Parametric Urbanism in Practice:
Investigating new approaches based on analytically driven methods

by

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Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Deakin University
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Abstract

This research contributes to the field of digital design thinking through the lens of parametric urbanism in architectural practice. Rapid growth in the application of parametric urbanism has prompted investigation into some of the effects digital parametric systems have had on the way we design. Largely missing in this discussion to date has been the exploration of relationships between design and established systems of cognitive theory and communication. Specifically, the modes of design thinking and subsequent working methods we employ in parametric design.

This thesis argues that we need consolidated work surrounding the digital design thinking and methods currently employed in order to take advantage of latent computational design benefits. This research assesses contemporary applications of parametric design and proposes a new method of system design referred to as Problem Centric Design. The proposed Problem Centric approach to parametric urbanism encourages working methods that are led by both the individual designers aspirations and the unique requirements of the design problem. This actively encourages hybrid-working methods that facilitate contributions from both human designer’s and computer systems.
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Glossary of Terms

**Biological Generative System(s):** The logic of biological generative design systems is derived from complex living organisms. These systems emphasise the process of form making as opposed to the final form itself. Evolution is a defining attribute as the system tests, learns and optimises throughout the generation process.

**Building Information Modelling (BIM):** the generation of digital information pertaining to physical properties of spatial data. A system aimed at managing, networking or sharing while supporting any decision making process.

**Black Box (System or Program):** a device or system that has visible input and output information but no explicit knowledge of its internal processing procedure.

**Causality (Cause and Effect):** is the relationship between a *cause* and the particular *effect* that results from the cause.

**Domain User:** is an authority in a particular area or topic. In the context of this thesis the domain user is the architect as an authority in the domain of design.

**Embedded Research:** is a joint venture between a research institution and a professional organisation to achieve a common research aim. The research is embedded within the professional practice in order to learn from and build upon existing working procedures.

**Generative System(s):** generative systems operate through the specification of procedural rules. These rules govern the process of making a design artefact and enable a system to ‘generate’ an outcome. There are two distinct
categories of generative systems known as biological and linguistic. Parametric systems are arguably a third distinctive type.

**Geographic Information System (GIS):** is a spatial and geographical data management system designed to capture, record, manipulate, analyse and present information.

**Linguistic Generative System(s):** linguistic generative systems are a grammar-based formalism. When applied computationally these generally manifest as shape grammars, which apply modification rules to a starting object in order to generate a new design.

**Optioneer(ing):** the process of testing multiple outcomes within a given set of parameters. Multiple options are produced in order to inform the best outcome for the problem at hand.

**Parametric (in Computational Design):** design process utilising digital systems that are capable of facilitating a particular focus, mastery, aspiration or dependence on explicit design parameters.

**Problem Centric:** is a form of systems design that encourages working methods to be formed around the problem space itself as the common element between human thinking and computing systems.

**Urbanism (Theory):** the sociological and spatial understanding of the way in which we inhabit and interact with our built environment (towns and cities).

**Workflow(s):** the working process of a coordinated activity and the understanding of repeatable patterns required for production.
Key Definitions

The following section looks at some of the key themes and terms used throughout this thesis to offer a more detailed background into each. The definitions cover:

- **Parametric Modelling** and why it is relevant to current architectural discourse;

- **Design Systems** and the interplay between design thinking and applied methods; and

- **Conceptual and Constructive** forms of design thinking which furthers the design systems theory discussion to encompass modes of causality into the workflows.

- **History and Context of Parametric Urbanism** and how the two fields of Parametric Design and Urban Design (Planning) have intersected.

**Defining Parametric Modelling**

Design space exploration has been a long-standing focus in computational research that is only recently emerging as a keystone in architectural design cognition, computation and generation. This area of research is concerned with two main areas of study. The first category is concerned with efficiencies in the production and representation of geometry through the use of computer-aided tools (Gürsel Díno 2012). The second and less understood of the two, is concerned with strategies for computational design thinking that will aid in the augmentation of designers’ abilities and encourage computational structures that support design exploration (Burry 2011,
An area of digital design research referred to as 'Parametric Design' very broadly covers a significant portion of this work. This classification is considered a subsection of 'Generative Design Systems’ defined by the human designer’s ability to delegate tasks and intelligence to the system, thereby facilitating a degree of autonomy. (Figure 1) These systems comprise any combination of structures such as rules, constraints, parametric dependencies, genetic structures, evolutionary generators and many more (Gürsel Dino 2012). This area has been significantly expanded in architectural work over the past decade and is generally associated with the use of advanced digital technologies in complex projects (Woodbury 2010).

Figure 1  
Diagram demonstrating the hierarchical relationship of different categories of computational design systems.

Despite the rapid development of parametric design, the concept and its applications in architecture have not been rigorously clarified. The documents and programs devoted to parametric systems scarcely indicate definitions, basic characteristics and/or general uses in building design (Alvarado and Munoz 2012, Tang and Anderson 2011, Stavric and Mariana 2010, Oxman 2006). The term 'Parametric Design' can be problematic in the scope of its definition. Parametric in itself can encompass all facets of digital and non-
digital methods of design and as such can be argued as “tantamount to a sine qua non; what exactly is non-parametric design?” (Burry 2011:18). The term can also broadly encompass many other facets of computational systems that have varying levels of ‘parametric’ relevance under different circumstances, combinations and uses. Some of these categories of design thinking and computing systems will be defined throughout the next two chapters along with further descriptions of their potential applications.

Regardless of the generalities in its literal definition, the term is widely understood and pursued throughout this thesis under the definition of a design process utilising digital systems that are capable of facilitating a particular focus, mastery, aspiration or dependence on explicit design parameters. Similarly, the term ‘Parametric Modelling’ is used to define the computational generation of design artefacts through the inputs, functions and outputs of parametric systems.

The basic principle of parametric modelling is derived from mathematical origins. Joseph-Louis Lagrange invented the method of solving differential equations known as variation of parameters in 1774. This method applied differential calculus to the theory of probabilities and became the first recorded use of the term parametric (Alvarado and Munoz 2012). These definitions led to the understanding that mathematical functions can have one or more arguments that are described by variables in the definition. These same functions can also contain parameters. Variables are described in the functions list of arguments while the parameters are not. Families of functions are defined for each valid set of parameter values.
Taking a standard quadratic function:

1. \[ f(x) = ax^2 + bx + c \]

Here, the function argument is defined by the variable \( x \), while \( a \), \( b \) and \( c \) are parameters that establish the type of quadratic function. Functions often derive their names or classifications based on the parameters used. Even though there is a large grey area between calculus and algebra that is formally ill defined, parametric mathematics can generally be classified under the banner of calculus due to the formal deductive logic systems. This refers to the variable nature of the input parameters and the subsequent generation of a finite set of results.

Parametric systems can, therefore, be theoretically considered a subset of algorithmic systems logic, although the definition represents no practical difference in computational terms. İpek Gürsel Dino (2012:210) describes this relationship; "Algorithms by default operate on parameters, and a parametric system's fundamental component is the algorithm itself, called the schema or definition. However, different than algorithmic design, parametric systems emphasise the explicit and direct manipulation of the parameter values in order to introduce a change on the design artefact." This description recognises the subtle difference in the use of parametric and algorithmic design systems that manifest during the design process through the interactions of the designer.

The use of the term 'parametric' emerged in the computing world during the 1960's and 70's (Kay 1987). When applied to a modelling program, this system of substitution allows for a high level of value substitution in the
variables and a specific application range set within the parameters. A key difference between parametric modelling and other CAD tools is in the process of modelling geometry. In parametric modelling software, solid primitives, called features, consist of common engineering shapes such as holes, slots, bosses, fillets, chamfers, protrusions and shells. These features, defined by a set of parameters, know how to behave relative to each other. Rather than drawing the geometry line by line and arc by arc, the designer specifies constraints and relationships between features. The geometry is a result of the specification of relationships. This means that when designers change and modify the relationships, the geometry will adapt to stay in sync. This kind of modelling streamlines design exploration by making it practical for designers to create many more design variations at a higher level of integrity and precision. A key concept in such systems is associativity, where changes can ripple through from components geometry through the design and all related representations (Aish 2005).
Parametric algorithms in architectural design are closely linked to a select number of general-purpose 3D modelling programs. The two programs used throughout this thesis are Generative Components (by Bentley) and Grasshopper (by McNeel). These systems offer a pre-defined set of functions, operators and conditional statements as well as the capacity to directly edit and code commands through the source scripting languages.
Defining Design Systems

Within the context of computational and generative design systems, the discussion throughout chapter 2 (pg 18) is largely concerned with the development and application of the following categories:

- **Computing Systems**: the foundation data (Inputs), problem solving system (Functions) and how this relates to and affects the design outcomes (Outputs);

- **Human Thinking**: the human workflows or process applied to select and utilise the design tools. This is also classified as the design methods or philosophy.

Both of these categories of design thinking are fundamentally based around the understanding of cause, effect and the interplay of facilitating systems. Aristotle first developed this in his theory of Holism, which spawned what is now known as System Theory (Ahlquist and Menges 2011). The term System Theory was first introduced through the work of Ludwig von Bertalanffy and his recognition that any given system is greater than the sum of its parts. (Figure 3) This idea of systems thinking has now expanded to determine that "a 'system' is a complex and highly interconnected network of parts, which exhibit synergistic properties, where the whole exceeds the sum of its parts" (Darzentas et. al 2014:2).
Figure 3  Ludwig von Bertalanffy’s simple feedback scheme. (Redrawn from Bertalanffy 1969)

This is an important diagram in understanding the basic theory of causality through an input, control apparatus and an output. It demonstrates a generic model of causality with the added feature of a feedback arrangement as a stabilisation and refinement method.

This proposition outlined in Figure 3 that a system is circular as it feeds back on itself aligns with the thinking of another field known as cybernetics, specifically second order cybernetics. The link between cybernetics, systems theory and design is only recently gaining a renewed interest, (Darzentas et. al 2014) and is therefore, a very new intersection of research between two relatively young disciplines in their own right. (Fischer 2015)

Ranulph Glanville defines cybernetics and the relationship to design in his paper ‘Try again. Fail again. Fail better.’

“It [cybernetics] is concerned with circular causality and the wish to control in a beneficial manner. It comes from a mechanical metaphor for the animate, which is now partnered by an animate metaphor for the mechanical. – Cybernetics can act as the theoretical arm of design, while design acts as the practical (active) arm of cybernetics.” (Glanville 2007:1174)

Second order cybernetics differs from first order cybernetics due to its recognition that the observer of a system is an integral participant in the
system they describe as opposed to a detached or unrelated third party. This distinction is particularly relevant to design as an activity that is conducted in response to complex and often ill-defined problems. This places the designer, as the conductor of design process of internal and external conversation, as both an active participant and observer.

There is, however, an irony in the communication of this theory in practice and one that this thesis has to recognise. In describing the system, one has to take the position of a third part observer in order convey information. This is an unavoidable consequence of communication about a system to those outside a system.

One of the key aspects of second order cybernetics is that a system is not purely circular, but recursive. The concept of recursion is a critical nuance to the idea of circular causality as it recognises that history does not repeat itself exactly. Although a process loops back on itself it has learned from the previous experience and builds upon it. This is likened more to a spiral than a circle, which has become a recognisable diagram in both design theory and cybernetics alike. (Glanville 2010)

**Defining Conceptual and Constructive Design Thinking**

The application of architectural parametric modelling allows for the “articulation of procedures for solving both well defined problems with a clear target, and complex ill defined problems having several workable solutions” (Gürsel Dino 2012).

An essential aspect of both cybernetics and system theory is the concept of linking events through key actions and dependent relationships. In terms of
Figure 3 in the previous chapter, the receptor requires a stimulus and a message in order to have any relationship with the control apparatus. In this, there are a number of variables in the type of stimulus or the type of control apparatus. Each variable will ultimately have a different outcome and ongoing effect in the system’s chain of events.

Given our understanding that design is an applied arm of cybernetics, design is subject to logical aims and procedures in an attempt to meet the requirements of a given problem. This introduces another aspect to the argument of circular process; Intent and the effect this has on the recursive system.

In order to facilitate an action in a given system, there needs to be a method that guides the decision making process. This recognition means that a system cannot be fully understood without due acknowledgement of both the action and the method. This is demonstrated in Figure 4 as an expansion on Bertalanffy’s system theory diagram in order to include other aspects of a working method.
Figure 4: *Diagram demonstrating the myriad of potential design tools. The specific path taken in order to reach a determined outcome is defined as the design method.*

Each of these actions classified as Input (cause), Function (process) and Output (effect) has a multitude of possibilities with unique internal processing requirements. The design method refers to the logic by which designers navigate a specific path of choices amongst the multitude of potential options in order to reach a desired design solution. This diagram intentionally leaves out the process of recursive feedback in order to focus on the micro and linear relationship of causality between input and output.

These processes of navigation can broadly be separated into two categories defined as Conceptual and Constructive parametric design (Stavric and Mariana 2011). These classifications are also known as Deterministic and Non-Deterministic parametric design (Senagala 2003). These classifications also resonate with the juxtaposition between the two Aristotelian causal modes, referenced in second order cybernetics research as causa efficiens (“because of”) and causa finalis (“in order to”) (Fischer 2015).
Associated and Generative modelling categorise functions and describe certain methodological implications of their use. Conceptually, this classification describes the type of design problem in question as either well defined with clear targets or complex and ill defined with several indeterminate but workable solutions. This distinction is also important to the understanding of Analytically and Normatively driven design modes which are discussed through chapter 3.2.2 (pg 49) (Hiller 2007).

Conceptual design in parametric terms is defined by the declaration of the parameters, functions or scripts through the design inputs. These can be controlled through the manipulation of raw numerical formulas or graphical representations such as law curves or graph variable bars (Hanafin et al. 2009). The outcome is an unknown result of the functions structure and the inputs that feed into it. This form of parametric system is only applicable to discrete parts of the building design process. No built project can ever be purely Conceptual. Any project reaches a point in which the form has to be rationalised for construction and this is an inherently Constructive process.

Constructive parametric design is defined when the output form, type or composition is declared in order to shape the inputs and functions and achieve a predefined product. In other words, starting with the desired end product and working backwards to develop the formulas and parametric constraints required in achieving the goals. This is possible through either analytic and prescriptive input data or specifically tailored functions. Architectural practices utilising this form of parametric modelling generally employ the setups to absorb complexity with minimum aesthetic
differentiation from their traditional design solutions. The benefit of this process, as opposed to traditional techniques, is in the documentation and delivery of the design project through an ‘intelligent’ model that can automate drawings for complex geometry while still facilitating design variations.

**History and Context of Parametric Urbanism**

Architectural and urban design throughout history can be classified via the dominant typologies that served the era. These typologies generally served a need for an externally dictated order of nature, religion or magic (Lynch 1960) resulting in a static recombination of fixed typological arrangements. The physical form of these cities were realised through both formal conventions and social hierarchical programs. This reliance on a higher order for a singular vision constrained urban design to a concept of representation where “elements of architecture are nothing more than a copy of ideal, platonic forms liberated of any trace of inherent order.” (Stavric and Mariana 2011:10)

Historically, defence has been a strong driver of urban order, which sits adjacent to the externally dictated orders mentioned previously. Defence is in some ways an external or higher order of imposed urban logic but driven by internal needs of safety (or perceived safety). The introspective aspects of this planning often reflect an internal control, dictated by an overriding social hierarchy. These urban structures of defence and control can be clearly seen in Hausmann’s boulevards of Paris and the expansion of the ring roads of Beijing in the 20th-century (Verebes 2009).

These external necessities, be they defence, religion or nature, gave urban design cohesive strength of conviction that is not as readily seen replicated in
contemporary societies other than those with centralised power. Spiro Kostoff describes this type of ‘Grand Manner’ urban design.

“The very expansiveness it calls for, and the abstraction of its patterns, presuppose an untangled decision making process and the wherewithal to accomplish what has been laid out. [Washington] ... was the only city in the United States that had a centralised administration... Elsewhere one could only resort to persuasion, and try to advance whatever fragments of the overall plan one could cut through the tangles of the democratic process... The presumption of absolute power explains the appeal of the Grand Manner for the totalitarian regimes of the thirties – for the likes of Mussolini, Hitler and Stalin.” (Kostoff 1991:217)

Despite the bureaucratic drawbacks, the ideal city, along with its power, beauty and the aspiration to enlightened social justice this could impose, brought about the concept of the Modernist Masterplan during the late 1800s and early 1900s. Ebenezer Howard, Frank Lloyd Wright and Le Corbusier were three of the most prominent names involved in this movement (Fishman 2012). Due to the work of these and other prominent architects and designers, the Modernist movement in architectural design reached its height of influence between 1930 and 1960. The philosophies of Modernism were formed around architectural ideology and characterised by rationality, truth to materials, embracing new technology, the moral superiority of the architect-planner and a commitment to architecture as a powerful tool in social reform (While 2006). The resulting urban fabric, however, was composed of isolated building forms that denied the existence of street networks, urban squares and gardens or any other interstitial urban fabric (Trancik 1986). Despite these criticisms of the modernist philosophy, the individual work of Le Corbusier throughout this period led to some early examples of manual
generative design methods. This generative construct was framed through his five points of architecture; Pilotis, Roof Garden, Free Plan, Ribbon Windows and Free Façade. These five points set up a formal grammar system from which any number of processes could be used to generate compliant design products (Asojo 2000). In stark contrast to the modernist ideals they were developed for, this type of thinking has become synergetic with more contemporary aspirations for dynamic and variable design methods.

The problems with realising the physical masterplanned city in a bureaucratic society were not fully realised until the 1960s when the reality of modernist planning methods came into question. Jane Jacobs’ seminal book ‘The Death and Life of Great American Cities’ criticised the policies governing the urban renewal projects of the 1950s as unnatural, isolated and the catalyst for the destruction of local communities (Jacobs 1961). Jacobs subsequently became one of the leading voices in the protest against destructive modernist urban planning policies as well as the dehumanised architecture of mass unitised housing projects (Mayer 2010).

One of the key realisations to come out of this work by Jacobs as well as other names such as Aldo Rossi, Kevin Lynch, Gordon Cullen, Christopher Alexander, Ian McHarg and Jan Ghel (Carmona et al. 2010) is that Urban Design is never implemented as a whole masterplan, with all of its geospatial intentions. Additionally, the social ideals that underpinned a lot of the geospatial decisions of the masterplanned image never operate in reality as predicted. This realisation carried with it a profound change in the way in
which urban planning was approached along with the tools and methods used throughout the design process.

The theories outlined by early pioneers led to the formation of what has become known as the ‘Design Methods’ movement that aimed to develop systematic evolutionary approaches to urban design (Mehaffy 2008). These first generation design methods led to the understanding that urban design was as a task of influence where plans, concepts and ideals changed along with the built reality (Lang 2005). Operating via this method, designers no longer defined any final form but instead worked to intermediate the process, which eventually led to the generation of form (Mehaffy 2008). This was a radical change for designers, particularly modernists, whose concept of design was focused around the final word in formal spatial composition. The methods proposed were fundamentally generative in nature, in that they produced unexpected results from well-defined and deterministic primary aims. This was also a breakthrough in the way urban design scale was treated from its micro to macro implications and exponentially added to the multitude of interconnected decisions and implications throughout the design process.

This initial wave inspired a second and third generation of design method theorists who added concepts such as argumentative processes to cope with complexity, or the dissemination of urban problems as a means of creating design methods. Christopher Alexander’s book ‘A Pattern Language’ (1977) was also a result of the growing awareness of complex systems in urban design. This work began to revise previous assumptions about rigid typological compositions and proposed new patterns that represented
recurring design clusters and configurations (Alexander 1977). “These pattern languages offered a grammatical system whereby the patterns could be recombined in redundant overlapping ways.” (Mehaffy 2008:59) This work was revolutionary thinking for urban planning, but still heavily criticised for its reductive logic, some of which has originated from Alexander himself in more recent years. These criticisms aside, the work did serve to reintroduce the notion of design as a methodological process back into urban design discourse (Mehaffy 2008).

Despite its criticisms, the design methods movement produced some of the fundamental theories that form our current research and applications of urban design. One of the more significant of these has been the formation of New Urbanism or ‘neo-traditional planning’. The principles of this movement have been summarised as:

“Metropolitan regions composed of well structured cities, towns and neighbourhoods with identifiable centres and edges; infill development to revitalise city centres; interconnected streets, friendly to pedestrians and cyclists, often in modified grid or web-like patterns; mixed land uses rather than single-use pods; careful placement of garages and parking spaces to avoid auto-dominated landscapes; transit-oriented development; well designed and sited civic buildings and public gathering places; the use of street and building typologies to create coherent urban form; high quality parks and conservation lands used to define and connect neighbourhoods and districts; and architectural design that shows respect for local history and regional character.”(Deitrick 2004:427)

The importance of this theory is in its analysis and clarification of a certain ideal view of urbanity. The categories do not define end solutions but instead follow the traditions of the design methods movement and suggest key areas
for consideration, or pressure points, in the development process. Like all urban theory in the past century, New Urbanism has suffered its share of criticism. Foremost in this debate is its favouritism towards greenfield developments, its lack of relevance to urban infill and the potential proliferation of urban sprawl.

As a result of this ever-changing theoretical field, New Urbanists, critics and other disciplines of urban theory alike have started to merge into a new field of interest. This field of emerging research is concerned with the development of urban codes in an attempt to supersede the old regime of rigid and often destructive protocols (Mehaffy 2008). This movement aims to replace traditional concepts of Euclidean zoning with sets of parametric specifications that are capable of adapting complex urban patterns in relation to contextual information. This approach differs from traditional planning “in terms of the process by which they are prepared; the substance of the standards they contain; the mechanisms by which they are implemented; and the built form they produce” (Parolek et al. 2008:11) 'Smart Codes' have found a natural synergy with certain computing systems for generational purposes but the underlying theories for code are not exclusively digital and are more closely aligned with the pattern language work of Christopher Alexander (1977).

The implications of these varied theories and methods for dealing with urban complexity are still not fully resolved and the methods proposed are a constant focus of contemporary research programs. One of the reasons for this uncertainty lies in the imprecise and varied role of the designer within a seemingly endless evolution of complex space and networks of relationships.
This is a distinct contrast to the well-defined roles cast by modernist beliefs in the moral superiority of the architect or planner. This leaves us with the indistinct prospect, or challenge, of doing the best that we can with the tools at our disposal. In other words, regardless of a particular belief in an urban design system, designers all have the task of influencing our environment as optimistically and positively as we can through the use of the tools best suited to achieving these ends. The best tools for designing an uncertain future are, therefore, those that allow for the greatest level of control and flexibility in the context of the complex and changing environment around us.

With this realisation, many researchers and practitioners have turned to computational systems in search of a solution to the problems of flexibility and complexity. Unfortunately, despite the initial urban design driven reasons for approaching this hybrid digital/urban theory research, the work quickly became focused on the potential for geometric generation and seemed to return to an urbanism more closely aligned with the ideals of modernism (Mehaffy 2011). Further perpetuating the negative views of Parametric Urbanism is the fact that it has received the least development and crystallisation of design praxis of the generative modelling disciplines (Tang 2011, Oxman 2007).
1. Introduction

This research investigates parametric urbanism as it is currently applied in practice in order to develop new methods and approaches. Although the concept of digital design thinking is the core focus of this thesis, Parametric Urbanism is used throughout as a means of defining and developing the research proposal to better understand digital design thinking. Parametric Urbanism is a compilation of two long-standing disciplines of research. ‘Parametric’ is derived from a specific subset of generative modelling and sits within the purview of computational design. 'Urbanism' is an area that encompasses all aspects of understanding the environmental social, political interactions of a society in order to develop the built urban fabric.

This intersection of parametric and urbanism, however, has brought with it a divergent focus. Firstly, contributions from technologists exploring the mathematic and geometric benefits of digital parametric modelling as it is applied to urban scale design; and secondly, from urbanists discovering the urban design merits of generative digital mediums and the implications they have on both urban theory and design product. This places parametric urbanism in a state of flux as it is caught in the crossfire of two well-established disciplines of design. As a result of the recent attention this discipline has received, Parametric Urbanism is well placed to discuss key issues of digital design theory in light of different contemporary design theory and digital technology. In light of this divergence, the following thesis approaches the problem through the lens of a technologist with a core focus on digital design thinking (converging with Systems Theory). This intentionally leaves aside a large portion of urban design theory in an attempt to focus the
thesis on the overriding systems, methods and design thinking governing parametric urbanism.

This research has been conducted as a shared endeavour between Deakin University and Grimshaw Architects in order to develop and test theories, systems and methods on active design projects. The practice collaboration was a fundamental part in forming the research method developed throughout this thesis. Conclusions of this research are presented, not as the definitive answer, but as an exploration into the relationships and potential connections that can benefit the combination of parametric systems and design theory.

1.1. Problem Statement

In order to structure a discussion around parametric urbanism, one first has to grasp the context from which it stems. For this reason, the problem statements of this thesis are explored in two parts pertaining to the general context of digital design thinking and the specific focus on Parametric Urbanism. These two broad areas of investigation set the background and context for the more specific research aim of investigating new approaches to parametric urbanism through the lens of analytically driven design methods.

1.1.1. The Problems with Digital Design

Computers have invariably changed our working methods over the past few decades. Unfortunately, this has had less of an effect on architectural working methods than it has on most other disciplines (Burry 2011). Digital design thinking and the working processes we employ to work digitally are still poorly defined and widely misunderstood across architectural design practice.
(Tang and Anderson 2011, Stavric and Mariana 2011). This subsequently falls short of the latent potential in these systems to augment a designer’s abilities through computational structures that support design exploration.

One of the main problems identified in this thesis is that the lack of understanding surrounding computational working methods has created a state of dependence on pre-programmed software packages. These packages trend towards fixed functionality and 'black box' processing with very little adaptability available to the end user. This is either unhelpful or even negatively affecting the way that we approach problem solving in design. This is due to a number of factors ranging from a rapid succession of new and innovative software packages entering the market, to the general lack of motivation in the architectural profession to shift from well-established methods of design production. This has led to a severe lack of understanding in digital design thinking, perpetuating traditional working methods. In order to address these issues, a better understanding is required of the potential benefits associated with digital, and specifically parametric, systems within the scope of the theoretical field of design thinking. This argument is outlined throughout chapter 2.

1.1.2. The Problems with Parametric Urbanism

The discipline of Parametric Urbanism is still in its infancy. Although its roots are in centuries-old generative systems theory, the current form of parameter driven digital generation has been around for less than a decade (Canuto and Amorim 2012). The shift in focus from manual generative systems to digital has been in large part due to the introduction of active parametric software
platforms. This has, for the first time, allowed designers to directly interface with and adapt their digital working environments (Woodbury 2006). The result of this active medium coupled with a suite of open source pre-programmed parametric tools has led to new avenues in complex form making and systems based relationships in design. These systems allow designers to program and manipulate high levels of complexity while still allowing for flexibility in optioneering and design iteration testing.

This ability to manipulate and generate complex relationships and networks has found a natural synergy with urban design (Karadimitriou 2010). Despite this growing trend towards new forms of generative urban design, "the integration of demographics, cultural and human factors has not fully been discussed under the umbrella of parametric design." (Tang and Anderson 2011:662)

To date, the majority of research has been concerned with the development of the technical aspects of digital systems that are tailored towards generative urban models (Stavric and Mariana 2011). Unfortunately very little of this research has been resolved in terms of a tested and replicable design methodology that quantifies cause and effect of parametric application within our current design practice milieu (Tang and Anderson 2011, Schnabel and Karakiewicz 2007). This has created a divide between the suite of technological applications and systems that are rapidly flooding the market, and the ability for design practitioners to learn new systems and adapt their methods of working to gain any efficiency. The result of this is a discipline that is plagued by superficiality in generic form making that falls far short of
its full potential (Meredith 2008). This superficiality in application is largely due to the fact that contemporary parametric literature talks a lot about systems and outputs but not a lot about parameters themselves (Mehaffy 2011, Karadimitriou 2010). This leaves the designer at the mercy of pre-scripted software functions with little to no understanding of the correlation between the input data and output of design results.

These issues have led to wide-ranging criticism of parametric urbanism in both the professional and academic worlds. The methods of application are criticised for their lack of rigour in forming design artefacts. This has inevitably led to serialisation, standardisation and a proclivity towards the geometric primacy of individual built form over the quality of the wider urban context (Vincent et al. 2010, Hensel 2011, Beirão et al. 2012, Canuto and Amorim 2012). Many critics also raise questions regarding both the rigour of urban theory underpinning the parametric models as well as the lack of formal methodological construct to guide parametric urbanism (Tang and Anderson 2011, McGrath 2008, Karadimitriou 2010, Mehaffy 2011).

1.2. Research Aims

There are two fields of exploration in this thesis; computational design theory and parametric urbanism. It, therefore, warrants an introduction into each field and an overview of the historic development and contemporary issues. This approach is not intended as a definitive field survey but as a means to structure a reasoned argument around the main contribution of this thesis.

The first section pertains to the broader framework of digital design thinking and the way in which computers are used in contemporary design practice.
The first review section broadly explores some of the ways computers have affected our thinking and approach to design problems in order to set the context for the more specific discussion on different methods of systems design. This line of inquiry provides a critique of different systems and methods of problem solving in order to inform the applied research portion of the thesis.

The second section refines the inquiry into computational design methods to look specifically at the emerging field of parametric urbanism and provide a critical review of the current research and applied design. This section is governed by the core research question:

*What are the key areas of weakness in the current working and computational systems that need to be addressed in order to form new ways of applying parametric urbanism in practice?*

**1.3. Research Method**

The research program has been developed within an architectural practice environment in order to gain a better grasp of the design problems and working processes associated with design delivery. The selection of a partner architectural firm was, therefore, critical to the success of this research and this method of embedded research.

