvature analysis and mesh rebuilding from original underlying geometry.
Later stages of the process involved developing a planarity algorithm within Grasshopper for Rhino. The meshes exported from 3dsMax were able to be imported into Rhino for analysis and modification to planarity if required. This was explored with Gehry’s comment on having some flat and some curved surfaces in mind. This could then be employed as a building became necessarily more complex. At a later stage I also became aware of extracting underlying geometry to alter the method for describing the surfaces, for instance where ruled surfaces might be a more appropriate solution, proving the method developed had additional flexibility.

At this later stage the benefit of the associative model becomes apparent. Now having an idea as to the required shape for the building one is able to create a definition that accurately describes the building shape numerically. This can be investigated through an iterative process while at the same time introduce further layers of analysis; for structure, solar gain, shadow casting, fluid dynamics/wind simulations, daylighting and so on. This is where the additional collaborative nature of digital processes comes to the fore as models can be shared with architects and engineers contributing to the same design model.
Figure showing the Grasshopper planarisation algorithm.
4.5 THE PROPOSAL

The design for the Viaduct Events Centre developed with the fundamental ideas being about how the building is used and the impact that it has upon the surrounding areas.

Programme + Design Rationale:

The programmatic aspects are relatively basic; a large open space, separate flexible meeting spaces, offices and utility spaces. Views out of the building are important and so the interior was to remain as open as possible which also aids in way-finding. This led to utility spaces being centralised with the other spaces moved to the edges. The building began to separate into two more distinct parts; the public exhibition and meeting spaces and, the office spaces and utility spaces (toilets, kitchen and preparation areas).
Section through building and site.
The main exhibition hall has the requirement for a twelve meter tall unobstructed space. With this being the main public zone it is logical to push the space to the north where sun and views are greatest. This also works with the orientating of the majority of the building to the north. There is the benefit too of placing the smaller office spaces to the south of the site and the potential to reduce the height of the building in this zone, reducing the mass and lessening the shadow cast by the building onto the site. The kitchen areas are located on the south western edge with access from the western ‘working’ edge. Two levels of kitchen service the exhibition space and meeting pods.

Numerous placements for the meeting spaces were investigated and moving them up from the ground floor created the potential for views in various directions. The decision to contain the meeting spaces within pods came about with the thought to make them an object within the large open space. This meant that the meeting spaces could be easily recognised from the exhibition space and could also view back into the exhibition space. The pods have a completely contained element as well as utilising the space on top of the pods. The space beneath the pods becomes more intimate within the overall volume of the building and can be used for seating and breakout spaces. The external skin of the building is opened to provide views in different directions enhancing the experience of the building. The entry space was brought to the centre of the building to enable direct entry to the exhibition space.
Figure showing image sequence demonstrating non-destructive modelling process.
Shape:

The shape of the building went through numerous iterations and types. Key drivers for the shape of the building were to minimise the shading effect of the building to the south, bring a self-shading effect to the northern elevation in order to maximise views and daylighting into the building, define an entry experience and, to provide an overall cohesive outline for the building. Throughout the design exploration a roofscape was considered in terms of making the space usable. This was abandoned as it became apparent that there was the potential for large amounts of usable open public space on the site. Moving the building from its current location to the northern edge of Halsey Wharf and altering the orientation to maximise the north elevation was a key part of this realisation.

The development of the final shape started from a simple tube solid. This shape was manipulated to account for the programmatic ideas discussed above. At the same time solar studies were dynamically used to adjust both the slope of the northern elevation and the overall height of the building from north to south. Maintaining sufficient height at the southern side of the building for two levels of office was important and fitted well with the overall building shape pushing to over twelve meters tall in the northern exhibition space. Maintaining views through the building was important as the design became more detailed. The changing curved shape additionally works to improve accoustic performance of the building.
Perspective of building from Waitematā Harbour looking back to Auckland City.
Ground floor and first floor plans.
Experience:

The tube was selected as the base geometry because of its open centre. This was to become the entry courtyard for the building, a smaller more enclosed space within the vastness of the open wharf, protected by wind from both predominant wind directions and shaped with vertical walls to reflect light into its centre. As you approach the entry you can see through the building to the Waitematā Harbour beyond.