Grimshaw were chosen for a number of reasons that made them well suited to the aims of this research. Before this research commenced, Grimshaw had an existing agenda to further their understanding of digital design and how it was implemented in the practice. This allowed for research and development time to be supported by the practice outside of ‘billable’ project working
hours. Other factors included Grimshaw’s explicit understanding of a design process from first principles, the process of innovation in problem solving and the resulting ‘honesty’ in design expression.

“The buildings we produce come from a detailed understanding of the functions they must fulfill, the conditions they have to provide and the materials from which they are constructed. This understanding is directly translated into form and detail.” Excerpt from the Grimshaw Practice Profile

The ability to explicitly understand ‘parameters’ in the design process made Grimshaw uniquely placed to significantly contribute to furthering the understanding of existing design thinking standards and subsequently shaping the new concepts of digital design thinking in this thesis.

The practice history of innovation in design can be largely accredited to their ability to collaborate with other specialist disciplines and expand the knowledge base through shared experiences. This gave the research a wider base of information when working with urban designers and planners who brought specialised knowledge generally outside of the scope of architectural design knowledge alone.

Research and development of the digital tools and methods have been ongoing throughout a number of embedded practice projects and were a key part in testing and developing the proposed method section of this thesis (chapter 5 pg 165). These were conducted as a continuous workflow that consisted of smaller inter-dependent modules. The modules are focused on addressing discrete design issues that are encountered during the project cycle that can benefit from computational analysis or generation. In this way a toolbox of analysis and design tools have been created that can be applied
within the methodological structure proposed in this thesis. Figure 5 demonstrates the process of establishing the research task within a project and the steps that have been taken to develop and test the different methods and tools.

![Research method diagram](image-url)

Figure 5  
Research method diagram.
From the inception of a design task and an understanding of the prevailing design agendas, governing principles and smaller sub-studies can be determined. These defragmented tasks are then analysed in order to determine the desired outcome and whether this is best obtained through traditional methods or through the use of parametric tools. This process of analysis also helps to clarify the problem type and whether it can be addressed through existing parametric tools or through the research and development of new tools. The design technique is then mapped out to determine a governing research program that will achieve the desired output(s) during the problem-solving task.

From this point, the development and testing process takes one of two avenues depending on the time allowed by the project. If the project delivery time allows, or if development can be continued outside of the initial project task, the development process can go through an extended research and testing phase. This process involves research into existing techniques and capabilities in the field, development and scripting as well as a desktop review with subsequent edits to the tools and methods. Once this development stage is complete, or if the timeline does not allow for extended research, the testing goes into the field studies phase of development. This involves ‘on the job’ development and validation of the tools. The ideal aim for this method is to achieve the full research timeline. The abbreviated version that goes straight from developing a method to field testing is a necessary addition to deal with the unpredictable nature of practice work and how this can effect the embedded research.
Validation of the tools, methods and outcomes is judged through two different avenues. Practice validation is judged by the immediate design team involved with the project as well as any subsequent uses of the tools on other design projects of a similar nature. This helps to draw a comparison between the new digital methods as against any traditional procedures the practitioners have used in the past. The second method of validation is through advocacy groups involved with the project. This method helps in judging the success of more subjective elements of the design outputs. This speaks to the quality of the design decisions that have been made through the use of the new parametric methods.

1.4. Research Stance

As Jeffrey Kipnis notes in his seminal paper ‘Towards a new Architecture’, no matter what your philosophy or approach to urban design, you will always be subject to a two pronged attack from critics on the right who “decry the destabilising anarchism of the New Architecture and the empty egoism of its architects; then, critics from the left rail against the architecture as irresponsible and immoral and the architects as corrupt collaborationists.” (Kipnis, 1993:97)

This can be construed as a fairly bleak view when approaching design philosophy but is used here to remind us there are negative aspects to any design method or research philosophy. This does not have to mean that there is no right answer, but should be used as a reminder that there is no 'single' right answer. Any design problem has a myriad of different possible answers and subsequent methods of achieving them. The prevailing stance taken
throughout this research is that design, as a way of thinking and acting, should not be scientifically restricted. This concept may attract criticism, particularly through the lenses of embedded research as an imprecise and unscientific method for conducting research. This thesis counters this argument through a stance best summarised by, Ranulph Glanville in response to similar criticisms of his design theory research. He argues, "if design is more like science, why should we bother to design at all?" (Glanville, 2007:1175) In other words, if a system is too scientifically restrictive then the process becomes formulaic and the answer predictable. It is recognised that this is a fine line to walk to quantify design methods as a means to further our understanding without over rationalising and restricting them through scientific systems. Designers require an understanding of the different systems available and a ‘best-fit’ approach to how they can be individually applied to achieve the individual and unique design outcome. This body of research has been structured around this ideal. In order to achieve this goal, an analysis of the current debate surrounding parametric urbanism has been conducted to identify areas of contention in this particular field of study. Through detailed review of these areas, a proposition can be made to counter the identified problems through a combination of new design methods.

“There will also be those who claim that this approach [to conducting design research] is romantic. But it is not romantic to accept that not everything can be defined and computed, or that there are ways of working that do not depend on such definition: and it is not romantic to value criteria and qualities other than the strictly measurable, or to accept that reality is as we make it. And, for that matter, what is wrong with romantic?”

Ranulph Glanville, 2007:1175
The embedded research method used for the following studies requires a mix of pure and applied research in order to first shape and then answer the relevant questions in the field of research. The pure research will form the background literature review of this study to shape an informed context for the design studies. The applied portion of this research will build on the conclusions of the literature review to propose and test a method for applying parametric urbanism in architectural practice. This is conducted within practice conditions, on real world projects in order to add value to the research development and help validate the success of the proposed method.

For this process to be effective, however, a stance has been taken as that of an architectural practitioner with the belief that designers have the ability to positively affect their urban landscape through considered and collaborative design thinking. This approach also lends itself to the belief that these same designers are the best qualified to shape the tools and methods that invariably craft their designs. This approach fosters a more intimate understanding, and subsequently, a more effective application of the architectural tools.

1.5. Scope and Limitations of the Research

The process of research and development in professional practice is subject to a number of prejudices associated with the practice design philosophy. These have helped to form the theoretical design method presented here but it also has to be acknowledged that this can provide a limited research outcome through operating within one architectural practice.

The development and application of these tools need to adhere to strict time requirements for project delivery. As such the embedded research process
helps to identify key areas that have further research potential. Where possible, these are developed outside of the initial project delivery time in order to allow unhindered development. These parametric tools and methods are then applied back into other relevant practice work as a means of assessing the research development. All of the design projects used in this thesis that are a result of project-based research have been supplied by and credited as courtesy of Grimshaw Architects.

A more detailed account of the limitations in this study are outlined in chapter 6.3 (pg 225) of the conclusions.

1.6. Thesis Outline

This chapter has stated the aims of the thesis along with the research methods that will be used to guide the embedded research program. The following diagram illustrates the general structure of the thesis and the hierarchy of the discussions contained within. As described earlier, this thesis structure is intentionally linear in its structure. This is a concession to the circular causality of the thesis topic and content for the sake of telling the story of the embedded research process.
The pure research portion of this thesis forms the literature review and is divided into two sections shown in dashed boxes in Figure 6 with the headings Computational Design and Parametric Urbanism. Parametric Urbanism is identified in this thesis as a subset of the broader topic of Computational Design. These are each discussed over two chapters to
describe the context of the main focus of this thesis. This relationship is demonstrated in Figure 6 to show the hierarchy and scope of the two lines of inquiry.

Chapter 2 focuses on Computational Design and argues that contemporary architectural design practice is plagued by a dichotomy of computational systems and working methods, none of which facilitate the design process and final artefact to their fullest potential. This case is built through a historic review of computational systems development and design theory. This review identifies points of weakness in the current model of computational systems design and the effect this has on architectural design methods. Throughout this review two aspects of theory, classified as 'Computational Design Thinking' and 'Human Design Thinking', form the basis for investigation. These two areas of research are aimed at determining how humans go about problem solving in design, how computers can most effectively contribute to the design process and, finally, how the design process and resulting design artefact are affected when the two are combined.

Chapter 3 refines the discussion of computational design methods to the specific issues surrounding the theory and application of Parametric Urbanism. The first section briefly looks at some of the key developments in urban design theory over the past century. This review identifies how and why urban design has intersected with computational and more specifically, generative design systems, in order to set the scope for the following discussion. The chapter then describes the discipline of parametric urbanism and outlines some of the prominent points of contention surrounding its
contemporary applications. Understanding the different sides of this debate is a key aspect in identifying some of the main areas of concern with the current theory and application of this type of design method. The section concludes by identifying four key areas of concern, summarising the main points of contention as well as the subsequent design implications of these issues. The final section of this chapter looks into the four points of concern in more detail in order to develop a strategy that addresses these areas of weakness.

Chapter 4 presents a number of practice based test studies that were conducted as part of the embedded research programme. For the sake of clarity to this thesis, the design studies described are all based on a single resolution of scale that covers different phases of design development. Each of the case studies describes the technical development of the parametric system as well as a description of the successes and failures encountered as it was applied in practice.

Chapter 5 combines lessons learned throughout the body of work to form the main research proposal of this thesis. The proposed method is outlined for a problem centric parametric urbanism. The empirical nature of the design proposition requires parametric definitions that are derived from a strong analytical basis. In order to formulate a framework that supports this goal, the method is described in two sections. The first is concerned with the scalar defragmentation of the problem to better define the individual design tasks. This process of defragmentation has a substantial effect over the problem type classifications, diagramming methods and scope of the generative
outputs. The second section describes a three-phase design method that guides the development of both analytical and generative parametric design tools. This method is aimed at facilitating parametric tools as an active medium that can contribute to working efficiencies and deterministic results. When combined, the proposed method promotes a staged approach to design with a focus on design solutions compiled from a series of defragmented problem solving tasks.
2. Digital Systems in Contemporary Architectural Practice

“At this point we are not at all clear about where we have arrived in the world of practical computing and speculative design and their full value, culturally as well as economically.” Burry 2011:13

The main hypothesis explored in this chapter is that our current state of computer dependence has negatively affected the way that we approach problem solving in design. As a profession, architectural design is struggling to find a balance between emerging computational systems and the dichotomy of traditional and digital working methods. As yet, there is very little understanding of how to facilitate the design process and final artefact to their fullest potential through new digital mediums. Understanding the benefits and downfalls of working with digital mediums in design is a critical aspect in the formation of a new methodological approach to parametric urbanism. This case will be argued through a historical review and critique of innovative computing systems relevant to design and the emergence of the human-centric approach to digital systems design. Throughout this chapter, a point of change is identified from past models of human augmentation via digital systems, to our current state where human working methods are largely dictated by the capacities of digital systems. This discussion will lead to a description of our current understanding of architectural parametric systems and the philosophical shifts in design thinking that these pose.

2.1. History and Development of Computational Systems

“Design is change.” (Woodbury 2010:7)

Developments in architectural design tools and mediums throughout history have all evolved in an attempt to better facilitate the need for constant
change throughout the design process. These tools have inevitably left their mark on the designs they have been employed to create. They have altered the working methods used in the design development process, which in turn have shaped the type of design outcomes that are produced by the particular tools' individual nuances.

In addition to the study of how certain computational tools have altered both the methods and outcomes of problem solving, the following historical review of computing systems highlights three distinct, but not necessarily exclusive, points:

- Computing systems have offered the most profound results when specifically tailored to augment, contribute or even dynamically participate in human methods and thinking.

- Computing systems have had significantly less impact on architectural working methods than in any other creative or scientific disciplines.

- A large amount of technical capacity (often well established computing standards in other industries) has been simplified out of architectural computing systems.

The development of computing systems and their application to the design industry is well documented in books such as Weisberg’s ‘The Engineering Design Revolution’ or Mortenson's more specialised textbook on geometric modelling (Monedero 2000). The following examples are a short summary of the most significant of these developments whose contributions represent a step change in the way we interact with computers. This study is conducted in order to set the context for our current era of digital design practice. The
following examples have been selected as key demonstrators of not only the
incremental development of architectural parametric systems, but the
effective implementation of computing systems to accentuate - as opposed to
constrain or dictate - a given design process. This study highlights the key
areas of contribution in an attempt to clarify the components of parametric
design systems as well as complementary design methods.

2.1.1. The Evolution of Computer Systems

Some of the forerunners of computational development can be traced back to
mathematical contributions during the 1800s, well before the development of
the digital computer. One such contributor was George Boole, whose
definition of Boolean algebra (Boole 1854) is still fundamental to the
geometric operating systems of modern Computer Aided Design (CAD)
systems. The operational logic is defined as a conjunction \( \land \) (True), disjunction
\( \lor \) (False) or negation \( \neg \) (Null), with constants represented by 0 and 1.

Boole's work into algebraic 'Truth Values' was one of the main influences in
the work of Claude Shannon whose master's thesis at MIT (1937)
demonstrated that electrical applications of Boolean algebra could construct
and resolve any logical, numerical relationship. His work is credited with the
foundation of digital computing and is reputedly the most important master's
thesis of the past century (Krippendorff 1989).

It wasn't until 1950 that Edmund Berkeley developed the concept of the
'sequence-controlled calculator' that the first personal computer, Simon was
created. This development is credited by many as the birth of the modern
computer and subsequently a turning point in the working methods and
operational thinking in all facets of human life.

2.1.2. Human/Computer Interface Systems

The 1960s brought with it new ideologies of a man-machine symbiosis, where
through novel digital interfacing “human beings would become more
productive and creative. The performance of ‘computerized society’ would be
a matter of performance between humans and machines, and this would
require concrete interfaces.” (Pias 2007:125)

One of the most prominent and significant developments of this time was
through the work of Douglas Englebart, who is credited as the inventor of the
mouse, hypertext, multiple-window screen displays and digital video/audio
conferencing (Drucker 1996). These developments were all introduced to the
public in 1968 through a live demonstration that has become known as ‘The
mother of all demos’. One of the most innovative things about the approach
to this development was the fact that Englebart spent years observing the
way office workers operated at desks and adapted the computing interface
controls and systems to enhance this operation (Kay 1987). This was one of
the first examples of human centred systems design (HCD). Although the
development of each of these operational and interfacing systems was
individually significant, Englebart’s greatest innovation was in his vision for a
collaborative community of workers that aspired to an improved collective IQ
and connectivity through the digital environment (Drucker 1996). Despite the
success of this demonstration, the vision for a digitally connected world was
unfortunately ahead of its time and beyond the technology generally
accessible at the time. The cost of implementing these systems was too great for most companies to bear and as a result the mouse and software interface methods were utilised without the full vision for a collaborative working community.

2.1.3. The Evolution of Digital Drawing Systems

Ivan Sutherland was responsible for one of the first instances of a computer drawing system. It was Berkeley’s computer Simon that was one of the principle inspirations for his work (Frenkel 1989). Sutherland's PhD thesis was entitled 'Sketchpad: A Man-Machine Graphical Communication System' (Sutherland 1962). Sutherland was the son of a civil engineer and learnt to read mechanical drawings at an early age. When the opportunity arose to apply his programming skills on a suitable computer, it seemed natural to use it to develop a system for drawing (Frenkel 1989).

Sketchpad introduced many graphical conventions that are still in use today. It used a virtual scale of 2000:1, and pioneered techniques such as zooming, rubber banding and sketching with a light pen to provide point coordinates (i-programmer 2012). The system also introduced element families, which were parametric cells that were drawn in a master file and copied around in the main drawing file. These cells retained live links to the master file to universally update any edits. This program was the first instance of an object oriented software system; the first interactive graphics program; and was based on the first non-procedural programming language (Kay 1987).
In his thesis summary, Sutherland describes the Sketchpad system as showing the most benefit as an “aid to the understanding of processes, such as the notion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it.” (Sutherland 1962:9) Although this was one of the first drawing systems to ever be created, some of these concepts of associativity have only gained interest in the architectural profession over the past decade (Woodbury 2010, Schnabel and Karakiewicz 2007). The first statement from this thesis, ‘aid to the understanding of processes’, is a key part of this early thinking about computing and its place in design. 'Process' refers to the Design Method and surmises that the computing system is, firstly, an ‘aid’ or augmentation tool to this process; and secondly, that through the act of describing tasks to the digital system one can gain a better perspective on the underlying ‘Design-Led’ processes at hand.
The first computational drawing methods and techniques after Sketchpad that were developed during the 1960s in practice were predominantly tailored to basic 2D primitives. It was around this time that the work of Bézier and De Casteljau began to introduce the capacity to create new entities. This work developed Bézier splines or B-Splines as well as three-dimensional extrapolations such as non-uniform, rational B-splines (NURBS); a concept that can be traced back to an article by A.R. Forrest in 1980 (Monedero 2000). This work was extended to create the base logic for wireframes and surfaces patches. Coon and Ferguson are two other names that contributed significant work during this period towards the development of a geometric language classified by mathematical, and subsequently digital, rules (Monedero 2000).

With the increasing capabilities of computers to generate complex geometry came the need for better interface systems and methods. One of the most influential figures in this domain was Alan Kay, whose work was heavily influenced by the work of Berkeley and Sutherland. Kay was one of the first people to introduce a feasible means for building a personal computer and outlined an early prototype design in his 1969 doctoral thesis. This vision for computing hardware design was significant, but Kay's major contribution was in his vision for computing as a communication medium (Barnes 2007). This was vastly different from the concepts of computing as a glorified calculating machine. This concept carried with it a new way of considering non-human communication and the implications of externalising thought processes that this required. This led to some pioneering work into interface language,
mediums and techniques; research that Kay now continues with programming language and interface methods for kids (Barnes 2007).

The 1970’s brought with it the advent of the microprocessor, making computing systems more accessible to the general public. The resulting hardware boom saw new machines flooding the market as well as a race to develop tailored software packages for every industry. For Computer Aided Drawing (CAD) packages, the increased form generation and visualisation hardware raised interest in the visualisation of surfaces and solids. This area experienced rapid and significant development through flat-shading (1970), Gouraud shading (1971) and Phong shading (1975), techniques that changed little and remained cutting edge for the next 20 years (Monedero 2000).

Although parametric capabilities have only been re-introduced to mainstream architectural design over the past decade, engineering design programs realised their potential in the 1980s. These programs were readily incorporated into working practices due to the obvious advantages in working efficiencies. Samuel P Geisberg, a maths professor turned programmer, developed the first comprehensive parametric program. Geisberg was the principle developer of Pro/ENGINEER, which was first released to the market in 1987. Geisberg was the first to integrate aspects of CAD software that were fragmentally employed by Matra Datavision, Intergraph and others, into a single rule-based constraint (parametric) system for all design analysis and manufacturing applications (Weisberg 2008). The modelling approach of Pro/ENGINEER used parameters, dimensions, features and relationships to capture intended product behaviour and create a recipe that enabled design
automation and the optimization of design and product development processes (Ahmed 2010). Geisberg proposed developing a novel approach for CAD software where everything was done with double-precision solid geometry and NURBS surfaces (Weisberg 2008). Although Geisberg was not the creator of NURBS geometry - this credit belongs to Dr Ken Versprille (Rogers 2000) - he was among the first to implement them in a successful CAD platform. Pro/ENGINEER was also one of the first applications of a step-by-step design action record or history tree (Weisberg 2008).

The first computer aided architectural design (CAAD) tools, introduced in the 1970s, were primarily a replacement for the drawing board. Although some introduced capabilities such as NURBS, B-reps and other solid geometry modelling formats, the platforms were generally based on a drafting paradigm. They improved productivity and accuracy of drawing creation without having to change the underlying processes applied to design (Woodbury 2010). Early versions of this tool were very cumbersome to use with designers having to place each point Cartesian space with only X,Y,Z values as a guide to creating geometry between these points. These systems still gained in prominence, despite potentially longer initial drafting times, due to their ability to make minor amendments and print multiple copies faster than analogue drafting would allow.

These tools, though based on the process of drawing, did not support a high level of exploration of design alternatives, variations and changes (Glymph et al. 2004, Woodbury 2010). Unfortunately, a number of the associative capabilities driving earlier systems such as Sketchpad were absent in these
versions of CAD. This was due largely to the knowledge gap between incorporating a new working medium into design practice and the changes that this level of technical ‘up skilling’ presented. Mark Burry (2011) speculates that this gap between design thinking or methods and the technical requirements of computing was also due to computer based work not being seen as a core activity of architecture. Computers were widely accepted as providing greater efficiencies in aspects of design work, but pen and paper remained the preferred medium for design development and communication. This led to the computational design software that was shaped around these manual processes and methods. As a result, generative geometric relationships dropped out of architectural design practice for nearly 20 years.

2.1.4. Contemporary Computational Design Systems

Contemporary CAD programs still use the same basic principle of defining geometry by points in Cartesian space. The major changes in architectural computing have been dominated by technical sub-disciplines driven by economics of design functionality and efficiencies in drafting software. As yet, there are very few design based programs that fulfil both the aesthetic and pragmatic needs to make parametric modelling feasible in practice (Aish and Woodbury 2005).

“The paradox is that for decades architectural software has striven to emulate the analogue working practice that architects developed over the past two centuries and, as a group, architects have not been especially motivated to assist lifting themselves out of the analogue design methods rut.” (Burry 2011:17)
Despite the lack of change in mainstream architectural practice methods, there is still a wide range of computational capacity in form generation, self-analysing structural systems and performative building systems available to the profession. These systems and techniques are widely published and individually accomplished in their respected fields of discrete research. Unfortunately, these areas of specialised computational design are not well defined in context to the holistic design process and their applicability to architectural practice methods (Oxman 2006).

These computational abilities have the potential to bring mathematical and geometric processes back into the forefront of design thinking, encouraging a greater understanding of the previously invisible foundations of spatial representation and generation. In order to realise this potential, there needs to be recognition of the unique design problems that computation poses to architectural research, “promulgated by a culture of discourse, supported by new technologies, and producing unique classes of designs.” (Oxman 2006)

This phenomenon introduces a new dimension to the problem space of architectural design, and with it, the need to readdress the way we think about problems and the devices utilised in solving them.

2.2. How Parametric Systems Have Affected Design Thinking

“Where computer aided processes begin with the specific and end with the object, computational processes start with the elemental properties and generative rules to end with information which derives form as a dynamic system.” Ahlquist and Menges 2011:10

“Information has become a new material for the designer.” Oxman 2006:242
Architectural parametrics has its roots in both digital animation and engineering (Schumacher 2009). Program platforms take their mathematical logic from engineering programs that have utilised parametric relationships in their core operations for years. Frank Gehry’s parametric platform Digital Project was developed on top of the Dassault aerospace engineering system CATIA. This has led to computing systems being transferred into architectural design from industries that developed them for different purposes. This sudden accessibility to previously unknown digital capabilities brings with it the requirement to re-examine current design theories in practice. From this foundation analysis, we can begin to build a sound conceptual framework on which to base future research into digital design methods and theory. Fundamental to this understanding is the human/computer relationship during the design process and the philosophical challenges that growing computational capabilities have on the human participants’ approach to design thinking.

Pencil, eraser, paper and ruler are all familiar tools of design with well-practised methods and techniques for their use. These techniques are successful because the tools can be utilised within different methods in order to attain a certain result. Robert Woodbury (2010) states that these tools, and the corresponding methods associated with their use, offer a basic functionality of ‘Add’ and ‘Erase’ as a means of creating and changing design ideas. Generative computer systems, particularly parametric systems, offer the first truly active medium for design. These systems are based on the same functionalities, add and erase, but also allow for the added functions of ‘Relate’ and ‘Repair’ (Woodbury 2010). Relating requires a clear
understanding of the relationships in play between elements or actors in a design. Repair comes after erase or change and is dependent on the relationships between actors to regenerate or re-relate the design. Relate, therefore, needs to be robust enough to work within a dynamic and changing construct while still facilitating the potential to Repair.

These functions as interactive mediums may be new, but as concepts are very familiar to the process of design. Designers have always used these functions as part of an internal problem solving logic that was expressed through the traditional mediums. Computing systems just allow for ‘Relate’ and ‘Repair’ to be externalised for the first time. This distinction is the reason that pencil, paper and other analogue mediums are not considered an active medium. They are pure recording devices of a designer's internal logic and thought process; they don’t offer anything back to the conversation. It is true that a lot of decisions can only be made, or realisations reached as a result of creating and observing a sketch or model, but the distinction is in the capacity of a system to positively contribute to the design process through generation and problem solving.

As Alan Kay (1987) would espouse, computers present a new challenge in quantifying and externalising this previously internal human function. Discourse in parametric modelling research has to focus on not only mathematical, scripting and geometric concepts, but also an active awareness of the processes that facilitate design thinking and problem solving. This is partly what Ivan Sutherland meant in the opening comments of his PhD thesis
when he classified computational systems as an “aid to the understanding of processes.” (Sutherland 1962:9)

2.3. The Evolution of Computational Working Methods

The following chapter consolidates the main points covered in the previous sections and illustrates the changing relationship between humans and computers over the past 60 years. This review summarises how different technological advancements have impacted on the way in which we work and approach problem solving. The chapter concludes with a critique of contemporary society’s state of computer dependence through outlining the strengths and weaknesses of current system design models.

As evidenced in the previous historic review chapter, there is no singular point where the world changed direction in its understanding and use of computing. The change has been a gradual and generational shift in thinking of computers as a tool for augmenting human problem solving methods to a dependence on digital systems to define the scope, reasoning and processes of problem solving. In other words, human problem solving is now largely dictated and constrained within the limits of a (set of) computing systems prescriptive functionality. One of the main outcomes of this philosophical shift in human/computer relationships is in the empowerment of digital systems’ as active rendering the human counterparts increasingly passive (Cooley 2000). This means that despite programming sophistication, the full potential of the medium still remains largely underutilised due to complacent human participation. The working methods have not been developed to the same level of sophistication as the systems could potentially facilitate.
Figure 8 demonstrates the shifting role of human participants throughout the development of computing systems and aims to highlight some of the benefits and downfalls of this development over time.

The diagram demonstrates chains of interaction and influence between human participants and computational systems during the process of problem solving. The problem space is representative of a series of design problems.
that require dedicated processing of information to provide an output or
design solution.

During the 1950s the relationship between human users and computing
systems was predominantly linear from computing competence through to
the output. This put a heavy focus on the programmers having to understand
all elements in the chain of information from conception to desired solution.
All communication and programming control was conducted directly through
the assembly language with relatively limited user interface between the
computer and the domain user. A disconnect between computing system and
domain user is evident through the reliance on a third party programmer. The
programmer acted as a translator between the problem, the domain user and
the computing system. The benefit of such a process was that despite the lack
of any direct influence over the computational system, the system remained
centred around the needs of the human domain user. This shaped the working
methods and design logic required to solve the problem within the full
capabilities of the system.

The dependence of domain users on programmers as the sole gateway to
computational problem solving remained into the 1960s and 70s. The
introduction of programming languages, however, made this domain of
computing increasingly more accessible for those willing to learn. This led to a
new wave of tailored interface languages that could mediate between the
assembly language, programmer and problem space. These languages were
often very discrete in their scope of application, as they were developed to
deal with a limited type of problem very well. This level of focus made them
inefficient in addressing a broad range of problems within the working process and resulted in sporadic use of computing systems for some problems and not others. As a workaround to these limitations, hybrid analogue to digital working methodologies were adopted. This unfortunately meant that the manual tasks were more easily adapted to accommodate the limited scope in the digital systems for the sake of utilising computational efficiencies.

The 1980s and 90s brought rapid systems development with more comprehensive and accessible programming languages. This allowed for more comprehensive and flexible software packages with direct domain user interface and input. These began to replace analogue processes and subsequently shift the core working methods increasingly towards digital dependence. Despite the domain user input, the programs were generally limited to pre-determined workflows. This did not lend itself well to the types of non-standard problem spaces, as encountered regularly in architectural design. As a result of these programming limitations, architectural practice persisted with predominantly hybrid working techniques, using computers for increased efficiency in standard production.

The 2000s saw the introduction of more comprehensive programming languages, providing a more transparent and accessible platform for the scripting interface. This accessibility allowed for the introduction of more adaptive system based toolkits in which the domain user could more easily change standard operations to suit different tasks. The level of flexibility ranged from custom application scripting to the variable settings of standardised functions in programs. In this model, the domain user is afforded
a measure of power over the type of systems and workflows that are used. This is a distinct shift from the previous decades as the focus is placed back onto the domain user and the users’ natural working processes as opposed to the computing systems dictating the scope of certain workflows. This change in the flexibility of computational systems offers the first opportunity, albeit an underutilised one, for the domain user to shift the working methods and subsequently choose which problem space is approached.

One of the system design movements that epitomises this type of domain user focused digital empowerment is Human Centred Design (HCD). (Darzentas et. al 2014) This form of computational thinking has been developed over a number of years in mechanical systems designs that rely on computing systems and a synergetic workforce to drive the core functions. This theoretical model is further ranging than just allowing domain users to manipulate their digital working environments. HCD advocates that a “more promising and enduring approach is to model users’ natural behaviour to begin with so that interfaces can be designed that are more intuitive, easier to learn, and freer of performance errors.” (Oviatt 2006)

Despite the potential benefits of this design model, there is still a fundamental flaw in the focus on human interaction with computers to the exclusion of how the technology can be shaped to change and enrich human skills (Rasmussen 2007). This is true also for the current state of computing dependence in architecture. Although programs offer more flexibility most operations are still based on existing working methods in which the domain user is unmotivated to explore greater potential.
On the other side of this argument, system design models such as Participatory Design, Interaction Design, and Agile Software Development (ASD) are concerned with optimising computational systems to their tasks and how humans can adapt their working methods to suit the systems requirements. These systems theories are task oriented, with the general aims of creating flexible programs that are designed and adapted through regular feedback loops with the domain user. Despite this feedback loop, each of these theories still relies on the separation of computing and domain competences, optimising one party and having the other change operations to suit.

The division between human or programming focused systems theories creates a large void between the two sides of system design development that requires mediation to align the strengths of both approaches to better align with the optimisation of working methods and production of a better final product.

2.4. Chapter Summary

This chapter has explored some of the key step changes in technology over the past few decades and some of the ways in which this has influenced the way we work and problem solve in design. This discussion has been led by the three principal hypotheses of the chapter:

- That computing systems have offered the most profound results when specifically tailored to augment, contribute or even dynamically participate in human methods and thinking.
- Computing systems have had significantly less impact on architectural working methods than in any other creative or scientific disciplines.

- A large amount of technical capacity (often well established computing standards in other industries) has been simplified out of architectural computing systems.

The discussion throughout this chapter sets up a theoretical framework that addresses the first broad scope research question and provides the appropriate context for the second specific research question to be discussed in chapter 3.

Chapter 2.1 (pg 18) outlines some of the milestone events throughout history that have impacted computational working methods with the aim of identifying and understanding points of change from past aspirations of human augmentation via digital systems, to our current state where human process is largely dictated by the capacities of digital systems.

One of the fundamental ideas to come out of this section is that computer systems have the potential to be an “aid to the understanding of processes”, a sentiment from pioneer Sutherland but echoed 40 years later by leading researchers Woodbury and Burry. Computers provide us with a system that forces us to externalise thought. Through external description of ideas to a machine, all reasoning is laid bare. This point recognises that any computational design problem is not solely technical but one of design thinking and its subsequent methods of facilitation. This point rationalises the scope of the research project to focus on strategies for computational design.
thinking that will aid in the augmentation of a designer's abilities and encourage computational structures that support design exploration.

The section concludes with a look into mainstream design practice methods and the realisation that despite rapid technical growth, advanced computer systems generally remain part of specialist sub-disciplines in design. Even though computer systems continue to advance, providing the potential for significant change, as a whole, architecture has failed to adapt to this evolution and instead retained the discipline's pre-digital working methods.

The awareness that computational working methods have unrealised potential to better support design exploration is furthered in chapter 2.4 where the discussion covers generative computer systems in contemporary design practice. This chapter states that computer systems have the potential to offer the first truly active medium for design. This is particularly true for systems, such as parametric systems, that allow for the functions of ‘Relate’ and ‘Repair’ that can actively participate in the design process. The concluding sentiments of this section reiterate that any research and/or application of parametric modelling requires discourse on the processes that facilitate design thinking and problem solving, not only the technical and mathematical aspects of form making.

Chapter 2.5 picks up on the discussions from both 2.3 and 2.4 through a diagrammatic demonstration of computational working methods evolution over the past 60 years. The conclusions of the previous chapters are discussed here in the context of systems theory, which looks more explicitly at the working relationships between humans and computers and targets the
discussion to the specific scope of the thesis. This demonstrates the changing role of computing systems within domain competence workflows. Further, a change is identified between linear Human Centred process of early systems to the more recent restrictions on the domain problem space by overly specialised and prescriptive systems. The chapter credits this change largely to the advancement of technology that empowers them as active systems while the human counterparts become increasingly passive. The passive nature of humans in these workflows is accredited, once again, to the lack of strength behind an integrated human computer working methodology. The working methods have not been developed to the same level of sophistication as the systems could potentially facilitate. This is discussed further in the context of Human Centred Design and other prevailing systems design theories that are tailored towards supporting either existing human workflows or improving the efficacy of computer competence programming.
3. **Parametric Urbanism**

The following discussion is conducted within the parameters of the research question,

*What are the key areas of weakness in the current working and computational systems that need to be addressed in order to form new ways of applying parametric urbanism in practice?*

A contemporary review of the current state of research and applied work in this field of design will be conducted in order to identify the benefits and downsides of Parametric Urbanism. The key topics that are identified are discussed in further detail in order to formulate a strategy for mitigating the areas of contention and weakness. This discussion will form the basis for a set of rules for Parametric Urbanism that will dictate the scope of the urban design methods explored through chapters 4 and 5.

3.1. **Origins**

A new (or renewed) appreciation for the dynamic nature of our urban environment means that urban architecture can’t be considered as static forms that are defined by the visions of an ideal canon but rather as a system of change that will generate complex and often unforeseen results (Stavric and Mariana 2011). This aspiration has led designers to consider equally dynamic systems and methods of design that are capable of facilitating design within complex environments and adapting to both immediate and ongoing change.

To date, this field of digital urban research has been sporadic and disparate in its aims and methods. One particular branch of this field has been most widely
classified in recent years as ‘Parametric Urbanism’; a term coined by one of the directors of Zaha Hadid Architects (ZHA), Patrik Schumacher (Schumacher 2008, 2009, 2010). Although the term was first published in academic literature in 2006 in David Gerbers ‘Towards a Parametric Urbanism’ (Gerber 2006), it is still credited to Schumacher as a term used in his Architectural Association’s Design Research Lab (AADRL) course guide and lectures in 2005-06 (Canuto and Amorim 2012). ‘Parametric Urbanism’ is also the term adopted throughout this thesis to describe the application of parametric modelling, as defined in the previous chapter, to the emergent theories of contemporary Urban Design, as discussed in the introductory definitions (pg xxvi). This area of digital urban design is distinct from other forms of Generative Urban Design and can be classified as a subsection of this practice in the same manner described in the Key Definitions section (pg xiv).

The urban theories outlined by Schumacher have been widely debated, (Schnabel and Karakiewicz 2007, Mayer 2010, Davis 2010, Beirão et al. 2012, Mehaffy 2011) and as such alternative titles have been proposed to better encapsulate this design movement such as ‘Information Urbanism’ (Tang and Anderson 2011), ‘Digital Modelling for Urban Design’ (McGrath 2008) and many more. The differences proposed in these categories of urban design are mainly separated by their scope of application and semantics in terminology. However different the terminology, the heated debate surrounding Parametric Urbanism is, in itself, evidence of the lack of any ordered or explicit theory that can consolidate this emergent field of research into a valid method for urban design. This debate will be described further in Chapter 3.2 (pg 42).
Understanding spatial phenomena and the expression of urban complexity has been a long-standing area of research and now provides the next challenge for architectural and urban parametric modelling and design (Karadimitriou 2010). The high levels of complexity and multiplicity of scale can potentially benefit from a set of programming and visualisation strategies designed to manage large data sets and optimise physical forms as determined by the designer (Leach 2009, Stavric and Mariana 2011). Of particular interest is the ability to design simultaneously across multiple scales of resolution while considering the multitude of networks and dependent relationships that exist in any urban environment.

3.2. The Current Debate Surrounding Parametric Urbanism

"Parametric Urbanism takes the paradigm and tools of parametric design into the domain of urbanism. The power of parametrics is usually exploited to cope with the rapid succession of design changes, i.e. for its ability to produce variations of a single building, or to generate versions of building components for a complex building geometry that does not allow for the repetition of elements. Parametric Urbanism suggests that these techniques of versioning can be applied to an array of buildings, so that a new version does not replace an older version but instead comes to join and extend the field of simultaneous versions in building up a complex urban field."

"Swarm Urbanism" 2006 Architectural Association brief by Patrik Schumacher

As discussed in the History and Context of Parametric Urbanism chapter (pg xxvi), the latent potential for parametric modelling platforms to positively affect urban development has sparked a new wave of cross disciplinary collaborative and embedded research (Oxman 2007). This has seen a number of research institutions and architectural practices entering into ventures of
research and experimentation with varying levels of success. The following
section discusses the current theoretical state of parametric urbanism as well
as some of the controversy and debate that surrounds its use. Throughout
this review, several main points of contention are identified. These areas of
concern will be discussed in further detail in the subsequent sections of this
chapter and will form the primary hypothesis that will help to shape the
theoretical design model for a problem centric parametric urbanism presented
in chapter 5.

Due largely to the assertions of Patrik Schumacher regarding ‘Parametricism’
as a new architectural style, widespread debate has begun throughout the
disciplines of both parametric and urban design research. The debates cover
issues with the use of the term ‘style’ and the reduction of the models to mere
formal composition (Beirão et al. 2012, Canuto and Amorim 2012, Mayer
2010, Davis 2010). Many critics also raise questions regarding the rigour of
urban theory underpinning the parametric models (Tang and Anderson 2011,

Much of this debate is focused around the assertions made by Schumacher
about Parametricism and the design implications of his ‘Categories for
Parametric Design’. Although there are many other voices and opinions
asserting their own ‘truths’ of Parametric Urbanism (Tang and Anderson 2011,
2012), the boldness with which Schumacher coins new terminology, declares
fundamental rules, and the general media attention that these receive through
Zaha Hadid Architects (ZHA) design work has placed him firmly at the centre of this debate.

3.2.1. The Urban Theory behind Parametricism

“The most common problem with architectural theories is that they have too often been strongly normative and weakly analytic, that is, it has been too easy to use them to generate designs, but they are too weak in predicting what these designs will be like when built. The theories of modernism were, for example, quite easy to follow in generating designs to satisfy normatively stated objectives. The problem was that the architectural means proposed were not the means required to achieve those objectives. The theories were weakly analytic. They did not deal with the world as it actually is. The normative dominated the analytic.” (Hiller 2007:41)

In his evocatively titled paper ‘Parametricism: a new Global Style in Architecture and Urban Design’ (2009), Schumacher defines the following categories of research and design consideration for the successful application of Parametricism or Parametric Urbanism.

1 - **Parametric Articulation of Subsystems**: The goal is to move from single system differentiation (for example a swarm of facade components) to the scripted association of multiple subsystems - envelope, structure, internal subdivision, navigation void.

2 - **Parametric Accentuation**: Here the goal is to enhance the overall sense of organic integration by means of correlations that favour deviation amplification rather than compensatory adaptation. The associated system should accentuate the initial differentiation such that a far richer articulation is achieved and more orienting visual information made available.
3 - **Parametric Figuration**: Complex configurations can be constructed variably allowing multiple ambient and observer based control systems that ‘optioneer’ variations in a design. The quantitative modification of these parameters triggers qualitative shifts in the design configuration.

4 - **Parametric Responsiveness**: Urban and architectural environments possess an inbuilt kinetic capacity that allows those environments to reconfigure and adapt in response to prevalent occupation patterns. The real time registration of use patterns drives the real time kinetic adaptation. The built environment thus acquires responsive agency at different timescales.

5 - **Parametric Urbanism (Deep Rationality)**: The assumption that urban massing describes a swarm formation of many buildings whereby the urban variables of mass, spacing and directionality are choreographed by scripting functions. In addition the systematic modulations of architectural morphologies produce powerful urban effects and facilitate field orientation. The goal is deep rationality, the total integration of the evolving built environment, from urban distribution to architectural morphology, detailed tectonic articulation and interior organisation. Thus parametric urbanism might apply parametric accentuation, parametric figuration and parametric responsiveness as tools to achieve deep rationality.

(Excerpt from Schumacher 2009:17)

In summary, the rules of Parametricism state that the system for design should be responsive, adaptable, comprised of multiple intelligent actors and capable of generating series of potential options based on variable input scenarios that are not limited in expression by basic geometry. When all of these elements are combined into a cohesive model it becomes a method of design that can be classified as Parametric Urbanism.

This theory acknowledges that, given our current understanding, static rules can no longer be applied to the design of urban environments. It also declares that descriptions of adaptable systems, as mimicked from nature, are
theoretically more applicable to determining the generative logic for desirable urban planning (Batty and Longley 1994). As a broad logic most of these statements align with the current theoretical aims discussed in History and Context of Parametric Urbanism chapter (pg xxvi). It is through Schumacher’s further description throughout the paper that outlines the theories and the intended application of Parametricism, that formal or geometrically governed tendencies become apparent. This is particularly evident in the void between Schumacher’s theory of Parametricism and the sole empirical evidence of its application stemming from Zaha Hadid Architects portfolio.

One of the reasons that this particular facet of parametricism has been criticised, and the first point of weakness identified in this chapter, is the distinct lack of any robust typological drivers behind the geometrically conceived designs. This leaves the design scheme open to critique from those who argue for a more robust design model that can be formed from analytical types and be validated against empirical evidence. Bill Hiller describes this type of analytical architectural theory in his book ‘Space is the Machine’ (2007) as aspiring towards normative complexes, telling us what to do and how things should be; as opposed to scientific theories that are analytic and about understanding how things are. Hiller goes on to describe architectural (or design) theories as “analytic-normative complexes, in which the normative is constructed on the basis of the analytic. It follows that properly theoretical content of architectural theories is specified by the analytic. If the analytic theory is wrong, then the likelihood is that the building will not realise its intention. Architectural theories, we might say, are about how the world should be, but only in the light of how it is believed to be.” (Hiller 2007:41)
What Hiller notes is applicable to the current methods by which Parametric Urbanism is applied to the design process. Normative design aspirations are generally driven by form, as desired by the designer(s) or by technical processes and pre-programmed functions that can be unrelated to the particular problem at hand. As a result, the analytic portions of these methods are often treated as secondary to the formal aspects and are therefore superficial in application. Normative theory is at the discretion of the designer, which becomes problematic when computational generation is factored into the process. This particular non-analytical process leaves aspects of normative judgement to be made by a computer system. In order for Parametric Urbanism to move forward, it requires a more solid foundation from which analytic theory can be integrated. Specifically, this relates to ‘Parameters’ and the level of embedded analytical research defining them. If a
computer system cannot make normative decisions based on experience and judgement, then we need to analytically determine how those decisions can be made sufficiently. This is relevant to the level of predictability and control of the design outputs, the level of empirical evidence validating the design outcomes and the ability of a designer to still obtain their own normative or aspirational design goals. This is also critical to the process of trial and optioneering in design that has long been recognised as equal in importance to analysis (Lawson, 2006). In order to implement such a system for analytic parameter definitions, an understanding of urban and architectural types and typologies is required. This area is investigated further in chapter 3.3.3 (pg 71).

In response to this lack of control over design outcomes, Michael Meredith argues that “To the extent the profession has utilised Parametrics today, there is very little instigating complexity other than a mind-numbing image of complexity, falling far short of its rich potential to correlate multivalent processes or typological transformations, parallel meanings, complex functional requirements, site specific problems or collaborative networks.” (Meredith 2008) This sentiment summarises the results of weakly analytical parametric design and the underlying source of much of the discipline’s criticism and contention. Better resolution of this issue will also aid in Parametric Urbanism’s adoption into the design industry as a replicable technique for addressing complex design problems.

Just as important to the modelling process as strong analytical inputs, is the need to have the right mechanism by which they are applied to design
problems. Critique has been directed at the current methods of parametric design that attempt to capture both normative and analytical embedded intelligence in a single generational tool (Mehaffy 2011, Meredith 2008, Hiller 2007). This process inevitably produces overly aggregate design solutions that are inappropriate for addressing the smaller scale due to their reliance on pre-set computational assumptions (Batty 2005). This is the second point of concern highlighted in this chapter. Parametric modelling should, therefore, be used as a tool that can develop desired trajectories of an urban space as a means of influencing a cohesive evolution across multiple scales of resolution (Karadimitriou 2010). In order to do this, further recognition needs to be given to the unique problems relevant to different scales of design resolution. The process of solving these problems and the subsequent methods and tools utilised in the process, are driven by more direct and controlled requirements that limit the scope of computational assumption.

3.2.2. Parametricism as the new Architectural Style

The second part of the debate focuses on the use of the word 'Style' to describe Parametric Urbanism as a formal design expression. This argument partly stems from some of the functional theory already discussed but extends to a more theoretical discussion on what classifies as a design style. Contemporary use of the classification of architectural style is more commonly of peripheral significance to the design itself as the architect strives to disconnect themselves from the strictures of stylistic rules (Beirão et al. 2012). This is a sentiment that is applicable to Schumacher's second rule of Parametric Accentuation, which states that urban form should not be limited by the tools we use to create it. The statement continues on to promote the
ability to introduce 'organic integrations' via 'deviation amplification'. In the
design examples used to validate these statements, however, this organic
form making seems to be employed in practice as a stylistic rule. These
stylistically driven design tendencies are further confirmed through the first
rule of Parametricism, Parametric Articulation of Subsystems, which
introduces the ideal of parametrically defined and self-similar urban scale
architectural design. This is, in part, linked to the type of model that
Schumacher is proposing where output data is compiled, not as an indicative
massing diagram of concepts and potential outcomes, but as a physical
proposition that alludes to architectural decisions and set physical and
aesthetic properties. For many Urbanists, this has strayed too far into
egotistical design programs similar to those of modernism. This attitude has
raised concerns as to whether a blanket application of parametric rules that
generate detailed designs is desirable to the design community and the
ongoing use of a preconceived urban realm. Additionally, will this type of
broad urban generation and its capacity to control complex relationships
avoid or exacerbate the traps of modernism?

The trend towards parametric and other forms of generative urban modelling
has inevitably seen the increased exploration of advanced architectural form
and program by those willing to learn new systems and push the boundaries
of design capabilities. Nurbs, point clouds and b-splines are some of the
complex geometric systems that are now made available for design
exploration thanks to parametric programs. As a result of this newfound
computational control, designs tend to privilege buildings as an object, which
in turn, breeds distinctive stylistic tendencies that can be recognised as
‘parametric’. This idea of ‘form over function’ has become one of the main architectural issues with the newfound geometric mastery offered by parametric programs (Hensel 2011). This hierarchy has been redefined from the strictures of ‘form follows function' that the modernist movement brought to the architectural world. This highlights the third point of concern identified in this chapter, which pertains to the type of model that is produced as a digital artefact and how this is both applied and communicated.

Architecture is defined as ‘the art or science of building’ (Merriam-Webster 2011). Architecture, therefore, should be more than just an additional aesthetic process added to a functionally minimum entity. In serving functional requirements, it moves beyond a purely artistic entity. It can be inspired by artistic concepts and drives but only in the service of humanistic endeavours. Mehaffy reiterates this sentiment from pioneering work such as Jacobs 1961, when he states “catastrophic errors can result from a confusion between the systems of art and the systems of living cities.” (Mehaffy 2011:480) Hiller argues that “Architects believe, and clients on the whole buy, the idea that architecture is a way of being concerned with the whole building, and a means of engaging the deepest aspects of what a building is. If architecture is defined as an add-on which ignores the main substance of building, then architecture would be an addition to building, but would not be more than building.” (Hiller 2007:10)

This is one the main points of contention with non-deterministic and highly normative theories of design as well as one of the greatest downfalls of tailored parametric programs. While the pure expression of complex form,
whether it be an accentuation of minimum function or total disregard of functional requirements, has immense artistic significance in visual representational media, as a tool for urban and architectural design it is notoriously misused. (Figure 10)

![Figure 10](https://via.placeholder.com/150)

**Figure 10**  
*Detail of Zaha Hadid Architects Kartal – Pendik Masterplan, Istanbul, Turkey. (Sourced from Schumacher 2009 pg 14-15)*

From an urban design standpoint, this has translated to complex expressionism and geometric primacy without regard to final use as built form. Technical tools that are capable of both rationalising and generating unparalleled complexity in form and program often take over as the driving methodology for design. While parametric programs open up new avenues of design information and expression they can never discard the shackles of human need. As purely aesthetic endeavours, the urban products generated in this manner are tainted by human inhabitation; as architectural artefacts they are riddled with ill considered and distracted spatial expression lacking
referents, narratives, history and forces that detract from the intended human experience.

At the extreme end of this argument many leading urban designers state that geometrically driven or not, urban form - and by its associations, style - doesn’t really matter (Beirão et al. 2012). As discussed in earlier chapters, one of the major critiques to come out of the modernist movement was that spatial masterplanning should not be practised due to the lack of theoretical and practical tools available to us as well as the self serving formal dominance that has been proven to detract from urban quality and flexibility (Karadimitriou 2010).

This standpoint raises the question of whether parametric modelling can be applied to urban design without reducing the design outcome to a formal object? This concern stems from the idea that any design tool, with its unique strengths and weaknesses, naturally lends itself to designs that play to its strengths. In the case of parametric modelling, the pre-defined tools lend themselves well to complex tessellations of components and curvilinear governing surface geometries. This is, therefore, the obvious and most utilised aspect of parametric modelling, favouring a stylistic imprint of curvilinear forms and morphing objects. (Figure 11)
This factor alone is not definitive enough to proclaim a parametric style and speaks to the state of a product rather than the drivers that create it. There are still normative aesthetic desires embedded in the choice to use a parametric medium over another but this is a personal choice driven by an aesthetic desire to produce the type of design artefact most easily achieved through parametric modelling. As described in the last chapter, a great deal of the aesthetic character of any design tool is much to do with the limitations of the tool itself. How it imparts its scope of use on what is produced can be distinctive.

This chain of thought brings us to the question of how we address the interface with parametric modelling to reduce connotations with style from its use? This presents a challenge to accommodate a wider design audience that can take advantage of parametric modelling without limiting the scope of the aesthetic choices through overly prescriptive program interfaces. The
proposed solution to this issue is not specifically interested in broadening the scope and interface of specialist programs, thus defeating the purpose of the programs’ particular specialism, but instead with a more robust methodological approach to dealing with data throughout the design process. Specifically this is concerned with the way in which multiple digital and physical mediums are utilised and the strategy employed to minimise the loss of data and/or intent through transfer and communication. This summarises the final point of weakness identified in this chapter and pertains to the methods used for interfacing and diagramming ideas in a computational design process.

There is undoubtedly consistency in the geometric solutions of architecture produced with parametric programs. Michael Meredith argues that the new wave of parametric design “fits within an evolution of so called post-modernism” (Meredith 2008:7) Mark Burry takes this a step further by arguing that “stylistic hegemonies have at long last died out, dinosaurs of an age when collectivism, suppression of individualism, obligatory conformity to the style, and dominant paradigms were at last deemed cultural constructs.” (Burry 2011:18) Whether the use of parametrics constitutes the coining of a new architectural ‘style’ is debatable. In stepping aside from this argument, the power of the tool and the inexorable change in the way architects design and build on a global scale is very clear and widely accepted. Style may not be the driver of such change but it is definitely a facet in the shifting design methods and thinking that can facilitate a range of stylistic tendencies, or equally, perpetuate the freedom of pluralism.
3.3. Pressure Points for Parametric Urbanism

The previous section outlines the current debate surrounding parametric urbanism and highlights a number of areas for concern that will be individually discussed throughout the following section. Despite the context in which they have been raised, these points are seen to be universally applicable to a designer's digital and physical working process regardless of any particular theoretical proclivity towards certain urban theories. These pressure points are indicative of the design thinking and communications process and raise fundamental questions that require further clarification, both as individual topics and as a collective group. The first area is concerned with ‘Diagramming’ and the arguments focused around communication and interface systems. The second area is classified as ‘Scale’ and is focused on the concerns of over-assumption and aggregation in ‘black box’ digital systems. The third area of 'parameter Definition' looks at the assertions that parametric systems are still lacking a strong analytical parameter base to drive the design generation. The final area is classified as 'Model' and explores criticisms that parametric generation has brought about a trend in design that produces superficial, geometrically focused designs. These areas of concern have been distilled into four lines of inquiry:

- **Diagramming Language:** How do we communicate between designers, lay people, and computers without restricting the working methods or the design output?

- **Scale (Digital and Representational):** How do we conceive, problem solve and generate a design at different levels of resolution without producing reductive and aggregate assumptions in the solution?
- **Parameter Definition (Types and Typologies):** How do we develop analytic parameters that can generate, constrain, adapt and contribute the design while still maintaining the normative aspirations of the designer(s)?

- **Model Classification:** What forms will the digital model(s) take in order to successfully represent the design data as a communicable urban model?

These categories are all interrelated and in parts symbiotic but have been distinguished in order to highlight some of the unique requirements within each in the context of Parametric Urbanism. They require a sound theoretical basis in order to operate successfully at an urban scale via the use of digital augmentation that benefits design outcomes. The following section looks at each of the four pressure points in order to develop a set of rules that, together with the problem centric method of systems development, will form the basis of the theoretical model presented in chapter 4.

### 3.3.1. Diagramming Language

*How do we communicate between designers, lay people, and computers without restricting the working methods or the design output?*

The diagram has been present in many disciplines throughout human history as a means of communicating ideas. Early iterations of town planning diagrams can be described as representations or systems of emplacement where magic or religion ruled (Lynch 1960). Claude Levi-Strauss described these early planning diagrams as a genetic code of social organisation that defined the physical construction of a village or city (Levi-Strauss 1973). The
Romans planned their cities around a cosmic diagram based on cardinal points with defined centre and axis. New residents would throw a lock of hair in the centre of town as recognition of the cosmic power represented in the city diagram (Shane 2010). The diagram was important to the defined occupation and ritualistic connection of community to the place of habitation and its hierarchical arrangement.

The term 'Diagram' is generally reserved for the act of communicating a visual ‘sketch’, particularly in architecture and design, but the broader terminology refers to any form of communication that is an abstract representation of an object or idea that is distilled into key concepts for the purpose of representation. In other words, a diagram can be described as the architecture or fundamental componentry of an idea or entity (García 2010).

The concept of reduction is critical to urban design as it is impossible to design within the same physical environment as the design problem itself (Arida 2000). The key to a diagrams' success is in the simplification of concepts to allow manipulation while embedding a reasonable level of understanding that can be packed and unpacked without losing meaning or intent. These distilled key concepts are of great value if they can be grasped and manipulated with a high degree of efficiency (Schumacher 2010). For this reason, diagramming is fundamental to the act of communication and problem solving making it a critical aspect of the systems used to interface between people, data sets or computers.

"Diagrams help us to see the city, but at the same time can blind us to the real complexity and fluidity." (Shane 2010)
As mentioned previously, the diagram allows for packing and unpacking of ideas from aggregate to disaggregate representation. One of the main pressure points in this process is in the procedure of decomposition itself. By what method, medium or system is the concept reduced? This requires simplification with the explicit understanding of inherent complexities that are alluded to. From this simplification come the prime relationships at play within a given system. This allows for manipulation within the refined construct that can then be built back to a functioning level of complexity. This is a scalable problem where more complexity requires an increasing distillation of ideas in order to be both communicable and, subsequently, a useful medium in problem solving. "Diagrams are especially useful in urban design, but dangerous in complex situations." (Shane 2010) Historically the basic 2D diagram was sufficient in mapping out magical or astrological concepts that augurs could then interpolate, but these static position diagrams are no longer sufficient for mapping the workings and potential of a city. Hybrid layers of networks, relationships and time are all now considered. In order to create and manage this level of multifaceted complexity, new control methods are required that can fully utilise the diagram systems. The continually developing nature of technology mean that designers require a deeper understanding of the methods and the design implications of their use in order to set up meaningful dependencies between an active design and the relevant data sources (Robinson 2011). Conveying complex concepts while minimising any loss of intent between the human and the computer systems is the crux of this problem.
“Heretofore, most interaction between man and computers has been slowed down by the need to reduce all communication to written statements that can be typed; in the past, we have been writing letters to rather than conferring with our computers.” Sutherland 1963

“Digital Modelling can expand Urban Design practice to an information and communication as well as a representational system.” McGrath 2008

Although writing over 40 years apart, both Sutherland and McGrath identify a key aspect in the way we view computational interface and elude to the potential for a more intuitive method of communication. Despite significant advancements in general computing, McGrath’s statement suggests that we have not yet reached the long-standing goal of intuitive design interface that can elevate digital modelling to a form of communication. This is relevant to the way we abstract ideas and concepts into an external format in order to plug them back into a computer. This abstraction and translation in communication is a form of diagramming. The level of intuition has direct impact on the level and type of information able to be conveyed, which in turn affects the level of information that can be lost through miscommunication or exclusion. In order to address interface systems we first need to understand the types of data that are relevant to the communication of design.

Data Types

Spaces, symbols, geometry and maths are all used to represent a physical concept by abbreviating the longhand verbal into the symbolic. This concept was originally based around the interface of ideas between people through the use of both physical and verbal interaction. With the introduction of
digital space came the need for these interface logics to be adapted in order to translate human input and human friendly computational output through an intermediate Boolean logic of 1’s and 0’s. This process added another level of abstraction to the already abstract process of diagramming ideas. The result of this is that digital tools have inherently changed the means by which we diagram (Schumacher 2010). In order to accommodate this change, without developing new software, a better understanding of existing program capabilities and interface systems is required. Specifically, this is aimed at determining which systems allow for increased complexity in explicit translation as well as novel ways for embedding implicit data into the explicit aspects of a diagram.

As designers, we have an intuitive familiarity with explicit data. Visual and physical stimuli convey directly communicable ideas in the form of drawings or models. This is the more traditional and recognisable understanding of a diagram. Implicit data types, however, are harder to manage. These are often implied by representation and embody the reasoning behind a diagram’s explicit distillation into prime relationships. Computers offer a new way of creating, manipulating and recording implicit data as embedded intelligence within the explicit outputs of the diagram. Numbers, layers and the hidden scripting logic behind all programs are implicitly embedded and recorded data. This type of information was previously only alluded to through the diagram’s symbology or backed by third party records in which a diagram’s explicit representational system referenced. This type of information is, on the surface, indistinguishable to humans but crucial in defining digital systems logic. The distinction between data types now needs a place in architectural
diagramming language. To fully utilise embedded complexity, we first require a greater understanding of the way in which we communicate design ideas through the range of physical and digital mediums now available to us. This re-evaluation carries with it the responsibility to understand the implications of reductive summarisation and implicit reconstruction of concepts as we work between scales, faculties and states of design.