You enter the building into a space with the meeting pods overhead. This provides a more human scale area for the reception and lounge and you are immediately orientated with the exhibition space, meeting spaces and, utilities that separate the public and private zones. A staircase from the exhibition space takes you up to a platform to access the enclosed meeting pods. From here the top of the meeting pods can also be accessed. The exhibition space is a large open, column free space viewing out to the Waitematā Harbour. The southern elevation of this space is vertical providing access for tall exhibition items along with general facility access from the west.

The north wall of this space reaches out over the edge of the wharf presenting a view directly down to the water below. This angle also works with the angles of the summer sun to self-shade the elevation meaning that greater amounts of glazing can be used to maximise daylight to the space and views outwards. This also increases sunlight in winter months to contribute to the heating of the space. To the south are two levels comprising office space of various types. Mechanical services are located to the west of the building.
Site:

As I developed the project I realised that I really should consider the potential of the entire wharf in a greater sense as it would have an impact upon the design decisions for the Viaduct Events Centre. With this being a hypothetical project I had the luxury to do so. Retaining the western edge of the wharf for wharf activity was part of the original brief. This makes sense as the entire area to the west of Halsey Wharf is used for commercial activity and provides an interesting backdrop to other activity taking place in this part of the city.

Having identified from the site analysis the potential for zones of public activity I thought of ways to incorporate them into an overall masterplan proposal. The northern finger of the wharf is bathed in sunlight all year round with the area to the south protected from winds by the buildings on Wynyard Quarter and the wharf itself. This part of the wharf is extremely underused at present so introducing some activity to make use of these environmental advantages seemed obvious. In other areas nearby people readily interact with the water’s edge where there is the small provision to do so and a major criticism of the entire waterfront area might be the lack of opportunities to get close to the water. There is the added advantage of only smaller recreational sea craft using this side of the wharf, moving in and out of the marina. Considering the original requirement for a public promenade I thought to extend this to provide a city beach with a saltwater swimming pool right at the end of the wharf. Additional hospitality facilities were included to give further reason to use this part of the wharf and also to provide nearby facilities for the Viaduct Event Centre.
Perspective of building from south of Halsey Wharf looking towards Waitematā Harbour.
Moving the building to the north of the wharf provided less of a barrier to the wharf itself. The current building casts a shadow to the south which creates a poor space along what has become a major pedestrian route from the marina in the west, into Auckland City centre and beyond. This proposal creates the possibility to utilise this space for parkland with trees sheltering the space and swales collecting water.

Landscaping can be introduced to provide grassed mounds for running and playing over or laying and resting on while also creating a noise and visual barrier to some of the commercial activity in the west. There is the potential to create a variety of types of spaces here with soft and hard surfaces that connect to the water, continuing much of the excellent work already happening in the area. The current existing building location makes it difficult to see how this design language might be incorporated and continued.
Detail of segment of building envelope.
Final Comments:

The proposed design satisfies the criteria originally set out and I believe it enhances the area beyond what the current building provides. I consider the dominant factor here is to do with the overall siting of the building, most likely out of the architects control. By shifting the building footprint many opportunities for the site are opened up and this proposal presents just one. In prioritising and allowing for the effect that the building has on its immediate surroundings I consider that this proposal provides benefits that the existing building does not. Shading of the area to the south is a critical one and something where I think the existing building fails on two counts; it provides a poor urban experience, shading a major pedestrian link and also, it offers an underwhelming entry experience to the building itself. Orientating the main exhibition hall to the north was a critical step in the design process to give good access to the entire wharf. Without this, the finger on the north edge appears cut off from the rest of the wharf with just a thin connection to it. Now there is a large area connecting the two parts of the wharf with landscaping proposed to highlight this connection.