**Systems for Managing Data Types**

Each piece of technology has its own internal operational language as well as a diagrammatic or representational output. Internally this diagram is representative as it translates data provided as inputs into the internal language required for sorting and processing. Externally this can be viewed in a number of forms. As an ordinary diagram this can be a direct summary of the coded language and logic of the given system (Schumacher 2010). This type of output gives a very accurate interpretation of the information but requires specialised knowledge from the human user to understand and communicate. In this case the data conversion and subsequent diagramming is translated and generated by the human participant.

The other mode of communication requires the data to be output directly as an intuitively understood summary of results and intent. As yet, this method is system specific and only of value between computer/human interactions. Still lacking from this process is a stable means of communication between different computer systems through a well-established human interface language. This summarises one of the key aims for the design methods proposed in this thesis; to create an ordinary and intuitive diagramming
method that is capable of representing both implicit and explicit design information. This aims to bridge the gap between technologies and designers, consolidating ubiquitous data into relevant design outcomes while keeping the data in a format that is communicable to both human participants and computer systems at any time. In order to be effective as a design method, this diagramming language needs to consider what is intuitive and explicit to relevant human participants and the required computer systems to minimise translation and subsequent data loss.

**Summary**

Throughout the following chapters, the term diagramming will refer specifically to the working diagram, a mode of externalising, simplifying and working through the act of problem solving. This is differentiated from the other type of diagram, identified later in this chapter, referred to as ‘model’. A model still has the capacity to hold implicit and explicit data but trends towards implicit recording as opposed to the sketch diagram, which is generally focused on explicit communication. Through this thesis ‘diagram’ will refer to the working process of active problem solving while ‘model’ will refer to the more passive recording of results in a digital database. These terms are intended to capture both the passive and active aspects of a diagram. Despite the distinction, both ‘diagram’ and ‘model’ are concerned with communication between both the designer and the chosen working mediums as well as to any relevant third party stakeholders. The other two topics are also subsets of the diagram discussion covering the meaning behind diagrammatic reduction, representation and symbology (Type) or the method by which a diagram is created and applied at an urban level (Scale). These terms are applied with the
recognition that, like a great deal of the theoretical terminology explored in this thesis, they capture only the polar extents of a concept and do not represent the multitude of crossovers.

### 3.3.2. Scale: Digital and Representational

*How do we conceive, problem solve and generate a design at different levels of resolution without producing reductive and aggregate assumptions in the solution?*

Urban environments cannot be considered introspectively. Each element within, regardless of any perceptions of whether it is successfully inhabited, has developed because of the symbiotic link with its surroundings. As discussed in chapter 0 (pg xxvi), any new insertions to this fabric need to be similarly linked into the existing networks of its context in order to be successful and survive. This level of consideration ranges from the macro to the micro in order to fully understand both the existing and the proposed in an urban realm. The more aggregate macro scales give clarity to zoning and networks that are not necessarily evident at human perspective. Conversely, the finer grain urban scales are not directly reflective of the higher-level governance that controls its general shape.

The 1950s and 60s gave rise to some of the pioneering mathematical models that demonstrated the way cities worked and the associated growth patterns. These predictive models used high-level patterns demonstrating land use and movement networks to generate a snapshot of a city's growth patterns at a single point in time. The models operated under the assumption that “distinct causes and effects” drive city growth and that these could be “factored into different spatial patterns with unique roles as either independent causes or
dependent effects." (Wegener, 1994) This approach worked to a certain degree by assuming that cities were based upon a relatively unchanging equilibrium of causality. In other words, even if the city expanded or contracted, the fundamental composition of relationships at the micro scale remained relatively stable. The models used in this type of city growth prediction could therefore be based on comparatively simple aggregate grammars that assumed very little change at finer scales of the urban environment. At the macro levels of design, all of the fine grain dynamic relationships are smoothed over and hidden resulting in a rigid template of micro scale embedded knowledge about the system that was being represented (Batty 2005). Under detailed critique, however, the high-level diagrammatic principle of this method began to fall apart. This is the fundamental problem with a model comprising solely of diagrams that are defined from high-level spatial patterns at the macro scale and one of the major criticisms of the superficiality in any mathematical and generative models of our urban environments (Wegener, 1994). In contrast to these aggregate models, disaggregation was proposed as a means to focus instead on finer scale actions and relationships as the driver for pattern generation. This type of modelling explores different systems for cellular or agent based evolutionary growth. This approach often requires individuals and groups to be represented as a way to properly incorporate micro scale temporal change as a more central agenda in the design approach (Batty 2005). This type of approach was more concerned with a computational approach to the study of the evolution of diverse spheres of human activity through the physical world as opposed to generational tools that could be used for design of new urban
environments (Epstein and Axtell 1996). Both aggregate and disaggregate approaches, however, essentially lead to the same type of critique surrounding their degree of exclusion. Both approaches are subject to a level of assumption that relies on prescriptive rules at one end of the process that produce non-deterministic outputs of information at the other end of the scale.

**Design Methodology**

The argument between aggregate and disaggregate design scale has further implications, not just on the final design proposition, but also on the ability of the working methods to properly accommodate the dynamic requirements of changing policies and social aspirations. In order to minimise the level of assumption and ensure a more tailored and flexible approach to specific problems, the scope of urban design requires a level of defragmentation into smaller and more manageable problem tasks (White 2008). This has direct associations with the type of design system and its ability to create change and record defragmented aspects of a design while still maintaining a holistic view and structure for the design. For this reason, urban design strategy should cover different scales of consideration as a method for categorising certain problem types. For the purpose of this discussion Galiana’s (2010) model for urban scalar consideration is used to classify four different scalar groups for consideration: Region, Community, Block and Building. (Figure 12)
These four levels of scale will be used as the basis for discussion throughout this thesis. These are general categories used for the purpose of classifying different design requirements and problem types at varying scales. Specific details pertaining to each of these different scales will be described in relation to the proposed method in chapter 5.2 (pg 175).

**Computational Scale**

The traditional approach to an analogue multi-scaled design method is a linear series of snapshots zooming sequentially in or out in resolution. This strategy
is based on a series of top down routine assumptions that, in effect, creates a single working scale at any time. Decisions can only be made at one point or scale at a time and then manually updated and validated sequentially at each of the other three levels. A parametric approach to this method has the potential to set the routine assumptions as constraints and work without a fixed scale at any point in this process. Any decision made within the digital space is automatically constrained within the design guidelines and simultaneously updated and validated across the entire scheme. The change in design thinking is subtle but profound. Instead of scale itself dictating the program for design development in a liner workflow, the proper regimen of thinking can be dictated by the specific design task and its unique set of design problems. This logic fits well with the problem centric approach to systems design. The problem is classified, the scale best suited is identified and the problem solving process is defined. At any point in this process the decision set is potentially comparable and accountable to any decisions previously made in the design process. (Figure 13)
Figure 13  *Diagram comparing the design process of manually validating between scales to the bi-directional validation of a parametric system.*

An important distinction to make with this definition is between the scale of design resolution and physical scale. The four scales of design described categorise concepts of physical scale or extracts of 1:1 scale. Design scale is an abstract representation of this that communicates aspects of reality through scaled modes of diagramming. This process is more fluid, and although it generally adheres to the rules of physical scale it is more concerned with resolution of ideas and consideration in the design process. This distinction is relevant to the diagrams in Figure 13, because although parametric modelling has the ability to address all physical scales
simultaneously, there is still a process of refinement required in the scale of
design thinking. This is a simple system based on the recognition that
computer environments can generate and record in infinite space but human
diagramming and problem solving requires a scale in order to abstract a
problem into a simpler format. Therefore, any good parametric system
requires an intermediary interface that can correlate the workflows into
something cohesive and communicable. In this model, the parametric
management of the process allows for a reduced level of manual checking and
qualifying decisions between scales. This is still beneficial to the process as a
design has only one shifting scale of linear consideration while the other is
automated. Traditional methods require management of these two shifting
workflows with design changes checked linearly back and forwards against
each other. This complexity requires careful management of all current
designs across all physical scale to ensure all iterations correlate.

Summary

The way in which we consider urban space is invariably based on a version of
a diagram. As previously discussed, this is a tool for simplifying something
complex that helps us to understand the prime relationships at play. Scale is a
conceptual system for ordering these diagrams into a more tangible scope. By
this logic scale is a diagramming tool. The introduction of infinite
computational space has changed the way that we operate between problem
solving and scaleless digital drawing and recording. In order to better align the
problem space with the computational systems that are used a more robust
intermediary system is required to gain controlled, deterministic results. This
strategy aims to reduce aggregation within the problem space while
minimising assumption and exclusion in the generative process. Defragmented
problem tasks when paired with accessible and adaptable software can also
provide a better understanding of the problem solving process and help to
mitigate the dangers associated with single package ‘black box’ generational
tools.

3.3.3. Parameter Definition: Types and Typologies

*How do we develop analytic parameters that can generate, constrain, adapt and contribute the design while still maintaining the normative aspirations of the designer(s)?*

“Understanding types is the basis for problem solving in all design” (Lang
2005). A type is a simplification of a more complex construct. As such, ‘types’
can be described as a classification method for diagrams that represent the
prime relationships of an urban artefact. For this reason, the representation of
type is a key aspect of the urban diagram. They are used to find and simplify
commonalities in formal or functional requirements of their use. This method
of distilling things into type is less often applied to representing aesthetics.

Aldo Rossi defines the concept of type in his book ‘The Architecture of the
City’, as ‘something that is permanent and complex, a logical principle that is
prior to form and that constitutes it’. Given this theory, ‘types’ are foundation
rules that form the repeatable and self-similar first principles of architectural
realisation. By this token, a type is not mimicable in physical sense. It is
necessarily reductive of its operational principles and not of aesthetic or
functional requirements. Rossi insists that a type is distinctly separate from a
reductive diagram of functional operations. Functionally derived archetypes
are described as “divested of its most complex derivations: type is reduced to
a simple scheme of organisation, a diagram of circulation routes, and architecture is seen as possessing no autonomous value. (Rossi 1982) This argument is not a rejection of functionally derived types or diagrams, but recognition of the different scope and applications that typological and functional diagrams serve in the architecture of a building. So conceived, the architectural type or urban artefact is classified by individuality, locus, memory and design to define an argument for the reductive principles of a type's design (Rossi 1982).

“Typology is ambiguous. In its purest sense it refers to the study and theory of types and of classification systems." (Lang 2005) Building types, open space types and city types all have to be categorised carefully by relevant and typological principles in order to be a valid addition to urban diagramming. This is a key element in understanding and communicating diagramming for the purpose of manipulation, problem solving and design. Without explicit understanding embedded in the simplified representation, the system breaks down. In this scenario specific functions are in danger of being applied loosely within general assumptions of the diagram's intent. This inevitably causes misuse of the system, which in turn leads to ineffective resolution of the initial intent (Meredith 2008).

**Contemporary Use of Types**

It has been argued that since the beginnings of modern urban design, practitioners have lost sight of the overall typological relationships that form our cities (Hensel 2011). Despite a promising trend in the 1990s where typology was poised at the forefront of design discourse, urban developments
have instead fallen into the economically driven urban formulas of subdivision and the introspective fascination with complex digital form making (Vincent 2010). Instead of expanding on the newfound understanding of urban typology, interest quickly shifted to the newer technical mastery of digital geometry and its translation into physical architecture. This shift in focus has led to an “obsession with topography and highly complex surfaces, leading to a primacy of the individual built form over the urban.” (Hensel 2011:56) This trend is spurred on by rapidly advancing capabilities in technology and geometric mastery in design. This has unfortunately shifted focus away prematurely from the promising methods in typological composition proposed by the pioneers in urban planning theory.

Prominent in the struggle to reassert the importance of typological composition is a group of theorists known as neorationalists and their program of inquiry for the city (Rowe 1991). They seek to overcome stereotypical applications of aesthetic or functional classifications of types. The neorationalists see the city as a series of fragments that can be classified by three rules. Anthony Vidler describes the criteria of these rules as meaning “firstly, inherited from ascribed meanings of the past existence of forms; secondly, derived from the specific fragment and its boundaries and often crossing between previous types; and thirdly, proposed by a re-composition of those fragments in a new context.” (Rowe 1987:191) What is proposed here is a rational approach to type classification from the analysis of existing urban environments and the subsequent recombination of subsets to create new typological scenarios. “We need theories of convergence and theories of
wholeness - and how it might be attained, drawing lessons from how it is in fact attained within natural systems." (Mehaffy & Haas 2012:89)

Urban design is, in a large part, mimetic in the sense that precedents with ideal qualities can be analysed, typified, diagrammed and re-envisioned for a new design application. Often the new design solution is an amalgamation of multiple qualities over a number of schemes in order to distil and reproduce the best in each. By this token, empirically and analytically derived values are considered an inevitable ingredient of decision. “Without some sense of better, any action is perverse. When values lie unexamined they are dangerous." (Lynch 1984:01)

The lack of a strong analytical foundation has already been identified as one of the most heavily criticised aspects of contemporary parametric modelling (Beirão et al. 2012, Mehaffy 2011, Meredith 2008, Hiller 2007, Batty 2005). The key to countering this criticism and improving the chance for success in digital design tools lies in the quantification and qualification of design ideals and the explicit understanding of how they deliver certain design outcomes. In simple terms of causality, this requires an analytical approach to cause (input) with a view to a more deterministic effect (output). Essentially this is a hybrid categorisation system involving the typological classifications that capture both aspirational and proven aspects of successful urban inhabitation. This is essentially a breakdown of functional types, as described by Rossi, into analytic elements that can be recombined to suit a new normative and aspirational context. This approach to formulating different types and typologies through the use of qualitative, emergent properties as diagnostics
is once again, a means for dealing with complexity that would otherwise be impenetrable (Mehaffy & Haas 2012).

Summary

Types are ambiguous but are critical to problem solving. They offer an empirical understanding of how things are built, how they operate and what the prime relationships are. However, it is not good enough to just follow the old trends of assumption that existing urban types are stable and unchanging. Instead, this chapter alludes to a more disparate but quantifiable approach to typologies. These can be formed and re-formed from recombinant parts that can address the aspects of urbanity that are unchanging and inextricably linked with specific functionalities as well as dynamic elements of these environments that are ever changing and evolving.

Benchmarking and the recording of quantitative urban data are used to form variable data sets, both the manual and computational basis of design, distilling key developments into mimicable figures that consider both the qualitative and the quantitative aspects of a precedent case. These are referred to as qualitative indicators and quantitative data, which form a foundation for generative types. Analytical control parameters are the formation of new typologies made up of recombinant type sets. This is a rational approach to type classification - analysis of existing urban environments - subsequent recombination of subsets to create new typological scenarios.
3.3.4. Model Classification

What forms will the digital model(s) take in order to successfully represent the design data as a communicable urban model?

Models are devices used for the abstract representation of reality, allowing us to explore, plan for and predict aspects of the physical world. Despite their limitations as a reductive medium, they can act as a “point of contact between theory and reality” and help us to “test hypotheses and to compare data.” (Canuto 2012) From an urban design standpoint, it is now a common belief that a model should represent development dynamics, networks and movement with the emphasis moving away from formal composition and spatial interaction (Beirão et al. 2012, Batty 2005). Despite this recognition, models still trend towards geometric generation and representation, detracting from the idea of models as a communication method (Meredith 2008). This issue is only compounded further by the newfound geometric mastery offered by parametric programs. As stated previously, the idea of ‘form over function’ in the design and modelling process has become one of the main points of contemporary debate (Hensel 2011) and one of the main distinctions between the diagram and model arguments outlined in this thesis.

Kevin Lynch argues that a good model should contain a statement of the situation (context and design aims), specify the intended performance and have all reasoning laid bare (Lynch 1984). This aspiration aligns well with the potential for parametric systems to aid in the understanding of process and subsequently capture and communicate these aspects in a model. For this to be achieved, there needs to be a clear method for applying design intentions and representing them in a universal fashion. This sentiment outlines two
distinct features of a model. Firstly, the model is concerned with the creation and recording of physical (digital) artefacts for information and design purposes. The second feature relates to the ability of a model to communicate the concepts and aspirations of a design within the design team and to any third party stakeholders. This needs to be done while still maintaining readable data that can be used by the computational systems. This second distinction can make the difference between a static recording of geometry and a tool that can be an active means of communication. This means that models are a sub type of diagramming differentiated through this thesis by the recording of explicit data, as communicated through diagrams with the addition to directly interface with implicit information.

How is a model represented and displayed in order to communicate a complex and interconnected web of social, political and ecological relationships? (McGrath 2008). The type of data and how it’s displayed embodies a large part of this argument for universal communication in a model. This, as in general diagramming, comes down to the display of implicit and explicit data and the exploration into new ways to represent and communicate the complexities embodied in a model. (Figure 14)
"The goal is not to produce malleable forms, but to relate changes in form with information related with all kinds of urban dynamics." (Beirão et al. 2012:173)

Part of the issue that has been identified with current forms of parametric modelling originates from the 3D foundations of the parametric systems themselves. As such, these systems naturally favour modelling results that are constructed and visualised as 3D artefacts. This geometrically focused interface naturally favours the crafting and morphing of objects. This differs from the more traditional design and model building methods of using accumulative or layered series of diagrams to capture a design's intent and evolution (Schnabel and Karakiewicz 2007). The distinction between the two is in the correlation between the input data that creates the parametrically generated object. Specifically, how the particular control mechanisms are validated and deemed relevant to achieving the prevailing design aims and supporting any existing urban networks and relationships. As described
earlier, this is largely due to the prevailing focus on the development of
technical processes, formulas and tools. This focus subsequently encourages
contemporary parametric literature to discuss systems and outputs to the
exclusion of the parameters themselves (Mehaffy 2011, Stavric and Mariana
2011, Karadimitriou 2010).

3D CAD space has the ability to record and arrange endless types of physical
information and implicit data. This offers new ways to compile, layer and
communicate information as it is produced through different design tasks.
This is distinctly different from having a single design artefact that speaks to
all problems and solutions. The defining factor is to re-envision the model as a
database of implicit and explicit information as opposed to a single
architectural representation of built form. The new proposal supports an
abstract and defragmented model based on layers of the governing
parameters and design principles born out of individual design tasks and
exploration. Understanding inputs and outputs of the model system is critical
to the designer interpolating data and creating design. In this way, the
recorded information can represent the core principles of the design, which in
turn, informs the diagramming, communication and a feedback loop into
further design work.

The ability to reinterpret urban design problems to their base principles
(parameters) and generate unexpected results has great potential in the re-
imagination of our urban landscapes (McGrath 2008). If a model is considered
a compilation of design objectives in either a series of fragments or a singular
formal artefact, the results of these individual tasks can be visualised in a new
context. This is an important aspect in a defragmented process of problem solving. The model offers an opportunity to assess and validate all or a selection of decisions against each other. This has the added benefit of avoiding a design process that comprises of small, unrelated silo tasks. As discussed in the diagramming chapter (3.3.1: pg 57), model data types also need to be consistent to the workflows they will be applied to and universally communicable at any point in the design process. A consistent data flow can be a means of testing and validating multiple areas, ideas and previously unconnected diagrams across multiple working scales.

**Summary**

This chapter outlines an argument in opposition to the widely criticised geometrically driven parametric model. This type of model has suffered from static and unlinked information processing that compromises the model’s ability to be used in further design testing. This approach is recognised as falling far short of the rich potential for parametric systems to produce more dynamic working and communication models. The chapter defines two main features of a model’s use in design. These are the recording of physical (digital) artefacts for information and design purposes and the communication of concepts and aspirations.

A significant portion of the argument outlined here is attributed to the misalignment between parametric control mechanisms, which communicate the design aims, and the model output as a representation of the design as a geometric artefact. This is credited to the contemporary fascination with new parametric techniques in morphology and complex geometric manipulation.
This has led to a widely criticised superficiality in the design output and an underutilisation of the model as a means of communication.

In response to these criticisms, the chapter then describes some of the underutilised aspects of a parametric model that can potentially help in the aspirations to make it a more dynamic communication tool. The ability to order and record multiple layers of output data and diagramming means that models can be a compilation of the prime concepts and relationships of a design. This design DNA has great potential to reimagine our urban relationships by combining, cross-referencing and recompiling design data to communicate both known and unexpected results. In this way the model can dynamically contribute to the communication, exploration and understanding of a design.
4. Design Studies in Problem Centric Parametric Urbanism

This chapter reports on the development of a series of parametric design techniques and their application across a selection of practice based design projects. A single level of scale has been chosen as a basis for the following descriptions in order to focus the discussion to the process and methods used. The following examples address a selection of design studies that have been broken into two distinct phases. These phases encompass the analysis of existing conditions and the application of design changes. Each of the studies is based on the embedded research conducted within Grimshaw. Table 1 gives a list of each of the design techniques described in this chapter along with a brief description of the individual computational processes and input data requirements.
### Table 1  
**An overview of the techniques presented in this chapter**

<table>
<thead>
<tr>
<th>Design Technique</th>
<th>Computational Process</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topographical Gradient Analysis</td>
<td>Grasshopper</td>
<td>- Topography Map Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Range of Gradient Search Parameters</td>
</tr>
<tr>
<td>Key Point Context Analysis</td>
<td>Illustrator</td>
<td>- Regional Analysis of Surrounding Context Information</td>
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<td></td>
<td></td>
<td>- A Typological Hierarchy of Key Points</td>
</tr>
<tr>
<td>Heritage Building Classification</td>
<td>Rhino</td>
<td>- Existing Heritage Studies</td>
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<td></td>
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<td>- Local Guidelines</td>
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<td></td>
<td></td>
<td>- Aspirational Design Guidelines</td>
</tr>
<tr>
<td>Tram Path Optimisation</td>
<td>Grasshopper</td>
<td>- Gradient Analysis Results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Track Path Start and End Points</td>
</tr>
<tr>
<td>Key Point Site Analysis</td>
<td>Grasshopper</td>
<td>- Key Point Site Analysis Results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Ideal Connection Paths Through Site</td>
</tr>
<tr>
<td>Heritage Building Model Generation</td>
<td>Grasshopper</td>
<td>- Building Footprints</td>
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<td></td>
<td></td>
<td>- Layers Delineating Classification</td>
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<td></td>
<td></td>
<td>- Spreadsheet of Building Information</td>
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<tr>
<td>Concept Diagramming</td>
<td>Illustrator</td>
<td>- Layers of Compiled Phase 1 Information</td>
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<td></td>
<td></td>
<td>- Digital &amp; Analogue Design Concept Sketches</td>
</tr>
<tr>
<td>Master Model Generation</td>
<td>Grasshopper</td>
<td>- Compiled Design Diagrams</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- A Comprehensive Analytical Database of Precedent Study Information</td>
</tr>
</tbody>
</table>

This chapter is intended to give a discrete view into an indicative design problem and outline the development of the tools and methods that address it. The structure of the following chapter will describe each tool with the aim of consolidating the findings into a proposed design method that will be described in the following chapter 5. Each technique will outline the scope of development and application, a technical description of the development process as well as a discussion outlining the lessons learned from practice based implementation.
4.1. Computer Systems and Tools

There were a number of reasons for the reworking and further development of parametric tools from existing research or commercial programs. Firstly, the availability of these specialist programs is often poor, particularly any work done as part of a research institution. Secondly, over-sophistication in the precedent work was often a big issue in problems that required straightforward solutions. For example, the following studies in gradient analysis are vastly simplified from the contemporary systems used for predicting weather patterns, water flow and particle movement. This level of analysis was unnecessary for the problem at hand and was subsequently simplified and rewritten to address only the required gradient response. Lastly, in order for this method of parametric urbanism to be applied in practice, it requires all of the tools and techniques to be both flexible in their use and accessible to those who need to work as part of a design team. This requires all of the computational aspects to be consolidated into a few key programs that share a single data format and are easily accessible and adaptable by the design team.

The context data for the studies were compiled from a number of different sources including CAD information from different survey reports, in-house analysis and recording as well as different GIS sources. For the following studies, desired information was either selected en masse by layer or alternatively separate objects were grouped and renamed under new layer classifications. They were then exported from the native GIS format into a master CAD file comprised of the layers of project data. This technique suited the level of information used in these tests but more automated data mining
techniques for extrapolating relevant information from larger databases is an area that requires further research. The data was kept in .dwg format as a universal data language between all of the programs used. The design process utilised specialised functions from Microsoft Excel, Arc GIS, Rhino, Adobe Illustrator and Grasshopper.

Rhino was used predominantly as a storage platform for consolidated information. This program was the consistent platform used throughout each of the phases as it received information from the GIS database, design sketches from Illustrator and parametric generation from Grasshopper. The NURBS modelling platform also allows Rhino to deal with complex geometry such as the doubly curved topography surfaces used in the gradient analysis.

Adobe Illustrator was chosen as the platform for digital diagramming due to its ability to retain object identity and perform advanced manipulation such as Boolean operations and offsets. This setup allows for objects to be created under layer definitions that can carry implicit data for use in the second phase tools. This process offered flexibility in 'sketching' design strategies while still maintaining a good level of sophistication in both the implicit and explicit data. It is also an industry standard so provided accessibility to the widest possible range of users.

Grasshopper is the parametric plug-in for Rhino and was used as the main platform for performing scripted analysis and generative functions throughout the design process. Although Bentley Generative Components was used in some of the early testing and development, Grasshopper was quickly adopted due to its wide range of pre-built functionality, base script editing capabilities
and the visual accessibility of its user interface. (Figure 15) As such the case studies selected for this chapter are generated solely in Grasshopper. The basic connectivity between components in this program helps to ‘lay bare’ the design process and geometric relationships while forcing the designer to more explicitly understand design causality in relation to decisions (Inputs), methods (Process) and solutions (Outputs). Both input and output data can be directly manipulated through this interface or be exported or imported from an Excel spreadsheet. Excel transfer of data was the preferred method throughout the following studies due to its layout capabilities and its inbuilt formula structure. The process of transferring data between these programs will be described further in the following chapters.

Figure 15 A snapshot of a typical Grasshopper script segment. Each box represents a component with an inbuilt functionality or command. The strings demonstrate the relationships or chain of command between each component.
4.2. Phase 1 Design Studies

Phase 1 is concerned with the analysis of existing conditions and the generation of a response or set of responses to this analytical data. The following section outlines three phase 1 techniques for Gradient Analysis, Key Node Generation and Historic Building Generation. Each of these is a hybrid technique that combines varying levels of analogue and digital working methods. This will demonstrate how the type of problem the designer wishes to solve can affect the shifting balance between analogue and digital working methods. This variable working balance is paramount to the successful application of parametric urbanism and demonstrates the inherent flexibility in the system. Each section describes the techniques and parametric tools that have been developed across two aspects of phase 1, referred to as Context Analysis and Analysis Response stages, as well as their scope, range of potential applications and further research.

4.2.1. Topography Gradient Analysis Technique

The following section reports on the Gradient Analysis Technique and the series of parametric tools that were developed to analyse existing topography for its angle of incline. This process was helpful in assessing the potential for automotive, tram and train accessibility as well as planting zones and disabled access. An individual map could be produced to identify a specific gradient range and flag problem zones in each of the studies. This aided in both the manual design development and the parametric generation of planning strategies that posed as little resistance to the site as possible.
The initial script was written by Daniel Fink from the Grimshaw Design Technology Group as a general tool to visualize differences in the terrain. This scripting logic for assigning colour ranges based on a relative surface normal value became the basis for the following research.

**Scope**

The gradient analysis technique is a means of parametrically assessing the relative angle of each facet of a meshed terrain map. A pre-defined colour is then applied to the facet depending on the individual results. This data is visually explicit while also embedding implicit colour and numerical data into the map for later analysis and use with parametric generation tools. At this stage, the parametric tool does not facilitate Multifield Data Analysis techniques (Nagaraj et al. 2011) for comparison between different test results. This type of comparison can be used for secondary analysis between gradient results. The comparison identifies strengths and weaknesses between symbiotic or synchronous areas of analysis. For example, this could be used to compare DDA access and tram access analysis data sets to identify key points of alignment and recommend potential positions for DDA...
accessible tram stops. This type of analysis can also be combined with search parameters to constrain the results within certain criteria fields. This has been identified as an area for future research but is outside the scope of the gradient analysis tool described in the following chapter.

The following studies were conducted at a community level of design consideration that required a certain level of topographical detail. The range of scales and their general uses are outlined in the following diagram.

![Diagram showing scales of environmental processes](image)

Figure 17  Scales at which various biophysical processes dominate calculation of primary environmental regimes. (Image sourced from Wilson & Gallant 2000. Reproduced from Mackey 1996, 'The role of GIS and environmental modeling in the conservation of biodiversity', In Proceedings of the Third International Conference on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, 21–25 January, 1996, edited by NCGIA.)

Figure 17 outlines the scope of some of the potential information that gradient analysis and related computational analysis tools can address. We are concerned with the ‘Topo’ level of detail for the following set of studies.
The first part to this technique is aimed at analysing existing contextual topography and returning data in a more clearly understood and usable format. This tool was developed in response to other gradient analysis tools that have little to no flexibility in the targeted output type, colour or range. This restriction often leaves data outputs as a purely visual feedback suitable only for analogue design responses. The main aim for the Gradient Analysis tool presented in this chapter is to provide a flexible analysis output with a view to continued data flow and applications in subsequent design stages. This type of ongoing data stream provided the foundation inputs for subsequent generative tools in the Analysis Response stage of design.

The initial analysis tool is loosely based on part of Marcus White's research known as the 'Gadiator', outlined in his doctoral thesis (White 2008:128-132). The method described by White utilises polygon meshing of topography surfaces. The tool measures the surface normal orientation at the centre of the polygons in relation to a Z-axis and returns a value for each facet across the surface. The outputs of this tool are linked to the rendering settings to produce a visual image of the topography with colour defining the relative angle of the topography. (Figure 18) This rendered image of results limits further application and analysis of the output data. Despite its limitations, the tool provided a good starting point for the following studies with a view to extending the useable output data produced by the basic facet angle evaluation.
Figure 18  The ‘Gadiator’ tool by Marcus White (2008:130) demonstrating a rendered topography image (Left) and the gradient range to colour legend (Right).

Technical Development

The first step in the process is to import the existing topography data and convert it into a format and geometry type that best facilitates the analysis process. Figure 19 demonstrates a generic range of data structures for topography mapping that includes Square-Grid, Triangulated Irregular and Contour-Based networks.

Figure 19  Methods of structuring an elevation data network: (Left) square-grid network showing a moving 3 by 3 submatrix centred on node 5; (Middle) triangulated irregular network; and (Right) contour-based network (Image sourced from Wilson & Gallant 2000. Reproduced from Moore, Grayson, and Ladson 1991 ‘Digital terrain modeling: A review of hydrological, geomorphological and ecological applications’, Hydrological Processes 5, John Wiley and Sons Ltd, pg 3-30.)

The third method of Contour-Based mapping is the most prolifically used in building site surveying and as such was the standard format of data available
in the GIS and CAD files. For this reason, Contour-Based geometric data was used as the foundation for the following tests.

One problem with meshing directly onto contour lines can be distance between the measurement points. If directly meshed from one of the many standard topography tools in CAD, the topography can become over-faceted and lose accuracy. With these tools, each mesh facet is strung between the topography lines, giving an abbreviated gradient that is subject to the contour measurement heights and destroying any capacity to refine the mesh for more detailed analysis. (Figure 20 Option A) In order to combat this, the process used here first models a doubly curved NURBS surface across the topography contours to create a finer, undulating terrain representation. (Figure 20 Option B)

![Option A: Meshing to Contour Lines](image)

![Option B: Surface Drape to Contour Lines](image)

**Figure 20**  *Comparison of topography modelling techniques*

This surface form is still only representational but provides an estimate of real conditions. This level of accuracy is dependent on the distance between the survey points as well as the complexity of the terrain. This approximated form of modelling has been adopted in place of interpolated refinement schemes,
such as the butterfly subdivision scheme, to generate a single piece geometry that maintains flexibility for further parametric refinement and generation tools later in the design process. More detailed studies that depended on accurate gradients would still require either an optimisation stage in modelling or greater level of survey information that relies less on the approximated geometry and more closely aligns with the surveyed points. This 3D surface is created in Rhino using surface patch with a low stiffness setting and can be created from either contour lines or a pre-meshed topography model.

From the initial surface, Grasshopper is used to import the geometry and process the rest of the gradient map. A quadrilateral mesh of the desired facet size can then be tessellated over the governing surface. Creating this mesh on top of an unchanging base surface allows for greater variability in the mesh sizes and greater integrity of the topography geometry. This permits a parametrically defined value to actively alter the facet numbers and subsequent string lengths across the tessellated surface.

![Option A: Lower String Length](image1.png) ![Option B: Higher String Length](image2.png)

**Figure 21** Different levels of surface meshing resolution for analysis.
At this point, the tessellated mesh is broken into individual elements so that each facet can be dealt with in isolation. The gradient analysis results are generated by measuring the relative angle of each individual mesh facet in relation to a fixed global Z coordinate (z). The angle is measured from the surface normal (n) of each facet and returned as a value between 0 and 90 degrees (R). (Figure 22)

![Mesh Facet Components](image)

**Figure 22** Components of a mesh facet and the extracted information to calculate a gradient.

The resulting values are then passed into a component that can assign different colours to each individual value range. The colour range is variable and dependent on the search criteria. For example, the generic gradient model assigned a different colour to values within 10% blocks up to 50% or 45 degrees while the tram gradient analysis assigned colour from 0 to 8.33% (1:12 or 4.8 degrees) of facets.
Figure 23  (Left) Generic colour mapped surface with visible normal arrows. (Right) The colour assignment component from Grasshopper. Each bar of colour covers a desired domain of angle values.

Figure 24 demonstrates a series of analysis types as applied to an indicative surface form. The image to the left shows a generic gradient of 10% increments as compared to the centre image of a more targeted search for a tram accessibility gradient. The topography map to the right of Figure 24 demonstrates the relative height of each facet in the surface. This tool proved useful in identifying potential water runoff, flooding and catchment areas as well as a secondary application for mapping heights of existing and proposed building stock by applying colours to building volumes. Used in conjunction with the gradient analysis results, this tool could help to identify key zones for optimal views across surrounding terrain with minimal gradient for cut and fill. This is an area of research currently undergoing development as part of the automated Multifield Data Analysis tool.

Figure 24  Types of topography analysis.
The final step in this process is to sort the results of the gradient mapping into smaller groups. This is a critical step in setting up the data structure for further analysis and generation in later stages. The colour assignments are tracked via their numeric RGB values and split into separately accessible data fields. This process relies on absolute colour values for grouping data as opposed to the gradated colour map demonstrated in Figure 24 (Right).

Gradients lead to incremental number values in between the defining colour groups that make data harder to target accurately. These maps are therefore only used for visualisation purposes. The use of colour based data sets in relation to the tram path generation technique will be described further in chapter 4.3.

In addition to the Context Analysis techniques described in this chapter, a secondary Analysis Response comparison method between results was developed in lieu of a more comprehensive Multifield Data analysis method. This technique utilised the RGB colour results to cull the multiple lists of data produced by each of the gradient analysis tests. The search method used the coordinates of each facet to create a datum list against which each of the different colour assignments could be aligned and compared. This was a quick way to search a number of test results for certain colour combinations that occupied the same coordinates. The results could then be culled to display only the regions that returned a positive match for the intended search.
Design Application

It was found during the development process of this tool that the topographical contour map gave a good appreciation for the general lie of the site but was not immediately explicit without more in-depth analysis of the information. Basic information such as hills and valleys can often require close examination of contour heights to gain a full understanding of the terrain. The gradient analysis operations offered immediate and explicit information pertaining to specific areas of critique. As described at the start of this chapter, there are a number of different areas and design problems that can benefit from gradient analysis. Figure 26 demonstrates the explicit data generated from three different analysis types.

Figure 25  Comparing the data lists in Grasshopper and culling those facets that return a negative search result. Blue areas demonstrate areas of alignment between search fields.
Figure 26  Gradient analysis results from one of the test sites.

The tram gradient and DDA analysis both display terrain within the acceptable range as green, minimal grade in yellow and orange, with significant grade displayed in red. The relative height map has the additional function of measuring the lowest point and the highest point and converts all values within this range into a relative percentage between 0 and 100. The colour gradient defines any percentage block between purple as the highest and orange as the lowest points in the terrain.

The discrete nature of these gradient searches led to specific results that were valuable in their own right as graphic information tools. The real benefit from this exercise, however, was in the comparison and combination of the different analysis results to fully understand the implications that the terrain would have on any design proposal. The ability to communicate and demonstrate any new method or tool within a practice environment is dependent on the perceived values in efficiency or quality of result. As a result of the intuitively understood graphic output along with the simplicity of the input and processing, this tool became one of the most readily adopted in practice across a range of different projects.
4.2.2. Key Node Generation

This section describes the development of a key node generation tool. This was developed as a way to average out a multitude of networks or paths and find the most optimal point of intersection. In other words where do you place a node so it has good proximity to pathways while limiting the detour from any one path? The following studies look at how to place key nodes of activity at the intersection points between both existing and potential network paths.

Scope

The proposed technique for key node generation was used to compute minimal path networks between a set of key points in and around the site and extrapolate points of major intersection. The key node generation tool was inspired by systems and methods that refine and optimise networking between key points (Lee et.al. 2012, Chen et.al. 2011, Pinninghoff et.al. 2008). The process of path and network optimisation uses a range of different logic systems from minimal branching between distributed points, as explored by Frei Otto (Schumacher 2009:19), to dynamic biological models of generation that ‘grow’ networks of minimal redundancy (Yamins et.al. 2003). Some of these methods and theories overlap with the work described in section 4.3 (pg 112). Two points of difference divide this work. Firstly, the consideration of multiple parallel and intersecting paths (described in this section) as opposed to a single optimised path (as described in 4.3.). Secondly, the consideration of topographical and contextual information in the optimised path generation differs from the technique described in this section that considers only planar network orientation. Specifically, the technique for
Key Node Generation utilises an attraction system between important pathways through the site. This type of model was first devised in the analogue wool thread models by Marek Kolodziejczyk, which looked at optimising detour path networks. The models worked by twisting thread clusters and creating a tensile fusion that averaged the thread's sur-length between points. (Figure 27)

The technique presented here uses the same concept of clustering threads but explores the additional aspects of specific perimeter nodes, path attraction hierarchy and identifying key points of major intersection. The tensile fusion of the wool thread models is replaced with a deformed fusion of straight lines between points. This deformation is parametrically variable through the attraction strength between lines.

Figure 27 Wool-thread models developed by Marek Kolodziejczyk to determine optimised detour path networks, Institute for Lightweight Structures (ILEK), Stuttgart, 1991. (Schumacher 2009:19)
Technical Development

As a digital model, these networks are calculated through the use of different line attractions between primary and secondary desire lines. The key points are manually identified from existing landmarks and major networks that have potential relevance in connectivity for the design site. This process involves translating the relevant key points onto the context analysis diagrams using relevant GIS and map data as reference. Dedicated layers are used to define a hierarchy of importance between the context points. From these points lines can be manually extruded across the site via a start and end point of desired connection. This manual process is intended to capture the main points of desired connection between landmarks or existing networks. This data is then transferred to Grasshopper and automatically sorted into different parametric actions via their layer assignments. Further lines are then automatically drawn between all points in the secondary network to create a web of lines. This logic assumes that any perimeter point will be in some way connected to every other point on that layer and that a median point of intersection can be extrapolated from the resulting web. (Figure 28)
The attraction force between each set of lines is set through a physics simulation program within Grasshopper called Kangaroo (Food4Rhino (b)). This component has the ability to simulate active forces of variable strengths such as attracting and opposing forces between elements or global gravitational pull and apply them to pre-compiled geometry. When animated, the geometry deforms under the forces applied to find a new equilibrium and therefore an alternative geometric composition. For the purposes of this study a simple attraction force is used to deform and clump lines together in a similar form to the models of Kolodziejczyk. In this manner, an average or optimal route can be calculated between multiple points of desire. In order to create the deformation, the network lines are segmented into chains of
smaller lines that can be attracted or repelled from other active sources. Peter Liebsch, head of the Grimshaw Digital Technology Group, developed the initial script for the Kangaroo interface and attraction. This attraction script was adopted into this research and applied within the key node process described here.

Different levels of attraction and deformation define the primary and secondary paths. This hierarchy is not limited to only two levels but was found to be the most effective classification system at this design scale. Generally, the secondary nodes represent existing road intersections or desired paths through the development site. The primary nodes represent major thoroughfares and connections to surrounding infrastructure or important landmarks. The primary paths are given an equal or stronger attraction force to that of the secondary paths, but are assigned a higher stiffness value to limit the geometry's deformation. This is aimed at creating a straighter path between primary nodes and forcing secondary nodes to cluster towards these elements as well as each other.
This method is not necessarily a system to determine road layouts in a literal sense, but instead is used as a means of extrapolating intersections between networks of paths that have been connected across the site from surrounding fabric. These intersections can be used to identify optimum positions for future hub development and higher density focal points of the masterplan layout. (Figure 29 Right) In this diagram, the nodes are relatively easy to see from visual analysis due to the low complexity of the example. This may not be so evident in more complex network maps. In order to address this, a simple addition to the script was developed that counted the number of line fragments occupying a certain area and created a circle from the average centre points of the lines.

**Design Application**

The pre-generation site analysis is used to identify potential primary and secondary thoroughfares through a given site as well as elements of interest in the surrounding region such as shopping centres, major infrastructure and recreational facilities. This analysis defines the hierarchy of surrounding
attractions and routes that needed to be most readily and frequently accessed.

The connection of primary nodes falls within the realm of a design decision and therefore is part of a feedback loop from phase 2. Any call as to the position and type of major connection through the site needs to be made as part of a more comprehensive design story. The secondary connections are different in this regard as they connect in a web that covers all possible solutions. The incidental nature of the secondary network web required recognition in any subsequent design action in order to utilise the generated information appropriately as design guides. This factor is why this technique was not used as a method for defining trafficable paths but rather a guide for common points of accessibility that can be accentuated by focused planning.

The nodes identified through the case study testing were beneficial in both validating initial ideas for hub or main street placement as well as identifying a number of secondary intersections that were not immediately obvious before this testing. The application of this tool in practice was dependent on the designer’s judgment in regards to the complexity of the problem at hand. The benefit of a tool such as this is in the processing of large quantities of data and producing a result that would otherwise have been laborious or impossible for a designer to achieve manually. This tool is, therefore, not reliant on a fixed resolution of scale but rather a level of complexity that justifies a computational approach as opposed to a more traditional and analogue problem solving method. This significantly limited the scope of projects this tool was applied to in architectural practice due to the scale and
complexity of the projects available during the research period. The exercises that it was applied to achieved a good level of success due to the low level of manual analysis and the simplicity of applying the script to basic line geometry.

4.2.3. Heritage Building Classification

The following section reports on the Heritage Building Classification Technique. This process was helpful in categorisation and understanding of existing building information. The process was also developed as a means of generating 3D representations and the tabling of both known and generated building data.

Scope

The technique for heritage building classification was developed as a means of dealing with large data sets on existing building stock within sites intended for adaptive redevelopment. It was also the intent of this tool to create a 3D representation of each significant building that could be used in further analysis and design as well as provide additional information derived from the generated mass. The technique was inspired by research into the use of GIS databases as a tool for automating the 3D modelling of existing building stock. The broader research area ranges from photo mapping onto 3D building surfaces (Gröger et.al. 2007), similar to the process used by Google maps, to the representation of different building semantics through database control mechanisms (Benner et.al. 2005).

This process relied heavily on the GIS data sets that demonstrated building footprints and correlating number tags as well as the building significance
reports provided by the heritage consultants. The compilation of this data was predominantly manual due to the variation and subjectivity in the classifications. This meant that no standardised rules could be formulated as an automated analysis response. The parametric tool offered a means to automate the process of merging the numeric data sets with the CAD information in order to generate a representational massing model.

**Technical Development**

The initial stages of this technique are concerned with compiling data from multiple sources and formats into a consolidated Microsoft Excel file. The sources of this data can be numerous or in some cases already consolidated, but the main aim is to attain as many of the building attributes as possible. These attributes can be descriptive of physical form, function, significance and future intent. The key element of these attributes is to have a common field such as a number or name that is unique to the building and can correlate the building data to the relevant footprint in the CAD file. (Table 2)

**Table 2**  
*Example of existing building attributes used in the heritage building classification technique.*

<table>
<thead>
<tr>
<th>Building Number</th>
<th>No. Floors</th>
<th>Floor to Floor</th>
<th>Description</th>
<th>Heritage Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>4</td>
<td>Post Office</td>
<td>High Potential Value</td>
</tr>
<tr>
<td>73</td>
<td>4</td>
<td>4.5</td>
<td>Assembly House</td>
<td>Exceptional Heritage</td>
</tr>
<tr>
<td>76</td>
<td>3</td>
<td>4</td>
<td>Assembly House</td>
<td>High Potential Value</td>
</tr>
<tr>
<td>84</td>
<td>2</td>
<td>3.7</td>
<td>Store</td>
<td>Exceptional Heritage</td>
</tr>
<tr>
<td>86</td>
<td>2</td>
<td>4</td>
<td>Substation</td>
<td>High Heritage</td>
</tr>
<tr>
<td>87</td>
<td>3</td>
<td>4</td>
<td>Store</td>
<td>High Potential Value</td>
</tr>
<tr>
<td>91</td>
<td>3</td>
<td>4.5</td>
<td>Assembly House</td>
<td>High Heritage</td>
</tr>
<tr>
<td>103</td>
<td>1</td>
<td>4.5</td>
<td>Store</td>
<td>High Heritage</td>
</tr>
</tbody>
</table>
If physical information such as height or number of floors is not available or cannot be measured in person or via photos, an estimate needs to be entered in order to create the inputs for the massing tool. Layer assignments for the building footprints are defined by either designer assessment or by an external heritage significance classification report. This is done so that through the live import export links between Grasshopper and Excel, classifications can be manually created in either the CAD file or in the spreadsheet with the counterpart process updating automatically. The quality and relevance of the final massing model and output data relies on a comprehensive database of information.

![Example of building masses lofted onto a terrain map.](image)

From this initial compilation of building information, Grasshopper can then be used to project the 2D building footprints onto the terrain map. The building attributes are then applied to govern the height of the extrusion applied to the building footprint as well as the number of floors for each. This process is described in greater detail in the Model Generation section in chapter 4.4.2.
and outlines the massing process for both existing and proposed buildings.
The resulting mass can then be digitally critiqued for different physical
attributes. The critique of physical attributes returned data that was unknown
previous to generation. This included data such as building volume or total
GFA that could be extrapolated from the known data of footprint area, lofted
height and number of floors in the building. These figures were linked back
into the Excel file on a separate page to form a new table of results. (Table 3)

<table>
<thead>
<tr>
<th>Building Number</th>
<th>No. Floors</th>
<th>Floor to Floor</th>
<th>Building Volume (m³)</th>
<th>Building Height (m)</th>
<th>Floor Area (per floor m²)</th>
<th>Floor Area (Total m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>4</td>
<td>4000</td>
<td>8</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>73</td>
<td>4</td>
<td>4.5</td>
<td>16200</td>
<td>18</td>
<td>225</td>
<td>900</td>
</tr>
<tr>
<td>76</td>
<td>3</td>
<td>4</td>
<td>3600</td>
<td>12</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>84</td>
<td>2</td>
<td>3.7</td>
<td>6660</td>
<td>7.4</td>
<td>450</td>
<td>900</td>
</tr>
<tr>
<td>86</td>
<td>2</td>
<td>4</td>
<td>16000</td>
<td>8</td>
<td>1000</td>
<td>2000</td>
</tr>
<tr>
<td>87</td>
<td>3</td>
<td>4</td>
<td>16200</td>
<td>12</td>
<td>450</td>
<td>1350</td>
</tr>
<tr>
<td>91</td>
<td>3</td>
<td>4.5</td>
<td>4050</td>
<td>13.5</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>103</td>
<td>1</td>
<td>4.5</td>
<td>33475</td>
<td>4.5</td>
<td>750</td>
<td>750</td>
</tr>
</tbody>
</table>

These studies were tested through the live linking function in Grasshopper
but there have been more recent developments such as the beta version of
Bumblebee (Neoarchaic). Bumblebee is a plugin set of user objects that allows
for the transfer of data between Grasshopper and Excel while allowing
Grasshopper access to Excel's analytic tools and graphic settings. While
Bumblebee has not been used for these studies, it does promise a much
higher level of functionality and control that will be explored in future
research.
Design Application

Building footprints exported from a GIS file are the basis of this technique. As such, a stable reference point for all of the data to be linked into is critical to the process. For the case study testing, this was predominantly physical CAD data that formed a reference point. Buildings could then be referenced from a stable location and naming convention. The example shown in Figure 31 displays all of the existing building stock on and around the site. These are generally compiled on the same layer and require division based on value and significance. This information can be derived from the heritage consultant’s reports, design aspirations as well as client and community participation.

Figure 31  Footprints of existing building stock as collected from a GIS database.
For the purposes of this example, three categories of building are displayed.

- Exceptional Built Heritage Significance
- High Built Heritage Significance
- High Potential Value (Adaptive Reuse)

These were separated onto individual layer groups and manually tagged to an Excel file using the building number. The remaining building attributes and information could then be entered into the input fields of the database.

![Figure 32](image)

**Figure 32**  *Layers and colours defining the different levels of building significance.*

The benefits of using this system were in the management and compilation of existing data as well as in the extrapolation of previously unquantified data. The process also proved useful in visually assessing and identifying clusters, patterns as well as further adaptive reuse sites that may align with the design
ideals. Adding and removing information was also very quick once the structure was in place. This resulted in a system that had ongoing relevance, as it was continuously adapted and refined throughout the design process.

4.3. Phase 1 Analysis Response: Tram Path Generation Technique

The following section describes a technique for generating an optimised tramline path through a site. This example has been chosen as a means of demonstrating how a first phase analysis tool can utilise information from phase 2 as part of a feedback loop. The information driving the placement of a tram track and stops is much more diverse than topographical gradient alone. The action of making a design decision based on existing data falls into the realm of phase 2. This example describes how design proposals can be analysed in relation to existing data in order to test its validity. For the purposes of this description it is assumed that two points have been identified across a site marking the end points of a tram’s path and setting the domain for the optimisation tool. This optimisation process will be conducted from the gradient analysis data described in chapter 4.2.1 (pg 87).

Scope

This technique responds to the data generated by the existing conditions analysis through the generation of potential design options. This tool is classified under the analysis response section of the first phase tools and is a secondary means of analysis and generation that informs the design. This step can either be applied directly to the context analysis data or be employed as part of a feedback loop to test second phase design decisions. The study described here looks specifically at generating optimised pathways for tram
accessibility to determine a ranked series of potential solutions. An optimal path is defined as the best iteration between the shortest possible distance and the path of least resistance. These pathways are generated from the tram gradient analysis of existing conditions to consider and recommend paths of least resistance through the site.

The process was inspired by automated road plotting tools that deal with different gradient and topography maps to generate new roads. The path optimisation tools generally use sophisticated cellular analysis models that can analyse a given number of neighbouring cells and weigh up suitability for plotting a new path incrementally (Galin et.al. 2010, Stückelberger et.al. 2007, Anderson and Nelson 2004). Galin et.al (2010) outlines a number of different approaches currently available for exploring procedural path generation:

- **City Street Modelling**: utilises varying biological algorithms such as L-Systems, Voronoï diagrams or Tensor Fields to synthesize complex urban street networks.

- **Interactive Road Editing and Sketching**: a hybrid method of analogue and digital methods involving the reshaping and combining of existing textured models to highlight ‘best fit’ interstitial pathways.

- **Variational Path Computation**: based on the theory ‘Calculus of Variations’, this method calculates curves across a governing topographical surface to determine one or many geodesics for the shortest path between two points.

- **Anisotropic Shortest Path Problem**: similar to Variational Path Computation, this method utilises varying means to determine the
shortest path with the added functional imposition of cost efficiency parameters.

The tool described in this chapter adopts the aims of shortest path and cost efficiency from the Anisotropic Shortest Path Problem but simplifies the process into three independent stages. Firstly the proposed technique generates two comparative routes, one straight line between key points and the other an optimised version based on the gradient and topographical height information. The second step outputs the length, cut, fill and bridging requirement results of each path option and returns a table of results from which the designer can determine the path best suited to the design proposal. This final step is divorced from the computational process and parameters due to the individual site-specific requirements of each potential design application. The design solution is an indefinite balance between a mix of variable factors such as its alignment with design aims, excavation costs, bridging and tunnelling as well as general track construction costs in different areas. The comparison itself is subjective and, therefore, not proposed here as a fixed part of the parametric generation tool. The scope is subsequently limited to the analysis of site conditions, generation of potential options and output of the data required by the designer and consultant team to make the most informed decision possible. Unfortunately, owing to project delivery timelines, this tool was conceived from a practice-based problem, with the solution subsequently developed outside of the initial project scope. As such, the tool has not yet been re-tested in a similar practice-based project but is outlined here as a means of demonstrating the process of development and scope for future research at this stage of the design method. This tool was
also one of the most valuable in this research program with regards to the lessons learned during the development process.

**Technical Development**

The following generation tool is described in order of its development process. Firstly, a process for optimising a path across a 2D representation of the gradient analysis results is described. Secondly, a 3D generation model is developed with the addition of relative height and cut-and-fill volume parameters to the optimisation model. Each of these processes utilises one of the inbuilt Grasshopper components known as Galapagos. This component uses evolutionary computation to continuously optimise a wide range of potential solutions down to a relative few that best suit the design intentions. This type of solver is generally applied to black box problems where no derivatives are known. The solver explores a wide set of combinations within the input parameters and gradually hones in on a solution. Although the solution is unknown, the solver uses a set of fitness functions to define an ideal set of goals for the model to evolve towards. This process will be described in relation to the tram path optimisation study throughout this section.

Data generated from the gradient analysis technique is used as the starting point for the tramline generation tool. Facets that fall within the acceptable gradient range are separated from the rest of the topography to form the testing domain. This is achieved by comparing two lists of data containing the coordinates for the centre point of each facet and the RGB number assignments. The RGB values create a pattern by which the point coordinates
can either be accepted or culled out of the data stream. The start and end points for the tramline, as defined in the previous section, are linked into the Grasshopper script from the master CAD file.

**2D Optimisation Process**

The first iteration of this study requires the data to be projected onto a plane in order to create a 2D representation of the gradient results. The 2D map aims to provide minimum path length and optimised path route in relation to the gradient data. This process considered only two fitness functions that aimed to minimise both the path length and the number of control points outside the acceptable gradient zones. Figure 33 demonstrates a number of generated paths between points on a gradient map. This shows that the shortest path is not necessarily considered the most optimal.

![Figure 33](image)

*Figure 33 Shortest path network controlled by node points. Optimisation is reached by placing the greatest number of points within the bounds of the acceptable gradient and height range, therefore minimising the requirement for site works.*

The 2D map is constrained within the bounds of the topography extents so that any point within this space can be defined by a relative parameter. (Figure 34 Left) This type of relative parametric value restricts all points within the testing area regardless of the actual domain size. As the start and end
points are defined by fixed domain values, they can take their coordinates from the design diagram. The remainder of the curve is defined by a series of numeric sliders that can vary the coordinates of their corresponding point and, therefore, the curvature of the path. (Figure 34)

![Diagram](image)

Figure 34  
Left) The parametric extents of a typical quadrilateral surface demonstrating a NURBS curve plotted by relative parameter values. (Right) A series of number sliders controlling the curve U, V (X, Y). control point values.

The number sliders form the first part of the required fields for Galapagos to operate. These inputs create the pool of domain values and are referred to as Genomes. Within this pool, the solver can then begin to select values with the greatest fitness levels and couple, coalesce and mutate increasingly specific value combinations to evolve closer to the fitness requirements. The fitness values themselves can be set to either maximise or minimise the values that feed into it. The values given here are minimised in order to find the best mediation between the line length value and the number of variable control points outside the desired gradient zones.

The tram path results from this stage were a good test in capacity for Galapagos and provided some useful insight into how to structure the second
phase of 3D testing. On the positive side, the solution was achieved quickly, especially given evolutionary solvers’ notoriety for drawn out computation times. This allowed the user to sit and watch the evolutionary process and understand more implicitly the process of refinement. Compared to the precedent material, this method produced a very quick and easy estimation of an optimal path without overly complex cellular behaviour or specialised scripting. The down side to this process was demonstrated in both the inability to empirically validate the ‘optimised’ results and the total disregard for any difference in relative height between the gradient zones. The success of this tool was, therefore, dependent on similar relative heights for the start and end point. These two factors heavily influenced the second stage of development to create a tool more closely aligned with the Anisotropic Shortest Path Problem.

Figure 35 A demonstration of two different planes of desired gradient analysis outside of the required height (H) : length (L) ratio of 1:12.
3D Optimisation Process

Based on the first stage testing, the second stage of the study included two new elements to the fitness function. Firstly, the relative height of the path was tested to constrain it within the acceptable gradient. This had implications on how the path could cut or bridge sections of the terrain in order to maintain a steady gradient. The second inclusion was a method for measuring the cut and fill for each path and create a fitness function that minimised the volumes of displaced earth. Once again, these fitness functions were tailored to encourage a path of least resistance.

The gradient analysis tool reported on the angle of each facet in the topography without any bias to height. Now that two reference points have been introduced onto the terrain, the relative height of each facet needs to be tested in relation to the maximum ratio of 1:12. This testing is intended to limit the path exploration within the required ratios and help to limit the amount of earthworks in the optimised solution. (Figure 36)

![Diagram](image)

*Figure 36   Each facet centre point is tested for its relative height to the start and end points.*

A direct line between the two points creates a datum level by which any given facet can be tested for height, depth and adjacency. This is measured from a series of points that is generated along the curve. The same number of points is then generated along the length of the intended path geometry. The points
can then be tracked and paired through their designated index values in order
to compare the relative coordinate data. The gradient ratio is calculated and a
true or false value is returned to create a culling pattern that disregards all
facets outside of the desired range. This creates a more accurate domain for
the evolutionary solver to act within. (Figure 37)

![Diagram](image)

**Figure 37**  *The blue zones demonstrate areas of the topography that lie within an acceptable height range. As the points shift, the topography domain shifts within the gradient data.*

Although the testing domain is now restricted, it still doesn’t ensure that a
path won’t stray too far out of the gradient range as it passes between the
desired gradient domains. In order to limit this impact, a fitness function is
used that measures a volume for both cut-and-fill and attempts to minimise
the value of each path evolution. The process is similar to that used by the
gradient domain culling. The first step is to create a datum plane by which any
point along the path can be measured for a gradient value. Unlike the previous
operation where the datum was drawn between the start and end points this
operation requires the final points that lie within the acceptable gradient
domain. This datum also has to consider the path length as it curves around
the terrain. This is achieved by projecting the path onto a plane that sits
between the two control points. A measurement was then taken to record the
relative distances up or down to the terrain intersection point. This value, along with the distance along the curve from the relevant control points, is then used to split the data into positive and negative results.