The final shape of the building has tended to be something of an oddity to me. Without any conscious desire the shape has come to resemble that of a Golden spiral of Fibonacci. This has useful benefits in the determination of numerical exploration but has the unusual outcome of it appearing as though I have simple resolved to place a shell at the end of the wharf. At each step decisions to move faces, edges or vertices here or there depended upon functional, environmental or aesthetic judgement, with the final shape being a response to these criteria. This final shape, the nautilus shell, is the outcome of that process and I am not uncomfortable with the result given the decisions involved. I wouldn’t contemplate altering the shape because of external formal associations and it could be considered they might even strengthen the idea. A story of Foster+Partners, City Hall London, (1998-2002) was that the concept was to design a pebble by the Thames, even though the project was driven by formal and environmental considerations. If such comparisons were to be made with my own work I would consider them flattering.
5. REFLECTION

Upon commencing this project, it seemed a straight-forward task to explore planar geometric typologies and produce an architectural response demonstrating the application of planar quadrilateral meshes. Quickly however it became apparent that the project extended in scope far beyond the initial parameters and that a wider investigation was required in order to bring greater understanding as to why it might be necessary to utilise planar quadrilateral meshes in architectural design processes. This was driven by a perception I had in the underutilisation of digital tools in a design sense, particularly given that the computer has come to be such a dominant tool in architectural offices. It was therefore critical to establish robust links between architecture that we design in the virtual world and architecture that we build.

This being a practical, project based course of study it seemed appropriate to focus the outcome on the way we construct buildings today and materials typically in use. The types of materials that we employ tend to be rigid and flat, or planar, due to cost. Even introducing curves in a single direction dramatically increases cost and is generally avoided. The way then that we use material for construction is at odds with the types of buildings that computer software enables architects to design beyond the conservative box.

For more than twenty years various software has allowed architects to postulate with buildings full of complex compound surfaces. While the software additionally allows for the description in space the points defining these shapes in order for them to be built, it is not exactly a fair claim for architecture to suggest these buildings are possible to be built today with financial restrictions always an issue, seemingly no matter the budget for a project. When we do see examples of curved or ‘blobby’ architecture it is usually reduced to a triangulated mesh of flat panels, often covering atriums and rarely exhibits all the characteristics that we have come to expect from architectural elements such as roofs and walls, depth of which being a primary example.
The ‘smooth’ surface of the digital environment is thus rationalised to a ‘thin’ faceted polyhedral in order to be constructed. There seems to be a disconnection between theoretical positions that suggest computer software should enable us any smooth surface when designing and the buildings that are eventually built. One wonders if architects are aware of this. Or if it matters given that much of what architects produce with a computer is rather conservative given the formal possibilities. This realisation became the moment for me in the project when it seemed important to widen the investigation more generally into what digital design in architecture might be influenced by.

At first glance the field of digital architecture is full of many terms and much jargon. As one investigates further it becomes apparent that these terms have definitions which are sometimes various and often overlap in meaning with other terms. It is then difficult to ascertain where one might position oneself within this and often one finds themselves establishing their own definitions. Dominant topics within digital design include computational, parametric, generative, algorithmic and building information modelling (BIM) as described in the chapter ‘Digital Tools’.

Rather than attempt to work within this area to any dominant existing theory, for this study I looked towards the source of digital design, the computer, in order to try to understand how one might best use the computer to complement or inform a design methodology. I looked into what the computer is, how it works and attempted to ascertain what it offered for architects to inform a design practise.

Taking the position that the computer has no intelligence of its own focussed me to investigate how information is input to the computer. There are numerous examples one can cite when taking this position, John Searle’s Chinese Room scenario being just one. From this position one essentially sees the computer as a finite machine with extraordinary computational power. Any intelligence a computer exhibits is merely a function of how well it is able to return information from its storage banks, now extended globally via the World Wide Web. This isn’t an exhibition of intelligence, merely an example in the spirit of Searle’s Chinese Room where an input elicits a pre-programmed response. This position places the emphasis upon the designer and their understanding of formal matters over abstract ones.
The real value of a computer then might be when we align its computational power with that of human intelligence. If we consider that humans are computation poor relative to a computing machine, we see that the computer extends the capacity of humans to deal with large amounts of information. In the case of CAD software, that information is predominantly to do with points in space and the computer’s ability to quickly manipulate and visualise them. With visual concerns highlighted we can now consider how we best use the computational power to carry out intellectual endeavours.