![Diagram](image)

**Figure 38**  *Each point along the plotted path needs to be analysed for relative height and readjusted if outside the height domain.*

The negative results that lie outside of the gradient range are moved back into the desired range by a value determined by the point’s relative height minus the desired height. The desired height is calculated by measuring from the centre to the edge of the testing domain at the correlating position along the curve. The data fields can then be recombined to form a new base level path that lies within the correct gradient domain. The resulting curves across the existing terrain line and the intended path form the testing region for the cut-and-fill volume.
From these two paths, one mapping across the surface of the terrain and one along the new optimal path line, two new sets of curves can be offset to define the extents of the required cut and fill. This is a variable distance determined by the tramline width specifications applicable to the area. These lines can then be used to create parallel surfaces and subsequently lofted into volumes of space that can be measured as cut and fill. The volume figure is then used in a function that compares it to the best possible outcome (zero cut-and-fill) in order to form a fitness function. The purpose of this function is to test each option and gradually recognise the combinations of genomes that result in lower volume figures. The figures pertaining to the physical properties of the path were recorded in a separate spreadsheet that could then be used as part of a schematic costing exercise to compare to the best cluster of results.

Design Application

Although the tool described here did produce results in some of the test cases, overall it proved to be a very cumbersome and slow generation process. Despite its failures as an effective urban design tool, this case study
was still included in this body of research due to the lessons learned in its
development and the impact this subsequently had in shaping the methods
proposed in chapter 5 of this thesis.

One of the main conclusions to come out of this series of tests was that the
simplest processes are often the most effective. This process demonstrated
that an optimisation tool could theoretically benefit the design process if the
complexity in the terrain and existing conditions requires it. There is, however,
a tipping point between the inherent complexity of the problem and the
complexity in the method or system applied to generate a solution. At this
point, there needs to be a decision whether it is an easier proposition to
manually work through the problem rather than to create a specialised
parametric tool to do the same job. Once this point has been reached, a visual
or manual analysis process will attain results much more quickly than a
computational process.

At the conclusion of this exercise, it was determined that the 3D tram path
optimisation tool was over-engineered for the majority of design tasks
encountered in Grimshaw’s practice work. This is not to say that the concept
for the tool is of no use in a more complex situation. In this case, however, the
programming of the tool was beginning to dictate the design process through
its many technical requirements. This restricted the problem space and,
subsequently, the solutions that were generated from its use. This was a case
of the tail wagging the dog. As such the tool was never implemented in
practice on any future projects. The benefits of the process were purely in the
lessons learned for the development of other tools.
4.4. Phase 2 Design Studies: Site Massing Technique

This chapter describes the different stages and processes required for the application of phase 2. The chapter is broken down into two sections that describe the process of design diagramming and parametric generation. These two areas cover the sketching of ideas in order to capture the design intent and the subsequent generation of a digital model that can be communicated and critiqued as part of the design validation process.

4.4.1. Design Diagramming

Design Diagramming refers to the process of setting up a digital sketch input that forms the foundation for the parametric generation stage. This step requires a deterministic approach to the diagramming process to ensure the correct format and language are used in order to capture the design intent and allow the parametric script to generate the intended outcomes for the exercise. In order to achieve these aims a good understanding of symbology, typology and data types is required.

Scope

Systems of diagramming urban design concepts with an implicit knowledge of underlying complexity have been a long standing area of urban design research (Lynch 1960, 1984, Levi-Strauss 1973). This research has more recently been explored for application in computational design and generation (Hiller 2007, Garcia 2010, Schumacher 2010, Beirão et.al 2011). This research has predominantly focused on two aspects of the underlying problem, classifying and representing urban grammars as well as the methods and interface systems that can computationally ‘sketch’ design concepts.
As discussed previously, one of the downsides to current urban design systems is that each piece of technology has its own internal operational language as well as a specialised diagrammatic or representational output. This results in designers having to specialise in specific symbology unique to the program's individual requirements. This can lead to misunderstanding and misuse of the embedded data that further compounds into unintended results in the design solutions.

The main aim of the following technique was to develop a simple language of diagramming the existing conditions analysis along with new design ideas from physical to digital mediums. One of the key requirements of this system was to reduce the technical representation to a more intuitive format and provide a method of sketching design ideas without a large amount of specialised knowledge. The resulting design information can then be used to drive the parametrically generated design diagrams.

The following design studies have utilised a relatively simple form of substitution to inform the model with both perceivable and imperceptible data. Colour is used as a perceivable or explicit means of communication, defining different changes in the model such as key nodes, zone types or networks. As a means of communication, definitions by colour are the easiest form of communicating to human participants as well as having the ability to be understood numerically or digitally. The imperceptible or implicit information can take different forms, but is most readily understood as layers or object classifications. This type of data classification is embedded in the live diagram and controls aspects of the design that does not need to be visually
communicated or allow a base classification of design parts when the
perceivable outputs are variable. The simplification of the sketch system puts
greater pressure on the analytical parameters database as well as the model
generation system.

The sketching method and structure is often dependent on the specific design
task and the type of analytical parameters that will be used in the model
generation stage. For this reason, the sketch phase is considered in tandem to
the techniques proposed in the following section. This also pertains to the
different urban themes and patterns that need to be addressed and the formal
parametric grammars that will be used to describe them (Stiny 1980). This
process is described in greater detail in the following section.

**Technical Development**

This stage of design required a widely accessible and understood interface
without the onus of specialised systems that might limit the intended user
group and detract from design intentions. For this reason, the computational
aspects of this diagramming process utilised existing functions within Adobe
Illustrator and were paired with a basic symbolic language to produce the final
design diagrams. Illustrator was chosen for a few key reasons. Firstly, it is
compatible with .dwg file format so all of the phase 1 information was
immediately available without any data translation. This fitted with the aims of
the problem centric methodology that aims to minimise data loss and
miscommunication between programs. Secondly, the program offers a wide
range of powerful drawing functions including shape modes, pathfinders,
Boolean operations, object classifications as well as drawing transformations
and effects. Lastly, as part of the Adobe suite, Illustrator has become an industry standard for computational illustration work and as such is most widely understood and available to the majority of practitioners. As a drawing tool, this program offered more sophisticated operations and flexibility than any CAD package. This helped in drawing different symbols representing urban grammars as well as classifying a range of hierarchical variations.

![Diagram](image)

**Figure 40** An example of a design diagram demonstrating different road network offsets, existing and proposed buildings and blocks. Although the colour values have been applied universally across each element for the sake of this diagrammatic output, the implicit layer classifications still delineate different typologies.

The main aim of the diagramming process at the community level is to define different block types within the zone arrangements and between the road networks and existing buildings. Blocks and buildings are not necessarily differentiated in this diagram unless they are key aspects of the development that require identification. The grain and mass within each sketched region will be defined in the model generation stage placing great importance on the
symbology used at each level of scale. As described in chapter 3, diagramming is a simplified representation of a much more complex system. As such, the symbology used at any particular scale of design has to correlate with the intended parametric input data and subsequently the desired model output. This has a significant effect on the level at which the drawing symbology is abstracted and the level of specialised knowledge and representational sophistication required to use the system. (Figure 41)

Figure 41  A demonstration of the increasingly explicit levels of symbology used to describe design ideas. (Building and block scale images courtesy of Grimshaw)
The diagram itself is comprised of a set of basic symbols and computational classes specific to the community scale of design. These were used to denote different design applications and classify the required types and variations within each. The diagramming process, therefore, has to be closely linked to parameter definition stage described in the following section 4.4.2 (pg 132). This symbology was developed to be simple and intuitive to the diagramming process while still retaining the capacity to embed varying levels of implicit data structures within the digital file. (Figure 42 & Figure 43)

![Diagram](image)

**Figure 42**  
*Hierarchy of classifications to integrate different levels of embedded data within the type definitions.*

The first tier class is generally the implicit classification of object layer. This allows for groups to be turned on and off or edited as a separate unit giving greater flexibility to the diagramming process. This is also the main point of identification for the generative script to assign particular discursive grammars. The second tier class is defined as explicit geometry or symbols. The symbols themselves are drawn from the basic geometric properties of the urban shape grammars they represent. These shapes can be classified as one
of two geometric types defined as open or closed elements. Within these basic classifications, a myriad of sub classifications are possible. The third tier class is the explicit assignment of different colours. This process can either be used to pair with and explicitly identify layer assignments or be assigned to identify different type or variations within each layer. Figure 40 and Figure 42 demonstrate the second type of class structure. The fourth and least utilised class involves the use of graphic types and styles. This final tier was used more as an output than an input. It was found that most of the complexity can be described through combinations of the first three categories.

The open and closed geometries can also be divided into active and passive types. The active levels are those elements that will feed into the generative scripts while the passive layers are those reserved for information purposes. These passive layers often comprise of existing conditions, first phase analysis, other scales of design resolution and second phase sketch design and serve as underlays for design diagramming and communication of ideas. This is not a fixed rule that governs an object as they can potentially be used as either passive or active in different applications. (Figure 43)
The open elements or lines used to define the paths and networks across the site are compiled from different sources including existing conditions, phase 1 network analysis as well as those elements diagrammed directly into the illustrator file. The source of the information can have an impact on the state of data that is shown in the model. For example, the diagram shown in Figure 40 demonstrates four types of different road data. The predominant network is taken from the network analysis and is, therefore, representative of a particular offset road width (or value range) that has been defined from the analytical database. The single lines define the centre of roads that are both taken from existing site data and those sketched into the Illustrator diagram. These are separated by layer types and will be offset via a width parameter in the model generation stage. The final type is classified as ‘incidental voids’,
which occur between the offset block regions. These negative spaces will be compounded further as the model generation divides the regions into even finer grains. Whether these results directly form part of the road or trafficable network is left to the block level of design consideration when building types can better define access requirements.

The closed elements or regions define any of the built or open space that requires some form of design action. At the community scale, the generative model is predominantly concerned with the built mass. The open spaces are still considered active layers, but will require a finer level of design detail in building type compositions to design beyond a zoning extent. The process of type classification and the way it is diagrammed is wholly dependent on the parameter definitions that will be used in the generation model. As such, a more comprehensive understanding of layer and type classifications will be gained throughout the discussion in chapter 4.4.2 (pg 132).

4.4.2. Parametric Generation

The following section outlines a technique for generating a parametrically variable massing model. The model output is a 3D diagram of the scheme and is used as a means of optieoneering, visualising and analysing aspects of the design in order to validate or disprove phase 2 design intentions. At the community level of scale, this model is concerned with defining high level networks and grids, building and open space zones and a basic typological composition of building clusters. Each of these is defined in a sketch-diagramming phase and then processed through a model generation tool. The parametric generation phase comprises of two parallel requirements that have
been classified as the Parameter Definition and the Model Generation stages. This process is tailored towards an analytically driven design model that can be used for both visualisation and communication of design concepts as well as provide a 3D representation for the purposes of communication and further analysis.

**Scope**

The technique for parametric generation was developed as a means of testing and validating a design or set of design strategies in a 3D massing diagram. This technique involves two interdependent areas of research and development; firstly, the compilation of an analytical set of parameters; secondly, the technical requirements of computationally generating a set of 3D urban scale design diagram(s). This process was initially developed as a basic massing technique that could optioneer different zoning types and scenarios across a development area. This was done for the purposes of visualisation, producing a set of impact data and validation of design concepts through computational and analogue analysis. The scope of the tool was then expanded to incorporate more intensive analytical parameters that were capable of generating higher levels of physical and embedded typology data.

This technique has been developed in response to superficial applications of formal and stylistically driven parametric urbanism as discussed in chapter 3. Specifically, work such as Rowe (1991), Hiller (2007, 2010), Beirão (et al. 2008, 2011, 2012) and Duarte (2005) have informed this approach to analytical model generation. Despite these authors’ assertions for a single generational system, each presents a case for a strong analytical foundation
that will inform any normative aspirations in design. Of these authors, the work of Beirão, Arrobas and Duarte has informed the methodology of developing parametric systems that rely on the input of a comprehensive massing diagram and the knowledge base of analytical parameters. This approach is critical for producing a 3D model output that is not driven solely by formal expression (Beirão et al. 2012). Their research suggests that all parametric design patterns, referred to as Urban Induction Patterns (UIPs), are a translation and parameterisation of the components of urban grammars. The authors further argue, “Urban induction patterns are generative urban design patterns based on parallel discursive grammars.” (Duarte 2005) These patterns are classified under six categories of repeating urban themes. The six themes include: (A) the creation of composition guidelines like main axes, landmarks and other kinds of initial composition elements; (B) the creation of urban grids such as rectangular, regular or radial grids; (C) transformations in the grid network; (D) the creation of public space such as different types of squares and plazas; (E) the generation of urban units such as neighbourhoods, blocks or building clusters; and (F) others like the management of land use distribution, building intensity or simple details like street design and urban policies (Beirão et al. 2012). The parametric generation technique proposed in this thesis relies on a similar classification of urban grammars in order to defragment the design tasks into individual problem solving exercises.

The generation model itself is only as effective as the diagrammed information that feeds into it. As described in the previous section, the design diagramming process classifies the overall thematic intent of the design model while the parametric generation model fills in the detail of the formal
parametric grammars. The composition of the formal parametric grammars includes an initial symbol, as diagrammed in layer, shape or colour type, a correlating parametric set of geometric attributes and transformation rules as well as an embedded set of implicit data. The implicit data can include any building attributes that accompany its typological classification that does not require physical generation such as urban policies and governance, function, use or aesthetic intents. At this level of design resolution we are only concerned with producing massing envelopes. Although these envelopes do not have a high level of physical data to generate in the 3D model, the basic block forms still need to retain the live link to the analytical data for further testing and scalar refinement.

Unlike the majority of the precedent research in this area, the problem centric method for parametric urbanism proposed here does not attempt to consolidate vast levels of urban parameters into a single generational model. The technique proposed here relies on the discrete application of certain parametric patterns that can generate potential solutions to a finite problem set. The problem itself drives the selection of tools and methods in order to return the desired level of detail to add to the decision making process. Paramount to this process is the recognition and separation of scalar resolution to ensure that no model steers assumptions in physical output past the foresight of the designer and/or the design system in use. This is, once again, about understanding causality in the methods and actions that are employed throughout the design process. In order to demonstrate this discrete application, two examples are used during the discussion. These examples show a regional scale site yield study (Figure 46) as well as a
community scale massing and population density study (Figure 51) in order to illustrate certain aspects of the generation tool.

**Technical Development**

This section describes the technical development of the model generation stage. This description covers elements of both the parameter definitions and the model generation. The focus of this section is on the process of formulating inputs and how these are processed to achieve deterministic outputs in the form of a digital model.

**Types of Parameter**

The following process for compiling working parameters is broken down into two stages that are classified as Benchmarking Studies and Parameter Definition. The Benchmarking Studies stage of the process is concerned with recording precedent study information and compiling it into a database. This database contains key attributes of a precedent design such as physical attributes of the developments, environmental performance as well as certain quantifiable elements of social aims and contributions. This range of information is impossible to define speculatively or in isolation without data that has been derived from existing developments. The new design proposal can therefore be validated against the ongoing development and success of the precedent work. This set of benchmarking data is paired with a set of qualitative indicators that draw a narrative of the ongoing performance and success of a given development. The pairing of qualitative indicators with the quantitative data is crucial in understanding the causality of certain combinations of benchmarking data and the subsequent formation of the input parameters. Figure 44 and Figure 45 outline some of the categories of
quantitative and qualitative data types that the benchmarking process needs to compile.

![Diagram](image)

**Figure 44** An example of quantitative data categories and sub-categories.

These data sets were developed as part of Grimshaw’s design work and were specifically chosen as the categories most important to their particular design aspirations. They are concerned with type classifications and urban grammars that can be universally recognised in multiple development studies. The specific data that is recorded in these categories define the quantitative attributes associated with different types as a means of describing the physical properties of individual design artefacts as well as their particular grammars and typological arrangements within the precedent study development. Volumes and quantities within a given precedent study are then standardised into a universal ratio or measurement type to give the data sets a relative comparability to other developments.
Figure 45  An example of qualitative indicator categories and sub-categories.

Unlike the quantitative data that relies on numeric measurement of urban design factors, the qualitative indicators are a compilation of different types of recordings. These can range from conceptual and built imagery to written descriptions and points of interest in the design process, construction and ongoing use of a particular development. These indicators are a means of judging the quality of a development within the scope of categories such as those outlined in Figure 45. This gives the designer a better sense of how certain analytical data can be used to shape specific normative or aspirational results. Databases are generally compiled as a set of benchmarking exercises that meet the particular practice’s design aims. This data in itself is generic and has to be averaged, combined and adapted to form a set of project specific input parameters within the general practice design philosophy. As discussed in chapter 4.4.1 (pg 124), it is also vital that the input parameters are formulated to suit the scale of the design problem at hand. This generally results in different sets of data compiled for each of the precedent studies that are relevant to different scales of design. The data is also heavily subject to availability so most of the datasets compiled as part of this research were gathered case by case. In other words, a certain set of studies were used
because of the information available on building type arrangements while a
different set of examples were used to cover regional zoning strategies. These
study developments sometimes overlapped, as block and region were
exemplary for the same example, but this was quite often incidental.

This stage of development did not have any custom programming
requirements. The database could be recorded in any manner best fit to the
practice. From this database, a range of defining attributes can be
extrapolated and applied in order to give the intended model a more carefully
informed physical outcome. A tool such as this was demonstrated to be very
useful for comparing relative values or percentages in order to classify design
decisions and their potential outcomes in a new development. It is important
to remember that the differing scale of the benchmark developments is a
crucial factor in the habitation and use of a design, so all figures still require a
measure of interpretative analysis and design translation to be of use in a
speculative design. This is not a definitive set of rules that can guarantee a
directly comparative quality of urban space, but is intended to narrow the
field of applicable solutions within the otherwise endless potential for a site.
This, along with intuitive or aspirational goals for the development, allows the
designer to define a range of different parameters that warrant further testing
at a more detailed resolution.

The Parameter Definition stage uses the benchmarking data to form a set of
parameters that embody the specific design aims for a new urban
development. This data set will form the inputs for the generation model and
ultimately determine the type of massing diagram and related output data that
is produced. For this reason, parameters need to be carefully formulated from the quantitative data with a view to the intended output of the model.

As a process for optioneering, these parameters do not need to form a comprehensive overview of the entire urban proposal at any one time. They should, however, focus on discrete areas of the design that can benefit from testing cause and effect through variable iterations and select the parameter sets best suited to the application. If required, this process also needs to consider the type of phase 3 validation methods that will be employed to further analyse and critique the 3D massing diagram. For example, the initial models produced as part of the research development for this tool were aimed solely at testing the built mass versus open space. This series of tests was concerned with building a comprehensive analysis of regional scale density models that could be compared to the immediate context and also tested with the client as a means to determining the ultimate development capacity for the site. As this particular design project had an open brief in terms of the built density, the aim of the model was to generate a basic 3D output that could be visually assessed with a good foundation of numerical data to validate the responses. The generation model derived building volume parameters from a database that paired key indicators such as job and population numbers together with the resulting physical attributes of open space ratio, number of dwellings, plot size and average heights. This model in itself only tested within a discrete line of inquiry that formed a part of a much larger urban design story. As such, the range of parameter inputs was formulated specifically to facilitate this desired output. (Figure 46)
Figure 46  Two examples of how a simple set of design indicators paired with benchmarking figures can be used to define the input parameters for a basic massing model at the regional level of design resolution. (Figures courtesy of Grimshaw)
At this early stage of the process the model was not concerned with any design decisions outside of the high level observations made at the regional scale. For this reason, the model could be generated across a standard grid with variable facet sizes, which was applied evenly across the site. The only impost placed on the massing was through a height restriction based on maximum levels in different government regulated development zones. This massing task also demonstrates how the urban design technique was tailored to address a discrete design problem and facilitate the application of certain parametric patterns that can generate potential solutions to a finite problem set.

**Model Generation**

The Model Generation stage uses the generative capabilities of Grasshopper to produce a (set of) massing diagram(s). The massing diagrams are produced in response to specific problems and provide a means of decision making through optioneering, testing and validating design ideas. This stage deals with the physical model and the geometric requirements of generating the input diagrams and parameters. As discussed, the diagram defines the physical extents and scope of different type classifications. The script has to be able to deal with these classifications separately and also provide an interface to the parameters required for each. Although this process is referred to as the massing tool, it is more commonly applied as a set of smaller modules. Each module is defined by further defragmentation of the desired output composition. For example, this could be divided into two or more parametric scripts applied to the same massing diagram to separately generate existing and proposed buildings from the different input databases. This
avoids long generation times or crashing the program through over-complexity.

The generative tool uses the boundaries created in the diagramming stage to define the massing type and extents. Each of the lines and closed regions are automatically collected by the parametric script via their defining layer classification and fed through the appropriate chain of massing control. The individual massing procedures can have a range of different sub functions unique to the geometric requirements of each typological class. Despite the individual variations within each typology chain, the process can be simplified into two distinct generative processes. Firstly the diagram outlines are mapped in 2D. This can either mean a single offset from the boundary to define a single building footprint or a more rigorous cellular division to define smaller block and building extents. Secondly, building attributes are generated within the footprint extents. This stage is described in this chapter in terms of 3D massing of individual buildings but could just as easily be confined to the generation of 2D building symbology.

The first process of defining the building footprint requires the measurement of the diagrammed regions area. This starting area is compared to the desired area range, dictated by the typological requirements, in order to determine whether the shape requires further division into smaller components. In order to process this data, a function referred to as an iterative loop was used. An iterative loop, or feedback loop, is a means of performing an action, validating it against desired values and then repeating the process with any negative
results until all elements fall within the desired range. This process requires a specialised plug-in component known as Hoopsnake (Food4Rhino (a)).

For the generative model, the initial regions that fall above the desired area value are divided through a pre-set algorithm to create a smaller grain of blocks. These new regions are then compared back to the desired area value. If the new blocks are still outside this range, they are fed back through the loop until they reach the desired value. All successful results are saved and fed through to the next definition at whichever loop they return a positive comparison. (Figure 47) Values to control the block area, offset and street size can be independently controlled in order to achieve the required density and grain for each zone type.

![Diagram](image)

*Figure 47  A region divided by two different division functions. The first division creates quarters while the second splits the new regions in half to more closely align with the desired area value.*

This process was chosen because of the relative simplicity of the division system and the subsequent speed at which solutions could be generated. Although not as accurate as some of the other potential optimised plot division methods, such as an evolutionary solver, speed and robustness in the system under complexity was the governing factor. One of the downsides to
this division method was in the potential for over-correction. In other words, even if a block was only slightly above the desired range it would be once again passed through the loop and broken into regions much smaller than the desired range. This, therefore, required the addition of a secondary check that took the negative results and compared them to a second larger figure in order to split the lists into division types. Those that were much larger than the desired area were sent through the full division function while those that fell between the two test figures were only split in two. This problem was further mitigated at the regional level of control where stringent dimensioning of the regions formed a more regular foundation for the community level diagrams and therefore less disparity between division loops.

For finer grain zones such as residential and light commercial, a further region division can be applied. For these types, the first division uses the iterative loop process to determine blocks and streets while the secondary division is a single tessellation of plots within the blocks. The input parameters for this process govern the size of the plots and the boundary offsets of the building footprint. The size of the plots also governs the number of buildings per block. In order to calculate this figure, the script grafts the data into unit categories comprising of the individual lines that make up each region and finds the shortest sides to divide in half. The desired plot area can be used to determine the number of equal segments a zone will be divided into. The building footprints are then offset to a predefined distance to determine the final block density. This process gives significantly less accuracy than the block massing scale but was still useful in testing the total impact of certain density
and height ranges across the site while still maintaining control over the zoning regions. (Figure 48)

**Figure 48  Two types of plot divisions tessellated within a block region.**

After the conversion of the diagrammed regions into building block outlines, the second level of building data is applied to create 3D building masses. The final building envelope that is created in this stage is an offset of the initial block. The newly defined building regions can then be either projected onto the site terrain or left on the 2D diagram. The building height and floor to floor distances can then be extruded up from the new footprint. (Figure 49) Once again, the offset and height ranges are defined by the benchmarking parameters and can be specific to each typology zone.

**Figure 49  3D building envelope extruded from the footprint offset and projection.**
Depending on the intended use for the output model, the height of the mass can either be lofted to a fixed height or be defined by a random number generator that gives the massing model a varied height. This generator is limited within a max/min range of overall heights and only generates integers of a variable floor to floor height value. The heights are therefore generated as full floors within a height range that is specific to its building typology. This tool gives the designer the control to set all types as a fixed height value or give any degree of variation between floors depending on the application. This tool was included as a communication method for the sake of some visual presentations to the extended design team to add a more realistic variation to certain types of developments. As such, it was not considered critical to the generation process that did not affect the area figures to a significant degree. At the block level, this random generator is removed in place of more accurate building height representation. (Figure 50)

*Figure 50*  An indicative 3D massing diagram demonstrating different types of parametrically generated high density massing. *(Pitts & Luther 2012)*
In this instance, the script has been arranged to generate the massing model from building defined parameters such as street width, building to block offset and height ranges. As a result, the model can be analysed in order to produce output figures such as Gross Floor Area (GFA), Floor Space Ratio (FSR) and Site Coverage. The benefit of this method, as opposed to manual techniques, is that at each phase of development or variation on the design, any mix of the input and output figures can be tabulated together to form a complete account of the design model. The data compiled in Table 4 demonstrates an overall summary of this type of design data. This example consolidates parts of the output and input data into a format that communicates the aggregate effect that any given design iteration has on residential, commercial and car parking volumes.
### Table 4  
**A compiled schedule of a models output data. (Table of figures courtesy of Grimshaw)**

**ASSUMPTIONS - SCHEDULE OF PROPOSED AREAS BY USE 7000 DWELLINGS / 3000 JOBS SCENARIO**

Summary of GBA calculations used to generate 3d massing studies and mix assessment.

<table>
<thead>
<tr>
<th>Dwellings</th>
<th>Broad Mix</th>
<th>Quantity</th>
<th>Mix (%)</th>
<th>NSA / apt m²</th>
<th>Total NSA m²</th>
<th>NSA/GBA Efficiency %</th>
<th>Total GBA area m²</th>
<th>Adjustment for articulation</th>
<th>Total envelope area m²</th>
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<td>85.00%</td>
<td>1050</td>
<td>20%</td>
<td>1190</td>
<td>68,430</td>
<td>72%*</td>
<td>90,003</td>
<td>90%*</td>
<td>100,003</td>
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<tr>
<td>2br Apartment</td>
<td>49.00%</td>
<td>2390</td>
<td>65%</td>
<td>202,200</td>
<td>134,720</td>
<td>72%*</td>
<td>126,972</td>
<td>72%*</td>
<td>131,954</td>
</tr>
<tr>
<td>3br Apartment</td>
<td>27.9%</td>
<td>1607</td>
<td>115%</td>
<td>104,993</td>
<td>92,654</td>
<td>72%*</td>
<td>96,394</td>
<td>90%*</td>
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<td>4br Apartment</td>
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<td>710</td>
<td>130%</td>
<td>40,005</td>
<td>34,660</td>
<td>72%*</td>
<td>41,914</td>
<td>90%*</td>
<td>48,000</td>
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<td></td>
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<td><strong>409,054</strong></td>
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<td><strong>508,036</strong></td>
<td><strong>72%</strong></td>
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<td>100%</td>
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<td>430</td>
<td>120%</td>
<td>80,000</td>
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<td>64,994</td>
<td>100%</td>
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<tr>
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<td>110%</td>
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<td></td>
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<td><strong>TOTAL DWELLINGS</strong></td>
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<td>100%</td>
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<th>Broad Mix</th>
<th>Quantity</th>
<th>Floor Area per unit m²</th>
<th>Total NSA m²</th>
<th>NSA/GBA Efficiency %</th>
<th>Total GBA area m²</th>
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<td>100%</td>
<td>13,050</td>
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<tr>
<td>300 bed hospital</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health</td>
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<td></td>
<td></td>
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<tr>
<td>Total Health</td>
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<td>6,000</td>
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<td>42</td>
<td>12,390</td>
<td>100%</td>
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<tr>
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<td>100</td>
<td>26,000</td>
<td>100%</td>
<td>26,000</td>
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<td>888</td>
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<tr>
<th>Carparking</th>
<th>Ratio</th>
<th>Quantity</th>
<th>Floor Area per unit m²</th>
<th>NSA/GFA Efficiency</th>
<th>Total GFA m²</th>
<th>Assumed below ground %</th>
<th>Total GFA above ground m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apartments - 1 bed</td>
<td>0.77%</td>
<td>895</td>
<td>20</td>
<td>50%</td>
<td>35,700</td>
<td>50%</td>
<td>35,700</td>
</tr>
<tr>
<td>Apartments - 2 bed</td>
<td>1</td>
<td>2,390</td>
<td>20</td>
<td>50%</td>
<td>95,200</td>
<td>50%</td>
<td>95,200</td>
</tr>
<tr>
<td>Apartments - 3 bed</td>
<td>1.5</td>
<td>3,570</td>
<td>20</td>
<td>50%</td>
<td>142,800</td>
<td>50%</td>
<td>142,800</td>
</tr>
<tr>
<td>Townhouses - In-Filling</td>
<td>0.4</td>
<td>1,207</td>
<td>20</td>
<td>50%</td>
<td>46,288</td>
<td>50%</td>
<td>46,288</td>
</tr>
<tr>
<td>Visitor parking</td>
<td>0.05%</td>
<td>1,050</td>
<td>20</td>
<td>50%</td>
<td>46,288</td>
<td>50%</td>
<td>46,288</td>
</tr>
<tr>
<td><strong>TOTAL CARPARKING</strong></td>
<td>0%</td>
<td>8,050</td>
<td>20</td>
<td>321,908</td>
<td>160,994</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total Dwellings   | 100%  | 7000    | 697,953     | 913,028    | 998,376     |                     |
| Total employment  | 100%  | 3018    | 99,986      | 127,686    | 160,994     |                     |
| Total carparking  | 100%  | 8,050   | 321,908     | 160,994    |              |                     |
| **TOTAL SITE GFA** | 1,207,708 |        |              |            |              |                     |

From this compound information, certain assumptions can be made about building efficiencies and compositional logic within their type categories. The parametric output data can then be critiqued to either inform a feedback loop of further testing or to continue the design process at a finer level of resolution. The initial success or failure of any given scheme is generally
driven by cost, risk, return and other areas related to project feasibility. This is an important part of the community level of design. High-level feasibility studies require certain broad assumptions that don't necessarily require testing at a finer resolution until everything balances. This search for equilibrium in the feasibility is one of the main reasons a good control mechanism, like Excel, was used to compile outputs, compare results and reset new inputs for testing. This process allowed for a very explicit generation, analysis and response (adjustment) within an intuitive interface system.

The type of information output described here made this massing and density generation tool one of the most utilised within Grimshaw projects. This was especially powerful in early stage optioneering to test a site's capacity in open briefs or to build a good case for or against more rigid planning requirements. (Figure 51)
Figure 51  Two options for a scheme demonstrating the basic mass associated with accommodating different populations and job ranges.
The model demonstrated in Figure 51 changes heights and massing offsets within the same base diagram in order to test multiple massing outcomes for a scheme. This particular model was concerned with comparing the massing and density outcomes for different volumes of residential and workplace areas. It was found that in models such as these, restricting the number of variable inputs gave a clearer understanding of the diagram. This once again addresses the need to understand the problem type and the type of diagram and generative model required to inform the designer’s decision-making process.

**Design Application**

As previously mentioned, this approach to generative modelling was one of the most widely accepted and applied in the practice studies. This was largely due to the open logic of the basic script that set up a framework to very simply divide blocks, offset building footprints and loft different heights. This basic script allowed for very quick alterations to be made to suit different projects problem types. This model also allowed the designer(s) to determine the level of analytical rigour that went into crafting the input parameter sets and also how sophisticated a diagramming language was used. The nature of the script and the Grasshopper interface allowed for users to replicate a segment to accommodate 2 typologies or 30. The scope was limited only by the complexity and quantity of input data required.

**Defining the Parameters**

Despite the need for a consolidated database of precedent information being triggered through a Melbourne based project, the data collected within Grimshaw was explored on a global scale. This was carried out in order to find the best examples of aspirational urban environments along with the cultural
differences that made their operation so successful. This data was predominantly collected through the process of a desktop study to collate all published descriptions, opinions and figures that could be researched. In the case of this initial project, Grimshaw was lucky enough to be a part of a study tour funded by the client group. This allowed first hand experience of the precedent urban environments to be recorded through survey sheets and individual journals. This was particularly important for understanding the key relationships that made these environments successful and helping to draw parallels between the quantitative data and the qualitative indicators. (Figure 52)

<table>
<thead>
<tr>
<th>Project</th>
<th>Date</th>
<th>Alt. (m)</th>
<th>Alt. (ft)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BedDeli, Surrey, UK</td>
<td>2000</td>
<td>1.7</td>
<td>10.38</td>
<td>4,875</td>
<td>2,380</td>
<td>244</td>
<td>83</td>
<td>84</td>
<td>196</td>
<td>148</td>
</tr>
<tr>
<td>Erlangen, Germany</td>
<td>2005</td>
<td>30</td>
<td>102</td>
<td>500</td>
<td>205</td>
<td>750</td>
<td>730</td>
<td>1.5</td>
<td>15.3</td>
<td>16.5</td>
</tr>
<tr>
<td>Hafen-City, Hamburg, Germany</td>
<td>2000-2025</td>
<td>12%</td>
<td>2,330,000</td>
<td>690,000</td>
<td>218,000</td>
<td>1,110,000</td>
<td>11,000</td>
<td>50,000</td>
<td>400,000</td>
<td>87.1</td>
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</table>

<table>
<thead>
<tr>
<th>Project</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
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<th>Alt. (ft/m)</th>
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<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
<th>Alt. (ft/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BedDeli, Surrey, UK</td>
<td>10%</td>
<td>10%</td>
<td>30%</td>
<td>30%</td>
<td>80%</td>
<td>80%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Erlangen, Germany</td>
<td>25%*</td>
<td>20%*</td>
<td>30%*</td>
<td>30%*</td>
<td>80%</td>
<td>80%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Hafen-City, Hamburg, Germany</td>
<td>25%</td>
<td>20%</td>
<td>30%</td>
<td>30%</td>
<td>80%</td>
<td>80%</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Figure 52  Three benchmarking study examples with a small section of the possible Quantitative and Qualitative data fields. (Figures courtesy of Grimshaw)
Each precedent study consists of key attributes that are considered desirable or aspirational. It was quickly discovered that the more ethereal aspects of quality could be hard to record in a database such as this. This was dealt with by creating attribute headings or tags that relate to certain elements within a development. (Figure 53) From these, elements of the database can be cross-referenced and compared to other developments based on the same attribute tags. This comparison can also help in the quantification of elements or figures that contribute to the quality of an environment. The tagging system in this research was utilised on a fairly basic level with spreadsheets, colours and headings. With further research, this has the potential to become a much more sophisticated system that can display snippets of specific and similar data from more tailored search criteria.

![Diagram showing categories of attributes: Liveability, Character, Adaptability, Diversity, Workability, Performance, Innovation, and Natural Habitats.]

**Figure 53**  *A selection of tags that can be used to classify certain qualitative aspects of the precedent studies.*

When combined with the design diagrams, the qualitative indicators and aspirational tags were a particularly powerful tool for the communication of data to stakeholder and client groups. The thematic tags gave the design story a more tangible and easily communicable foundation.
Although determined to be best practice, the qualitative indicators were not always used formally. Once a database of different projects was compiled of general information, aspects could then be used on different projects as applicable. In smaller design studies or projects that did not have any relevance to the pre-compiled data, the process reverted to the experience of individual designers to make judgement calls on the quality of outcomes. This was a less formal version of the data groups already discussed but still allowed a designer to tabulate quantitative parameter sets for the purpose of generation. (Figure 54)

<table>
<thead>
<tr>
<th>Type 01</th>
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<th>Target Plot Footprint m²</th>
<th>Building Offset (%)</th>
<th>Floors</th>
</tr>
</thead>
<tbody>
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<td>200-300</td>
<td>40%</td>
<td>1-3</td>
</tr>
<tr>
<td>TOWNHOUSES</td>
<td>65%</td>
<td>500-700</td>
<td>20%</td>
<td>7-11</td>
</tr>
<tr>
<td>APARTMENTS</td>
<td>= Building FP</td>
<td>SUB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR PARKING</td>
<td>16%</td>
<td>150-400</td>
<td>5%</td>
<td>4-11</td>
</tr>
<tr>
<td>COMMERCIAL</td>
<td>= Building FP</td>
<td>2 x SUB</td>
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<tr>
<td>retail BUILDING</td>
<td>2%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CAR PARKING</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
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<th>Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHOOL ZONE</td>
<td>100%</td>
<td>1500-2200</td>
<td>75%</td>
<td>1-3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type 03</th>
<th>% Split</th>
<th>Target Plot Footprint m²</th>
<th>Building Offset (%)</th>
<th>Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESIDENTIAL</td>
<td>97%</td>
<td>200-300</td>
<td>40%</td>
<td>2-3</td>
</tr>
<tr>
<td>TOWNHOUSES</td>
<td>65%</td>
<td>500-700</td>
<td>20%</td>
<td>5-8</td>
</tr>
<tr>
<td>APARTMENTS</td>
<td>= Building FP</td>
<td>SUB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR PARKING</td>
<td>3%</td>
<td>2700-3300</td>
<td>30%</td>
<td>2-4</td>
</tr>
<tr>
<td>COMMUNITY BUILDING</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR PARKING</td>
<td>15%</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Type 04</th>
<th>% Split</th>
<th>Target Plot Footprint m²</th>
<th>Building Offset (%)</th>
<th>Floors</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESIDENTIAL</td>
<td>100%</td>
<td>250-450</td>
<td>40%</td>
<td>1-3</td>
</tr>
<tr>
<td>TOWNHOUSES</td>
<td>20%</td>
<td>500-700</td>
<td>20%</td>
<td>3-9</td>
</tr>
<tr>
<td>APARTMENTS</td>
<td>= Building FP</td>
<td>SUB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAR PARKING</td>
<td>70%</td>
<td>450-650</td>
<td>65%</td>
<td>1-2</td>
</tr>
</tbody>
</table>

Figure 54 Four different type sets demonstrating the different input parameters that will control the generation of the massing model.

From the precedent data it was possible to compile different type sets comprising of the desired target parameters. This information could be single figures for a specific output or limited ranges in which multiple models of different data composition could be optioneered and tested. The optioneering was highly sought after in practice due to its success in using determinable
figures to explore previously indeterminate results through the process of model generation. (See Figure 57)

**Design Diagramming**

This was one of the most successful elements of the model generation process within practice conditions. The basis of model generation was purposefully focused around the industry standard technique of Illustrator diagramming. This allowed for any number of design diagrams to be tested through the model generation phases even if the initial intent for the diagram was not parametric. This was possible due to the synergies between diagramming and parametric scripting requirements. Both require classifications of elements for either explicit visual communication of ideas or implicit program recognition and generation.

![Diagram](image)

**Figure 55**  *Example of a zoning diagram at the regional scale that can be used as the basis for block division and model generation. (Image courtesy of Grimshaw)*

This process was therefore easily explained to members of the practice on a technical level that did not require a lot of learning beyond the concept of
parameter-based relationships. Although the resolution behind the analytical databases varied across different projects, this diagramming process and model generation phase became sought after for its easily accessible and readily understood benefits in speed, efficiency and validation of design concepts.

**Generating a Massing Model**
The scripting and generation for this tool were found to be very stable and predictable in its outcomes for block division and building massing. One of the lessons learned through producing a number of these generation tests across different projects was that the success or failure of the massing generation stemmed from the initial diagram. This reconfirmed the importance of a deterministic approach to model generation. The diagram needs to be produced with the final output in mind in terms of the testing scale, stage of design resolution and the diagramming language required from the generation script.
Figure 56  Massing model generated from the parametric massing script and superimposed onto an aerial photo taken from a light aircraft. (Image courtesy of Grimshaw)

For Grimshaw as a practice, this tool was a great way to test design moves right from the first principles of design thinking. The mix of visual output and analytical data meant that all stakeholders involved in the design process could connect with and respond to a range of different strategies. This level of connection offered a more diverse level of understanding regarding the intentions and outcomes of each proposal in order to more effectively navigate a way forward in the design process.
The main design objective at the community scale development is to begin to determine the relevant parameters that require further testing and the variable value ranges that will drive the block level testing. Figure 57 demonstrates the gross output figures from the generated model. The right hand side shows correlating post generation output data for each zone type.
This shows aspirational and indicative strategies for the zones. This will help to refine the scope of exploration of more detailed block level input parameters.

4.5. Summary

This chapter presents a series of design studies that have been developed within the scope of the arguments set up in the literature review section of this thesis. During the practice-based studies, a number of observations were made throughout the development of this method of design. The following sections outline a few of the major points of interest encountered in practice by the immediate design team as well as broader observations from practice members, client teams and advocacy groups.

4.5.1. Practice Validation

It was found that having a deterministic view towards the intended outputs of the process right from the start of the design process was critical in formulating the most effective workflow. Understanding this at the beginning of the process helped to determine the scope of the required input parameters and subsequently what type of data would be used to form the parameters. This also helped to manage the simplicity in the user interface, which was a key contributor to the success of these tools in practice. It was quickly found to be untenable relying on the minority of parametric software specialists to guide every alteration across multiple projects. Simplicity in the interface, transparency in the systems variables as well as intuitive parameter sets allowed for a range of different architects to have access to the toolsets. This was particularly interesting to see as architects who had no previous
parametric experience began to think differently about how they could affect their digital tools to optimise the design process. Although most of the alterations of the scripts still fell to a few ‘specialists’, it was a much more engaging and thorough process to have team input into the design of a digital environment.

Flexibility in the system was also an important consideration in minimising preconceived scripting logic that might not suit a design beyond the project it was developed for. This is why a methodology was used as a means of guiding design thinking and systems development as opposed to a more prescriptive and inflexible system. The defragmented method for defining problems that required testing was also a key component of adaptability. Any change to the system or retesting of the design is relatively small and efficient. This was particularly important for the process of parametric optioeering. Once a system was in place, alterations could be quickly made with the effects seen immediately in the design output.

Communication was one of the key factors in the successful application of these tools in a practice environment. This was not limited to how a design process or product was communicated but more importantly how to raise awareness and demonstrate general capability to members of the practice. Sharing information on a global scale through presentations of successful projects and the working methods behind the designs helped to spark an interest into the potential applications for this research. Internal presentations and progress reviews also helped to critique the design output and offer suggestions for improvements to the working methods and systems. In
support of this active engagement, a wiki style database was also set up to allow any member of the practice to post scripts and design outputs as well as share ideas and ask for support from other members. The fact that the tools and processes were accepted and actively sought after was validation of the successful communication of parametric capabilities. Paramount to this success was the change in thinking at letterhead level. This meant that project leaders had the awareness to rethink the problem solving process and reimagine the potential outcomes for a particular design task.

Although there still needs to be further work developing the overall holistic model of operation, the defragmented problem centred nature of the tools was immensely successful and gained exposure well beyond the initial intentions of the research.

The phase 1 analysis tools gained particular interest at the higher levels of scale. This was true for master planning as well as single building projects. The ability to analyse wider context is applicable to both. This level of analysis became popular for a number of reasons. Discrete lines of questioning meant that the parametric tools could be very focused on a solution. This meant that there was a small set of easy to use parameters that led to a clear generated result very quickly. Not a lot of prior knowledge was required and there was a clearly seen benefit in efficiency and effect. This naturally appealed to a larger audience in practice.

The building scale tools were mainly applied to small clusters of buildings. Single buildings had more bespoke requirements than the parametric tools developed to date could control. Campus style arrangements, particularly
those with complex functional compositions or quantifiable physical parameters benefit from this process.

### 4.5.2. Advocacy Group Validation: Clients and Stakeholders

Although there was no formal review of the parametric methods behind the design work, it is still of interest to note some of the observations made from client and other advocacy groups involved with the end design products. Advocacy and client groups generally saw only the final output of a design exercise and were not exposed to the delivery mechanisms behind the work - parametric or otherwise. The success of the parametric process could still be measured in the translation between designs in working format to how they were communicated through presentations to third party stakeholders. It was a specific aim in a number of projects to set up early template diagrams and have the parametric systems feed directly into them. Updates could then be automated from a working output into the template. This was appreciated in terms of working efficiencies within the design team but demonstrated through the ease in communicating new ideas quickly and clearly to the relevant third parties. The process also achieved the goals described in chapter 3.3.4 (pg 76) for universally understood data formats to be used throughout the design process.

The process of presenting design work that was a product of these design studies also helped to demonstrate the theory of computational tools as an aid to the understanding of process. Even with only a cursory knowledge of the design process, the rigour behind the outcomes was apparent in the explicit parameters expressed as the design’s prime relationships. No move
was incidental from an analytical parameter basis, which helped lead the
stakeholders to a better understanding of a design's intentions and
implications. This also helped to give common ground to the discussions.
Design alterations were more easily communicated when everyone
understood the analytics behind an outcome and could contribute to the
refinement of the product.
5. A Theoretical Model for a Problem Centric Parametric Urbanism

“Innovation risk can be mitigated through understanding what has been done before and the lessons that were learned.” - Grimshaw Design Philosophy

“(scientific) research is a form of design—a specifically restricted form. If this is so, it is inappropriate to require design to be "scientific": for scientific research is a subset (a restricted form) of design, and we do not generally require the set of a subset to act as the sub subset to that subset any more than we require the basement of the building is its attic.” Glanville 1999:87

5.1. Design Method

The following chapter outlines a methodological framework derived from the literature reviews and design based testing of parametric urbanism. In light of these discussions and subsequent practice based testing, the method takes an empirical approach to urban design and as such, requires a strong foundation of analytical data in order to form the parametric constraints at each stage of the design process. The general framework for this method is described in two parts.

- **Resolutions of Scale.** Concerned with four scales of design resolution and its interface with scaleless digital space in order to produce a design workflow with a cohesive master model. The resolution in scale has a significant effect on the problem types, diagramming method and generative capabilities of the computational systems.

- **Three Phase Design Method.** This looks at the three phases of program development that aim to expedite, accentuate and/or generate the design intent. This process features a feedback loop between phases to refine the design product. Data is visually available
at any given time and readable by both human participants and computer systems. There is also potential to optioneer multiple design iterations with variable sets of precedent data.

Each of these areas will describe a staged approach to design development and the unique requirements of each. The method is described in generic terms in order to highlight the fundamental relationships between human participants and computer systems. The four scales of resolution as well as the 3 phases of the design method are all theoretical groupings that outline a type of action and thought process. This is purely a problem solving and communication method. It is acknowledged that there is a vast grey area outside and between each of these classifications, which need to be recognized in any practical application of the method.

5.1.1. Scope of this Design Method

“The participants in the development of any urban design project will be arguing with each other and themselves as they speculate about what the issues are and how best to deal with them... Conjectures are tested by individuals using their own logics based on their predictions of the consequences of different design actions.” Lang 2005:26-27

Despite any personal views on Urban Design philosophy, the delivery of a project in 'real world' circumstances is never quite as clear-cut as the theoretical models. Each design member and stakeholder will have a different theoretical standpoint and argument for its application in design that immediately imposes varying generic reactions and approximations that steer the design towards a preconceived solution. These preconceptions are unavoidable and, if properly understood, helpful in utilising past knowledge
and experience of participants. Jon Lang (2005:27) states that despite these
different standpoints, certain similarities and consistencies are evident across
each of the decision making processes that involve “deciding to engage in a
situation, developing a brief and a building program, finding the finances and
seeing the program through to completion.” (Figure 58) The difference is in
the control methods and the decision-making constructs that govern how
each step will be carried out. Recognising these similarities, Lang goes on to
classify four generic types of urban design procedure.

- **Total Urban Design.** Where the urban designer is part of the
development team that carries a scheme through from inception to
completion.

- **All-of-a-piece Urban Design.** Where the urban design team devises a
master plan and sets the parameters within which a number of
developers work on components of the overall project.

- **Piece-by-piece Urban Design.** General policies and procedures are
applied to a precinct of a city in order to steer development in specific
directions.

- **Plug-in Urban Design.** Where the design goal is to create infrastructure
so that subsequent developments can ‘plug in’ to it or, alternatively, a
new element of infrastructure is plugged into the existing urban fabric
to enhance a location’s amenity level as a catalyst for development.

The design studies described in chapter 4 have some overtones of the piece-
by-piece method but are predominantly based on the All-of-a-piece Urban
Design model of control. This has influenced the diagrammatic structure of
the method described in Figure 60. Depending on the type of design a particular project demands, the proposed method described in the following chapter can be restructured to facilitate any of the generic types described above assuming that the core structure rules of problem centric parametric urbanism are followed.

Figure 58 demonstrates Jon Lang's generic model for urban design that outlines the different influences, stages and design process from conception to delivery. The following chapter and the methods outlined within are concerned with the central highlighted band of design actions.

Figure 58  Jon Lang’s generic model for Urban Design decision-making process. This model forms the basis from which the control method and decision making construct can be applied. (Redrawn and adapted from Lang 2005:26)

The areas of Lang's design model that lie outside of the dotted band are considered under the heading of Design Intent in Figure 60. Although some of these points are addressed in part, the main focus of the following chapter is on the design actions themselves and the process that connects them. The
label of Design Intent therefore covers both the type of approach or theory applied to the design as well as the participation and views of stakeholders in the project. This includes both secondary and participatory roles of stakeholders and existing residents involved with a given scheme. Design Intent also encompasses a number of different sub categories in decision-making between phases and across different levels of scale. These relationships have been simplified and combined under the single heading of Design Intent for the sake of clarity in the text (Figure 60).

The design method proposed in this chapter is an inherently hybrid technique that is derived from the adaptability of human participants and the acceptance of the superior analytical calculation and generation capabilities of the computer. The prominence of either human or computational counterpart is essentially determined by the nature of the problem and the requirements of the design solution. This arrangement is intentionally flexible in order to maximise results from the source best suited to dealing with the problem. This also means that the method is never purely human or computationally driven, thus avoiding an unnecessarily rigid construct for the urban design process and outcomes. Any biological or linguistic generative computation can be integrated into this method, but only with due consideration of the random or non-deterministic results and how they are used to inform the design strategy. As already discussed, this method is focused around an empirical system of parametric urbanism in order to exploit the deterministic nature of analytically derived parameter controls. As such, this type of method can never be considered a means of facilitating a purely rationalist approach to urban design.
5.1.2. The Problem Centric Design System

The discussion of systems design throughout chapter 2 is relevant not just for architectural design, but also for a number of industries that rely on computing systems. The Human Centred Design (HCD) approach aligns with the way architectural computing systems have been developed, in that CAD systems have been tailored to existing and preferred drafting methods. As discussed, this model of systems design holds the inherent problem of maintaining a methodology that doesn’t recognise or fulfil the full potential of either the human participant or the computational system (Burry 2011, Oxman 2006). Libraries of pre-compiled CAD details and objects are an example of how efficiency can prevail over best design practice. This can lead to a process of copying and pasting geometry as opposed to learning, developing and optimising the system as a design artefact.

On the other end of the spectrum new technologies, such as parametric systems, have fallen victim to technical primacy in which users are firstly required to learn a new process and secondly, adapt their ways of working to suit the specialist system (Gürsel Dino 2012, Rasmussen 2007). In the case of parametric systems, this is not because the system will not allow a more balanced approach but because the methods of applying them to design work are still poorly defined. This has unfortunately led to designers outputting solutions not because it is the best solution to the design problem but because it is a product of the computer systems’ pre-compiled toolkit. In this working model, design is reduced to the non-deterministic product of a black box system. The more specialised the program or digital system, the more
restrictive it can be on human interaction and their power for qualitative influence (Cooley 2000).

In response to this dichotomy of architectural systems and the working methods required to utilise them, it is proposed that a more balanced approach is required. One that allows the human being to handle the qualitative and subjective judgements while the computational system is left to quantitative generation. This way of thinking changes the working methods at a fundamental philosophical level that builds on the ‘natural behaviour’ of the user to create a working process that is led by the requirements of a given problem.

What is needed is a Problem Centric approach to design. This suggests an approach that is formed around the problem space itself as the common element between human and computing processes and the critical drivers that shape efficiency and efficacy in the working methods. This approach is derived from system theory, cybernetics and the Law of Requisite Variety, which states that in order to create stability in a system, the control mechanisms must be at least equal to the number of states that require control. (Darzentas et. al 2014)

In order to realise this, the working logic is reverse engineered by the domain user to form an understanding of the problem space and the desired outcome of solving a given problem. This process aims to identify problem types, such as the qualitative or quantitative scope of the problem, and uses this to balance both the human and computational contributions to produce the best possible results. (Figure 59)
Figure 59  *Proposed relationship diagram for Problem Centric design.*

Figure 59 demonstrates a model where the domain user is empowered to interface directly with the computational tool kit. This is a variation on the aims of systems theories such as Participatory Design, Interaction Design, and Agile Software Development (ASD), but with the additional aim of merging the computing and domain competence, empowering the domain user to affect their systems and workflows directly to best suit each task. For this model to operate, it first assumes that there is very little difference between the programming language and the adaptive tool interface and as such, requires a user that can interface equally with both. The programmer is still present in setting up the fundamental construct of an open source program, such as McNeel has done with the parametric software Grasshopper, but is now no longer needed in the design and development of domain specific systems. A generational shift in computer competence is fundamental to the success of this model. Domain users are becoming more digitally savvy, therefore closing the gap between domain and computing competence. The problem space is therefore assessed by the domain user as the authority in forming a best fit working method that incorporates both the dynamic flexibility of the human user and the prescribed processing power of the
computer. This is based on a sound understanding of emerging trends in systems development but additionally requires the domain user to become master of computational design thinking.

5.1.3. Rules for a Problem Centric Parametric Urbanism

Chapter 3 expanded on some of the issues associated with the current context of computational design and, more specifically, parametric urbanism. Each sub-section formed an argument for certain actions that can address each of the identified issues. The following points summarise the conclusions of both the pressure points for parametric urbanism identified through the literature review and the lessons learned throughout the chapter 4 design tests. The following rules for parametric urbanism also consider the problem centric systems design theory described previously. This aspires to construct a more holistic methodology that achieves more effective outcomes through integrating individual strengths of both humans and computers.

- Diagramming Language:

The design method needs to utilise a consistent diagrammatic language that can be explicitly communicated at any point to all of the computational systems used in the design process as well as any human designer or stakeholder. The language should be intuitive to draw and read, minimizing the need for reworking data into presentation format diagrams. The language needs to represent both explicit and implicit data types through a simple and intuitive interface that minimizes over-aggregation, assumption and subsequent data loss.
- Scale (Digital and Representational):

Through the recognition of different levels of scale, the design problems can be defragmented into smaller tasks that can be better aligned with problem solving techniques. The defragmented problem solving process is aimed at producing more controlled and deterministic results with a minimum of computational assumption through over-aggregation. Due to the scaleless nature of digital environments, any system has to be capable of both scaled intervention and scaleless automation to be employed at the designer’s discretion.

- Parameter Definition (Types and Typologies):

The design method must adhere to a structure that incorporates both the quantitative and qualitative aspects of the design aspirations to create a closer alignment to the formation of control parameters and variables. A set of case study projects will be used to compile a typological database of parametric observations. This empirical database will allow for the recombination of desirable attributes in order to form a new set of analytical design parameters that have a strong relationship to the design aspirations.

- Model Classification:

The design method must recognise that a model is a diagrammatic database of design thinking as opposed to a single static representation of formal spatial qualities. Once recorded into a stable format, these discrete layers of 2D and 3D diagrams form a larger, more complete urban story that can be used for the purpose of testing, validation and communication of the proposal. Information has to be universally understood between the required digital
systems as well as the human stakeholders and designers at any point in the process in order to limit data loss, misinterpretation and reworking of digital data for human consumption.

### 5.2. Resolution of Scale

The design method outlined in Figure 60 addresses 'Scale' in digital design that can result in highly standardised and aggregate responses that don’t address the issues at hand. The proposed method utilises the levels of scale discussed in chapter 3.2.2 (pg 49) to structure an approach for the application of parametric urbanism. The ascending scale of numbers from 1 to 4 alludes only to the level of resolution and should not be construed as a limitation on the chronological order of the methods used. Each of these scales and their corresponding computational tools can be employed as either an ascending or descending system (either top down or bottom up approach) or as recombinant sets of individual pieces that can be employed as required by a specific design project. Each of the four scales is presented individually to highlight the unique problems that arise in each. These key problems are identified as a means of describing the scope and type of problem space that the design method and corresponding parametric tools might address.

Although the process of creating a master model is linear in terms of its macro to micro design process, at any point in the design's progression, the model can be considered as bi-directional in its ability to simultaneously consider data previously collated.
Figure 60  Overview diagram of the proposed parametric design method

As discussed in chapter 3.2.2 (pg 49), one of the major criticisms of some approaches to computational urban design is that they can be over-simplistic in the assumptions of aggregate relationships and superficial in their ability to predict change at finer scales (Batty 2005). This is true for the computational systems themselves if considered in isolation from the design process. The ability to refine and change design responses at an increasing level of scalar consideration has therefore become a fundamental part of this design method. This means that no single computational system dictates broad assumptions across all levels of design, either top down or bottom up. Instead each scale is approached with a set of computational tools specifically tailored
for the unique problems that arise within each scale of consideration. The flexibility and diversity of the relationships at any scale is wholly dependent on the rigour and integrity behind the analytical parameter definitions. This is tailored to avoid the over-programming of design detail into digital systems that generate results too far beyond the designers’ foresight and control.

**Region**

Regional scale design methods focus on analysis of existing site conditions and context as well as initial mapping out of design aspirations that will guide the subsequent finer grain decisions. Most of the problems encountered at this level of design are associated with the analysis of wide ranging conditions and constraints that will affect the design scheme. Whether the design is greenfield or urban infill, the main aims of this phase of design are to gain an understanding of the current state of play and begin to test the tolerances and opportunities for any new design addition.
Figure 61  Regional scale context study of neighbouring massing and density ranges. These basic density figures were linked to a parametric script that generated the indicative density ranges across each region. (Image courtesy of Grimshaw)

For this reason, the considerations are predominantly non-physical in their nature and more about mapping systems, trends, identifying opportunities, gap analysis and constraints. Areas of focus might include:

- population growth and movement patterns,
- primary infrastructure provision (transport, water catchment and supply, sewerage, electricity),
- employment (distribution, opportunities, major forces),
- socio-economic demographics (age, wage / wealth, household size, ethnicity),
- cultural conditions and influences,
- provision of housing (quantum, distribution),
- provision and distribution of core services (hospitals, schools, police stations, law courts, etc),

- activity / town centres (location, operation, expansion),

- preservation of natural resources,

- agriculture, industry and means of production.