At this point Antoine Picon becomes an important figure. Rather than continue to argue for the use of computers to model abstract phenomena that leads to the ‘generation’ of architectural form, Picon argues that this is in fact a process that involves no design at all. If we consider the areas of an architect’s training primarily involving the understanding of shape and space alongside dealing with programmatic and technical matters, guided by history, then we could suggest that the architect brings a knowledge of shape, space and human behaviour that the computer and its computational powers are there to compliment and amplify. What we tend to witness with digital tools however is an entirely different set of knowledge applied by architects to the shape-making process. The shape isn’t being designed but an algorithm that will generate some shape. This algorithm is most often sought from the biological sciences but most certainly are events attributable to physical affects. These are either not well understood by the architect (through having limited, if any, training in biology or physics) or are extremely complex and the programming of which into a computer cannot contain all variables and data that we witness in nature (again, especially as an architectural education usually contains very little computer programming training). This then results in architects attempting to deal with something they have only a limited understanding of, leading to results that may appear complicated but are at their core simplistic or overly simplified. It might also distort the real issue for architects designing with computers which is to be more familiar with geometry, maths and computation.
The idea of complexity is an interesting one. In *Airman’s Odyssey* (1942) the French writer Antoine de Saint-Exupery (1900-1944) wrote, “Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away”. As an aviator this concept would seem obvious to Saint-Exupery, aircraft rarely have extraneous detailing. The concept is not foreign in architecture, particularly in modern times. Mies van der Rohe’s, “less is more” being an obvious candidate. In neither case are the authors of these words calling for simplistic responses to a problem but one that is considered and complex. Mark Burry continues this idea in his discussion of Simplicity.

Burry comments on the tendency for architects to combine and repeat simplistic algorithms to achieve highly complicated visual outcomes. This reflects unfavourably upon the architect’s ability to understand complex mathematical functions that are not part of their formal training. Software provides a way to visually engage with mathematics, but without a real understanding of the algorithms behind the shapes displayed onscreen architects might merely be considered to be fiddling as sculptors in this realm. So then, how do architects engage with the computer as a tool to enhance the exploration of form? At the heart of all architecture is geometry. It is a fundamental aspect of our art and has been for centuries. Renaissance architects worked with proportions to sculpt architecture and later, Modernist architects sought to impose new proportional systems based on units and standardisation. In these cases there is the ability to work within a system, it is not an absolute answer and the variables are multiple. As the architect defines a space they are aware of the consequences upon the appearance of the building and how the inhabitants might use the building. Whether dealing with symmetry or asymmetry the architect, through their training and experience, aims towards designing a building of beauty, considering rhythm, proportion and harmony.
Why then do we appear to ignore this history and tradition when attempting design with a computer? Why do architects adopt an approach where a system defines absolutes that must be adhered to and cannot be manipulated? Why produce curved shapes for their buildings that require modification to their shape in order to become structurally and economically sound? It seems to my mind that rather than expecting the machine to produce the answer, architects should be more engaged with a geometry understanding when using a computer, particularly given the computer has the wonderful ability to visualise instantly the three-dimensional qualities of the shapes we design. Yes, computational analysis aids in further informing our designs but is there not a place for the guiding hand and eye of the architect defining the shape in the first instance?

Where to begin in understanding the shapes that we define within a virtual space? If nearly any shape is conceivable and able to be constructed, at least in theory, then how might we initiate a methodology for using the computer to satisfy Chris Luebkeman’s “appropriate application” of the technology? Norman Foster talks of the, “silent, invisible electronic world” of the computer and that this must become a physical built reality at some point. This suggests that fundamental to the process is the consideration of the physical material properties that a building will be constructed from. Jim Glymph, of Gehry Partners, considers material to be at the heart of the process: “Architecture needs to return to a more direct association between the material, craft, the physical reality of the building.”

Detail of building demonstrating integrated structure, skin and services, developed from a planar quadrilateral mesh.
After these attempts to more completely understand how and why digital tools are implemented in the architectural discipline, I found myself coming back to the instigating proposition; to establishing some constraints in the use of geometry in a computer, in this case, planar quadrilateral meshes.

First of all, planar. The materials that are used to construct buildings today are flat, predominantly steel and glass but also timber and composites. To introduce curved surfaces, singular or doubly curved, increases the cost of projects beyond what is reasonably expected and we see in this document how Frank Gehry uses digital tools to control this. Here we see one of the great proponents of digital architecture and architect of many ‘bubbly’ buildings telling us that his buildings are predominantly comprised of flat surfaces. What is interesting about Gehry is how closely his design methodology is linked to the fabric of building. From initial sketches design models are built utilising strips of material forming ‘ruled surfaces’. Right from this initial stage there is the intrinsic knowledge that the building will be able to be defined by a series of flattened or straightened elements. In analysing this process and understanding methods to construct digital surfaces, it becomes clear that perhaps there is some way to understand and explore geometric shapes within the computer in a similar way, a digital Gehry if you like.

Quadrilaterals. We establish that the quadrilateral mesh has a number of advantages over triangular meshes and these advantages give reason to introduce this constraint. One might argue that it is the lack of constraints that has hindered curved shapes becoming a mainstream part of architecture, leading to digital tools being employed for computer aided drafting as opposed to computer aided design. Yes, architects use computers for efficiency in the production and communication of construction documentation but when we consider design, it appears that digital tools have brought limited benefits or advancement in formal responses.

And meshes. We see that the mesh has a sound ideological basis for digital design when considering Peter Schröder’s arguments and, also that the mesh is really how we see a constructed building. The smooth surface is an illusion, the polyhedron is what the buildings around us really are.
This leads back to the study of geometry. In the Preface of *Architectural Geometry*, Helmut Pottmann describes “modern computing technologies” leading “to a real geometry revolution”, particularly when considered against the “variety of shapes that could be treated by traditional geometric methods” being “rather limited”. We may argue that architecture can exist on paper or in digital realms but architecture is really best experienced in its full, built wonder. The ability to define any geometric shape with digital tools is thus meaningless unless we can build it, within all the rules and constraints that exist with the current construction environment.

The course of study consequently explored what rules exist with which to explore surface types that would result in planar-quadrilateral meshes. Alongside this research a method to use digital tools for direct manipulation of shapes was pursued, to enable one to ‘sculpt’ within the digital environment with the knowledge that the shapes defined will be buildable.

The approach to modelling developed for study here can better be described as poly-modelling or sub-division (sub-d) modelling. The approach is common in the visual effects and games industry but is not one common to architecture. This I find peculiar given the early adoption of visual effects industry software to explore or ‘generate’ architectural form. This software was utilised for its physical systems, particles and wind for example, things to amaze spectators. This may have tied well to the rhetoric for a calculus based, systems driven architecture of the time but we have seen that this may have been a limited position. That calculus, as argued by Antoine Picon, “provided firm boundaries that could not be tampered with”⁶⁹, tells us that for these architects it was not the resultant form that was of interest but rather the processes in generating it. Again, I find this an interesting point to note given that digitally produced buildings are often seen as gregarious form making exercises where in reality the shapes produced are more a result of a scientific or numerically mathematical endeavour.

Sub-d modelling is utilised in the visual effects industry to produce geometry outputs of various mesh densities depending upon the amount of ‘memory’, or ‘RAM’ (Random-access memory), an application requires to render or process geometry. I have argued that the computer is a tool to aid the limited computational capacity of humans and we might draw a parallel here between the limited ‘RAM’ of a human operator in this sense. Thinking in this we we can understand how a designer is more readily able to interact with the digital sculpting of an architectural shape with this method.

In my eyes then, geometry comes back to being the basis for a methodology that enables architects to utilise the computer for the design of doubly-curved surfaces; to explore the geometry revolution digital tools are said to bring. The development of a digital process to explore architectural form in the classical sense of proportion and adjustment takes precedence over the formulation of arbitrary abstract phenomena to describe curved shapes. This is important so as to connect architects with the tool in front of them such that the computer becomes a design partner, supporting the application of design decisions, not leading them.

No-one can be expected to fully embrace technology unless the advantages can be expressed in terms that make sense to them. For architects, the fundamental act of describing geometry is the act to make sense of. In harnessing a digital methodology that enhances the exploration of geometry, architects can move beyond any perceived conservatism and utilise the computer to explore architecture in a formal sense and stimulate computer aided design.
6. REFERENCES
6.1 BIBLIOGRAPHY