At this scale, decisions might focus on identifying key levers for growth and developing strategies for how to employ them. Whilst the outcomes of these development strategies are physical, the decision set is based on relationships between systems, forces and trends. This process is focused around establishing a set of objectives that will govern development at the finer levels of design resolution. Although this can still be classified as a design act, it applies more to the framework being created than to the objects born of that framework.
Figure 62  Regional design diagramming. (Image courtesy of Grimshaw)

Due to the wide scope and quantum of considerations at the regional scale and its associated data records, the supporting computational tools need to be predominantly focused on analysis. This type of processing allows the computer to follow sets of rules for compiling, sorting, refining and outputting more legible and relevant data. This scale is also heavily reliant on diagramming languages and the systems that compile the diagrams digitally. This process is critical for capturing the analysis, analysis response and strategic planning in a format that can be used as a basis for finer grain studies. The parametric massing generation tools are relatively simple in their geometric requirements at this level of strategic planning.

Community

The community level of scale focuses on establishing principles and objectives that have more immediate physical implications on a specific location than
that of the regional scale. Some of the key design objectives and problems can include:

- Uses distribution / functional zoning,
- Land sub division / grain,
- Topography and natural features,
- Historical and social / cultural context,
- Movement network, permeability, hierarchy, legibility,
- Shaping density / plot ratios / building massing and heights,
- Public open space provision including location, types, scales, hierarchies, qualities,
- Housing typologies and social / affordable housing mix,
- Shaping development patterns - concentrating development in certain areas (including a notion of activity centres, transport nodes and corridors), preserving select existing character, mapping different characteristics,
- Heritage conservation,
- Safety and passive surveillance,
- Landscaping typologies, natural environment preservation, biodiversity and habitat.

Here, design begins to directly focus on the physical environment in specific terms, although not necessarily in detail for each individual site. The design process is an iterative act of applying and testing different approaches across
these dimensions of consideration. This can be approached in isolation or in various combinations as the complex interplay between each is explored.

Figure 63 Layers of diagrammed existing context information at the community level. This demonstrates how layer and colour assignments can be crucial for explicit communication of different concepts exported from the same master file. (Image courtesy of Grimshaw)

Given this focus, the computational tools predominantly support methods of diagramming and a general testing of built capacities through volumetric massing and density generation. The community scale design tool is a means of applying indicative sites within the previously defined design zones. The generated massing envelopes are defined by regional governance, building type compositions within zones and any of the relevant existing conditions analysis.

**Block**

The design process applies the broader community principles and implements them into a specific physical proposal for an area that imagines outcomes down to individual sites but does not dictate the exact manner in which they may be executed materially.

- Establishing specific building envelopes for specific lots – massing, setbacks, heights, site coverage / plot ratio, density – in part driven
intrinsically by use-based objectives, in part extrinsically by aspirations for a particular quality or qualities of urban environment

- Area analysis and targets by use
- Street design – scale, dimensions, materiality, furniture, landscape
- Public open space design - scale, dimensions, materiality, furniture, landscape
- Establishing rules for materiality / form in an effort to establish a character / language for an area and to facilitate / reinforce community level principles and objectives – material palettes, details, signage, property boundaries articulation and street alignment interfaces

Table 5  Example breakdown of building types and distribution as determined from benchmarking studies.

<table>
<thead>
<tr>
<th></th>
<th>Mix</th>
<th>Beds</th>
<th>Sq ft</th>
<th>Sq m</th>
<th>Parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detached</td>
<td>5%</td>
<td>3</td>
<td>1050-1250</td>
<td>98-116</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>4 to 5</td>
<td>1250-1600</td>
<td>116-149</td>
<td>2</td>
</tr>
<tr>
<td>Semi Detached</td>
<td>15%</td>
<td>3</td>
<td>925-1050</td>
<td>85-98</td>
<td>1(50%) to 2(50%)</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>4</td>
<td>1150</td>
<td>106</td>
<td>2</td>
</tr>
<tr>
<td>Terrace</td>
<td>15%</td>
<td>2</td>
<td>750-900</td>
<td>69-83</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>3</td>
<td>950</td>
<td>87</td>
<td>1(50%) to 2(50%)</td>
</tr>
<tr>
<td>Flats</td>
<td>10%</td>
<td>1</td>
<td>500-550</td>
<td>46-51</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>2</td>
<td>650-700</td>
<td>60-64</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The generative tools, and the parametric constraints that govern them, are similar to those of the previous community scale massing phase. The main points of difference are in the benchmark or case study derived input information and the ability for the parametric tools to generate varying type clusters based on variable control inputs. This places a greater focus on
building typologies and the rules that govern both their physical properties and their functional relationships.

Figure 64  A block level massing study demonstrating footprint extrusions to variable heights. The output data helps to understand the implications of certain input options. (Image courtesy of Grimshaw)

Building

The purpose of this level of modelling is to more accurately address the requirements of building design within the constructs already set during design development. In some aspects, this scale has proved most difficult in the development of parametric design tools. This scale of design is often too great to apply building level detail across an entire master-planned design. Despite this, the generative tools have demonstrated their use in testing key areas in a site. This is the only scale at which ‘architecture’, in the sense of the
buildings’ function and aesthetic is considered. Urban design considerations can be affected through the block scale, however, the architectural does still incorporate the urban in its conception. Some considerations at this level of scale include:

- Functional and aspirational brief,
- relationship to site and surrounding environment and context,
- building form, materiality, spatial quality, openings, tectonics, junctions, interfaces and connections,
- construction methodology(ies), components and systems, services integration and delivery, structural systems,
- dimensions, spatial planning,
- cost,
- performance (thermal, acoustic, fire),
- environmental considerations (waste, energy consumption – embodied and in-use, renewable energy, water conservation / collection, biodiversity and habitat, materials sourcing, reuse / recycling).
Figure 65  Example of a generic building type study demonstrating the geometric and spatial parameters that are classified for each. (Image courtesy of Grimshaw)

Due to the type of data input and output from this scale of design, this phase was more closely linked into the excel file as a means of both controlling and recording information. The results of this level of massing information were much more sensitive so the output required a means of directly changing yields to meet lettable goals and other key aspects of the development brief.
Through a set of pre-defined type constraints, such as the examples demonstrated in Figure 65, the model could either report back or be controlled by building mass to open space ratios for the site, heights, building separations, light access, plant and core requirements, circulation as well as unit numbers, sizes and/or Net Lettable Area. It is the intent to avoid any building specific architectural design response and make the output imagery clearly typological and demonstrative.

Because this scale deals with issues that have direct aesthetic and architectural implications of a building, the generative outputs of this design process have to be carefully considered. Each of the key points listed above can be tested in discrete explorations through this design method but the level to which these are combined has to be considered in terms of the individual designer and the intended architectural integrity.

5.3. Three Phase Design Method

This section describes the design methods that have been developed in order to produce design analysis and response for each level of scalar resolution. These methods have been developed in three distinct phases in order to individually address different stages of the design process while optimising both designer and computer input. This also adheres to the problem centric design system as well as the addressing the rules for parametric urbanism outlined previously.

The first phase design methods are a means of compiling and analysing relevant contextual data for a given site. This phase has a particular focus on the type and format of the data as it is collected from different sources and
analysed. This addresses the previously identified rule for avoiding data loss or misinterpretation with a view towards continued workflow through subsequent design stages. This phase deals only with the analysis of existing information and not additions or manipulation that would classify as design decisions. Any design decisions are classed as Phase 2 but can be fed back through Phase 1 for testing and validation. The second phase design methods use the first phase analysis results along with a precompiled data base of parametric controls to inform and develop design strategies. The focus is on informing and capturing design intent through a digital diagramming process and then generating a set of 3D massing diagrams for further testing and validation. The third phase of design is concerned with post-generation analysis of the model. This phase is designed to critique the physical attributes and performance of the design diagrams generated in phase 2. This phase includes processes such as fluid dynamic simulation or radiance analysis that can further validate or disprove phase 2 decisions.
This series of analysis and generation methods can be applied within any scale of design resolution as a means to solve discrete problems. Figure 66 is a detailed description of the design method boxes represented in Figure 60.

Each of the following three phases are briefly described here in general terms in order to highlight the key relationships and workflows intended. One of the key considerations throughout these phases is in a consistent data stream from input to output. This aims to eliminate dead end data that cannot be reused in other processes without significant conversion and the potential for data misinterpretation or loss.
5.3.1. First Phase Design Methods

The first phase involves the compilation of existing site information and the process of analysing and responding to this data through a set of design responses. The following process has been developed as a means to offer a designer the flexibility to combine large data sets and target relevant subsections that can inform the specific aims of a design task. The key elements of this method are

- The compilation and targeted critique of data sets that inform a designer of the existing conditions,
- the compilation of a parametric ‘kit of parts’ comprising pre and/or custom built scripts that perform a discrete analysis task,
- discrete analysis of the existing conditions through both analogue and digital methods to identify strengths, weaknesses and generally inform the ‘state of play’,
- the formation of analytical diagrams that explicitly demonstrates existing conditions and analyses results.

This process provides a more informed means of developing conceptual design strategies in a format that can later be tested and critiqued through other digital systems.
Figure 67  Overview diagram of the first phase design method

Figure 67 outlines the process of data refinement and targeted analysis that will inform the design diagramming stage of phase 2. Both the targeted data collection and the analysis response stages of this process have a particular focus on custom parametric tools.

Raw Data

The main objective of this initial stage is to collate all relevant project information from different data sources and mediums. Through the development of new recording software and sensor hardware, design teams now have the ability to collect or access huge amounts of data for specific tasks and fields of interest (Bourke 2006). The resulting databases can record prevailing environmental conditions as well as track the movement of people, measure consumption of resources and pollution. These and other relevant contextual influences can be recorded over multiple timescales to accurately map out information in a number of different formats. The sheer quantity of
some of these data sets has accentuated the need for new means of mining and utilising relevant information for architectural application.

Each collection method and system can have its own specialised output language making it a difficult task to compare results in their native formats. Management systems such as Geographical Information Systems (GIS) are gaining prevalence in urban design as a means of compiling a large quantity and variety of information (Gröger 2007). GIS offers a high level of data control for existing conditions that can be more easily visualised and accessed. Depending on the quality of the database, GIS can reduce search times for information and provide a singular platform for exporting pre-structured information.

**Targeted Data Collection**

Certain design actions require key conditions to inform the opportunities and limitations. The design objectives are, therefore, a crucial part of narrowing the data set. As the data is refined into key sets, it is converted into a consistent format that will become the standard working format for the project. The method of data refinement is, once again, conditional on the complexity or quantity of data at hand. Automated methods such as data mining can be utilised to search and refine large quantities of information. In the majority of cases it was found that the data formats already defined layers and groups that could be captured and converted, thus facilitating the first stage refinement. Further computational searches and refinement were generally incorporated into the parametric analysis tools in order to gather the specific input information required to perform a given operation.
Context Analysis

From the larger set of relevant data this stage is about deciding which parts need further critique. In order to prepare for the analysis response, further refinement or additions may be required. This is generally a simple process of adjusting object states such as layer or colour assignments to ensure that the information is both explicitly displayed for manual analysis and implicitly for the sake of script recognition. Although the layer assignments are not directly visible, it is still visually important to be able to switch certain groups on or off to gain a better comparison between data types.

Analysis Response

The analysis response stage is based around the analytical critique of existing conditions through both manual and computational means. Manual analysis refers to observational analysis and response, while the computational process relies on a set of parametric tools tailor made to make the data more explicitly accessible. These tools can either be part of a pre-compiled set, developed from previous experience, or custom built for the task at hand. A critical aspect of this technique stems from the awareness of complexity in both the problem itself and subsequently the method used to solve it. This relates to the problem centric methods previously discussed and aims to keep the parametric tool as an aid or collaborator to solving problems rather that becoming an additional one in itself.

From the input data, the analysis response stage provides data conversion to help make the data more easily understood and communicable. This explicit output is for the benefit of the designer(s) as well as for third party
communication such as clients, consultants and stakeholders. The output from this process also has to be in a format that can be seamlessly folded back into future design processes. This phase culminates in the formation and compilation of Analytical Diagrams. This process has to be closely aligned with the diagramming language as the Analytical Diagrams form the basis of Phase 2 Design operations.

5.3.2. Second Phase Design Methods

The second phase is targeted at developing design concepts through a process of sketching and computational generation to form a series of 2D and 3D diagrams. Unlike the first phase, this phase focuses on facilitating active design contributions to a scheme. This is predominantly about creating workflows that provide a good interface between designer and computer. This phase has been developed as a means to achieve greater efficiencies in the design process based around proven precedent data that helps strengthen and validate different options. The key elements of this method are;

- Defining discrete problems that have a finite scope in the method for solving. This derives its scope from the discrete purpose of the intended solution (or output).
- Diagramming design concepts in a format that is explicitly communicable to both third party collaborators as well as to computational systems.
- The development of a set of analytical control parameters that draw their variable inputs from both qualitative and quantitative aspects of selected precedent studies.
- Developing a set of parametric generation tools that combine both the design concept diagrams and the analytical control parameters to generate a 2D or 3D design diagram.
Figure 68 demonstrates the proposed method along with the key workflows and relationships. This highlights the three separate stages that are required to inform the parametric tools through a process aligned with the problem centric philosophies.

**Design Problems**

The first step in this method combines the previously collated first phase information with the prevailing design aims in order to define the problem space. This is basic strategic planning for the project and, as in the first phase data refinement stages, looks to highlight certain tasks that need specific development and testing. In light of the analysis results the design aims may require editing, additions as well as further resolution in certain areas of the proposal.

Once the problem space has been defined, the problem type needs to be determined. This process requires an understanding of the intended design outcome for the scheme. Is it going to be highly differentiated or will it be comprised of determinable patterns? These two classifications are the extreme ends of the possible realm so each design problem will have to be assessed assuming a sliding scale between the two. If the solution is highly differentiated, it may require more traditional and analogue working methods to reach the intended output. If the output can be summarised in determinable patterns, it is likely to be a straightforward process in programming and generating results computationally. This sliding scale is dependent on an individual's design requirements as well as their particular
technical expertise. This means that certain users will have a higher capability in approaching the scripting of differentiated outcomes than others.

Figure 68 demonstrates the intersection between the definition of a problem type and the parametric toolbox where certain parametric tools can be used to address the diagramming process before the final model generation stage. Throughout the practice based studies it was found that the majority of parametric work could be completed in the final model generation after manually sketching in Adobe Illustrator. Most of the automated functions used here were standard Boolean and geometric manipulations that helped with drawing efficiencies. In this manner, individual diagrams could be quickly drawn to a high level of sophistication and then compiled before the final parametric generation was formed. Despite this, the method still acknowledges that more sophisticated and specialised sketching scripts could be applied to further streamline the process. This is allowed for in the theoretical model but is recognised in the scope of this thesis as future research.

**Design Diagramming**

The diagramming process, whether manual or automated, needs to culminate in a standardised format that adheres to the previously defined diagramming language format. Figure 68 demonstrates the ability to use different mediums in creating and resolving ideas to a point they are ready to form the input template for model generation. There is the benefit of efficiency in completing the majority of work in a digital format but this can equally be built as physical models or drawn on paper. As conclusions are reached, however, all ideas
have to be captured in a standard digital format within the construct of the diagramming language.

The diagramming language itself needs to address the rules outlined earlier, including the basic symbology that makes up a substitution system or representational graphics. It also requires a system for classifying explicit data such as colour or line weights. The explicit data also has implications on the parametric scripts in the way they recognise the associated implicit data for conditional computational processing.

**Empirical Data Generation**

Generating control parameters for the model generation stage is reliant on a comprehensive analysis of precedent studies. This initial benchmarking process aims to create a database of relevant projects that comprises both quantitative data and qualitative indicators. The quantitative data gives an empirical foundation to any new variables that are plugged into the parametric generation tools. This avoids a large quantity of trial and error by giving the new design proposal proven data ranges that are attached to performative outcomes. The qualitative indicators record individual perspective on the quality of a given development. This helps to record an individual designer’s judgement of the relative quality of a given precedent study and helps to validate the use of the quantitative data when compiling a new set of control parameters.

The final stage of the empirical data generation is formulated through a comparison of the design aims and the precedent study database in order to construct a relevant set of analytical control parameters. These input
parameters will drive the model generation tools and as such only need to address each discrete problem as opposed to a definitive parameter set for the entire project.

**Parametric Model Generation**

The parametric generation stage of the process can vary greatly in its requirements for addressing a given problem. A common thread is in the aim of taking a diagrammatic concept sketch and generating a format that can be both communicated and critiqued. The parametric tools are written around the diagramming language format and have a direct link to the control parameters that inform the model's generation. The step between diagram sketch and parametric generation is a critical one in capturing both the implicit and explicit data from the sketch into a model. Through the generation phase, the data is expanded upon or changed to a more widely accessible and communicable graphic. To achieve the rules for parametric urbanism described earlier, the original sketch diagram should still be explicitly communicable at any point. However, depending on its place in the process the diagram can still be a more aggregate version of designer's shorthand for efficiencies sake.

Although this is intended to be a custom process defined and built by the designer, there still needs to be an acknowledgement of two types of external program links. The first is an embedded relationship, which keeps the data format constant through a live link to an external program. The link between Grasshopper and Ecotect through live linking script of Geco is an example of this relationship (Food4Rhino (c)). Grasshopper provides a standardised
parametric modelling platform and uses Geco to link to Ecotect and take advantage of its advanced analysis capabilities. Alternatively this can involve the complete export of data into another program, which breaks the live continuity of the modelling process. This is an important distinction to make in the generation of models. External programs are used for complex logic that can’t or don’t need designing into an internal parametric toolbox to create a fine line between this step in phase 2 and the need for phase 3. For the purposes of this description, it is assumed that all format changes into external programs be considered phase 3. In an ideal case, the third phase is not required at all and that all aspects of a problem can be addressed seamlessly in the second phase model generation loop.

For this reason, both the first type of embedded design analysis as well as the purely internal analysis scripts in the parametric toolbox, are still classified as part of the phase 2 method. This distinction is made due to the tight feedback loop between generation, analysis and response during the model’s generation and refinement. This makes a definitive distinction between the types of parametric logic difficult. For example, if a radiance analysis tool is built with a view to informing the density of a development it can be scripted as an element of the generation model that limits the design in the first instance. In this case the tool is part of the generative logic and not a separate phase that is implemented after generation occurs.

**Model Attributes**

The final stage in the phase 2 design method is in the recording and communication of the generated results. A large part of these results are
visual and as such are saved directly into the master model as layers of
colours and geometric arrangements that demonstrate different aspects of
the strategic planning concept. Alongside this information is a large quantity
of numerical data that is considered an inexact data output. This means that
although a set of input parameters are derived from precedent studies with a
targeted result in mind, the generation is still discretely focused on a narrow
field of interrogation.

This leaves a large quantity of physical data as unknown until post generation.
For example, a particular model may combine a series of 2D figure ground
diagrams with a set of height restrictions and floor to floor ranges. The input
data can target these heights but the final GFA falls into the category of
inexact data. This type of questioning was found to be a common and critical
aspect of parametric optioneering. What is the output of decision A, B and C
and which is most aligned with the design aims?

This data is of particular interest to the client and stakeholders involved with a
project. As such, it requires a means of succinct and flexible communication
that can deal with multiple iterations with a minimum of manual editing. This
is generally handled in an external program that has better numeric, tabling
and graphical functionality than the native CAD format of the master model.
Live linking through scripts allows for any data to be automatically tabulated
for one or multiple design options.

5.3.3. Third Phase Design Methods

The third phase method is the least prescriptive of the described techniques
due to its varying dependence on external programs as well as a multitude of
possible performative outcomes from the second phase model generation. Phase 3 is considered optional in the overall design model and heavily dependent on the sophistication of the first two phases. Ideally any post generation analysis would be conducted in a controlled and continuous fashion as part of phase 1 and 2. As discussed in the previous chapter, it is also recognised that in practice there is a large grey area between whether a certain step in the process falls under the purview of the generation phase or one of the analysis phases. This is particularly true when considering multiple feedback loops between phases.

The third phase of development is still necessary for classifying post generation analysis that utilises established specialist software. This phase can also include processes that will become considered part of phase 1 or 2 but are still in development and produce undesirable output data. This undesirable data includes any output that cannot be used in the continued computational workflow. This can either be data that can only be manually interpreted by the human participants and/or data formats that require extensive translation to convert back into the design standard.

The key points of this phase include

- Defining the problem space in regards to which aspects of the model require testing,
- Defining the desired output and selecting the correct program that corresponds to these needs,
- The conversion of data to comply with any external program requirements.
Figure 69  **Overview diagram of the third phase design method**

Figure 69 demonstrates two main processes that determine the program selection and the data conversion as a means to producing the desired analysis result. As a model is generated, the first two actions in the third phase are to readdress the design aims in light of the second phase results and to define any new problems that require testing. The type of analysis tested in this phase is generally related to physical and performative aspects of the design.

The first stage of this method requires an understanding of the desired output in order to properly define the problem space. This process requires the designer to develop a list of gaps in the phase two design scheme and a strategy for how these can be analysed. This is a relatively straightforward process that will help to determine the exact program that can facilitate the required analysis.

The second part to this process is the conversion of existing data into a readable format for the chosen analysis program. This process can also include the addition of any new data that the program may require in order to
perform an analysis operation. Once an analysis operation is complete and the
design is reanalysed, the decision can be made as to whether all elements are
successful and can be recorded into the master model. Depending on the
requirements of the design exercise, the master model is then used as the
basis for the next resolution of testing and development. If the design does
not meet the analysis criteria it is then passed back through the development
loop to either phase one and/or two at the same scale of design resolution.

5.4. Summary

This chapter describes one potential methodological approach to a problem
centric urban design process. Both the scaled approach and the three-phase
design method have been described in order to highlight some of the key
issues that can arise during design and the different aspects of design process.
This method utilises both the problem centric methodology as well as
adhering to the four rules for computational urban design outlined at the start
of this chapter.

In a considered and holistic approach, each scale impacts each other scale,
usually in a linear chain of successive influence and reflection, bi-directionally,
not just downward. Tools used at each of these scales need to be fit for
purpose, and allow a cross exchange of thinking. A separate consideration is
that the design of such tools should not just consider the task itself, they need
to consider those who may undertake the task, and the context in which the
task is undertaken.

It is important to note that in this process there are a number of different
types of problem, and subsequently, problem solving methods required at
each level of scale. In general terms, the high level regional and community scales benefit from processing complexity in the context information as well as sorting and ordering this information through computational analysis and database functions. This is heavily reliant on data mining or organizational systems as well as exploration tools that rely on simple controls for increasing working efficiency.

The lower levels of block and building benefit more from the variable nature of parametric definitions to optioneer and test various physical iterations of a design study. This process depends on a good understanding of typology in order to generate the parameter definitions and drive a successful generative modelling process. The diagramming language and means of communicating ideas, designs and data are one again key to the success of this process.

These concluding points outline the key differences between the proposed method and the examples noted in the literature review chapters that take a single level of scale for problem solving and attempt to embed all considered and potential levels of complexity into the computational model. The inherent dichotomy in scale means that only working from a single level places too much trust in the associated levels of scalar assumptions. Despite these sentiments, any level of computational generation, no matter how carefully controlled, requires some level of assumption to be made between the parameter base and the variable sets that control the outputs. This is true in any system where something has to be communicated to the computer, which in turn is entrusted to make some form of contribution. This is a basic requirement of receiving a result from a computer. The above technique aims
to minimize this and treats any computationally generated results as a placeholder solution that will be tested and validated as the design progresses. This is truer to the more traditional understanding of an urban design methodology while still taking advantage of computational processing. The proposed method constructs a specific workflow that reconciles strengths and weaknesses of both the traditional and computational approaches.
6. Discussion and Conclusions

The thesis presents a method for applying a problem centric parametric urbanism within architectural design practice. This method addresses some of the issues identified in current computational and urban design working practices, focusing on the way in which designers interact with and utilise digital systems for problem solving. The aim of this chapter is to discuss and draw conclusions from the main findings of this research in order to identify the contributions and limitations of the work.

The following chapter is presented in four sections. Firstly, the pure research aspects of the thesis (chapters 2 and 3) are discussed in relation to their argument for different approaches to computational problem solving and Parametric Urbanism. This is concluded with a discussion about the main outcomes of the case study development (chapter 4) and how this can be consolidated into a design method (chapter 5). Secondly, the research contribution is presented in relation to both the research field and architectural practice. Thirdly, the limitations of the research are discussed in order to conclude the recommended areas for future research. Finally, the thesis concludes with an overview and closing statements.

6.1. Findings and Discussion

6.1.1. Design and Systems Thinking

One of the main arguments framed throughout the literature review was based around the assertion that our current state of computer dependence has negatively affected the way in which we approach problems through
computational systems. This has subsequently influenced the methods by which we as architects design.

Digital program dependence has prevented the necessary critique of outdated working methodologies despite the rapidly evolving toolset at our disposal. As such, new generative design systems have been spread into discrete aspects of architectural design without complete clarification of their particular features (Alvarado and Munoz 2012). This has led to redundant technical capacity being simplified out of CAD systems in architectural practice. As a result, an increasing void between these practice standards and emerging specialist digital design research has appeared. Parametric modelling systems have been placed at the centre of this argument due to their inherent potential for addressing variable parameters that are empirical in nature and deterministic in application. This is a deliberate selection to help combat some of the uncontrolled aspects of other computational and generative modelling techniques.

This form of computational system is becoming more powerful. In recognising this, we need to be aware of its, currently latent, potential as an active working medium. Along with this recognition is also a caution in the use of active digital tools. As programs become more sophisticated it is easy for us to become complacent, passive users. Sophistication in programs is only going to reach its full potential as a design tool if the designers are armed with an understanding of computational design systems and methods.

Design thinking, however, is a difficult area to approach under our current understanding of proper design research. As Glanville (2010) describes, design
(research) has developed an expectation that it has to be scientific. This is not necessarily correct or helpful. He further states that science is a specifically restricted form of design. In order to deal with this some research has begun to look to other fields for the mechanisms required to frame proper conversations about design as an activity. This specifically refers to disciplines such as cybernetics and system theory. Designers are always part of the design. This is an irony in the generally accepted design research process of simplifying problems to be scientifically tested in order to reach a quantifiable result. This is where areas, particularly second order cybernetics helps to describe the circular process with a designer as a critical party involved in the design.

In terms of computing this is helpful in recognising computers as another active participant in the process of design. As described by Woodbury (2010), the systems can now be considered active in their ability to contribute to the design process. This does not mean that they are equal or interchangeable. Designers draw on experience and judgement to make qualitative decisions that are not necessarily (or necessarily should be in a lot of cases) defendable, quantifiable or ‘right’. Computers can process faster than humans but do not have the foundation of forethought or experience to draw upon. This is where the designer needs to quantify aspects of the design process in order to utilise the computational processes positively towards their own design ends rather than blindly. This does not rule out random exploration where a designer makes judgement calls on unexpected results. This is equally not about creating a single scientific process that governs how we design with computers. This is best summarised by Hiller (2007) with the term ‘analytic-
normative complexes’ in which the normative is constructed on the basis of
the analytic. It’s a fine line to walk, but this is where the relationships between
processes and an understanding of the circular causality in actions helps to
clarify the key relationships in a problem while leaving individual design of a
process or system up to the designer.

In parallel to this argument for stronger understanding of design thinking, it is
recognised that there has been a gradual shift in the way we use and interact
with computer systems in the process of problem solving. This shift is credited
largely to the advancement of technology that has empowered them as active
systems while the human counterparts become increasingly passive. This is
due, in part, to the lack of strength behind integrated human computer
working methods. The working methods have not been developed to the
same level of sophistication as the systems could potentially facilitate. In
terms of this body of research, this point leads us to the conclusion that we
need to gain a better understanding of the specific requirements of
parametric modelling in urban design. It is also determined here that one
method of developing this understanding is through the lens of more
established systems of cognitive theory and communication such as systems
theory.

6.1.2. Parametric Systems Thinking at an Urban Scale

Chapter 3 refines the previous discussion on digital design thinking and
system theory to focus on how these relate to parametric urbanism. Within
the context of the previous chapter’s conclusions, this discussion aims to
address the primary research question.
What are the key areas of weakness in the current working and computational systems that need to be addressed in order to form new ways of applying parametric urbanism in practice?

Section 3.2 (pg 42) looks at the current state of play in the research and application of parametric urbanism. This is explored within the scope of the research question as a means of identifying the main points of contention and debate surrounding parametric urbanism within the academic and professional community. The first aspect of this argument questions the validity of computational techniques in forming meaningful urban design solutions. It is argued that there is an "image of complexity" rather than any sound analytical basis for parametric urbanism. Bill Hiller notes, “it has been too easy to use [computer systems] to generate designs, but they are too weak in predicting what these designs will be like when built." (Hiller 2007:41)

These criticisms are important to the discussions of Analytically and Normatively driven design modes and also links into the following debate surrounding parametric design (parametricism) as a new design style. Each of these categories is fundamentally about design drivers and whether they are well defined with clear targets or complex and ill defined with several indeterminate but workable solutions. Each of these problem types links back to the earlier classification and discussion of conceptual and constructive design theory.

This point helps to reiterate the important role parametric logic can play in bringing an analytical parameter based platform to support urban models driven by analytic normative complexes. It also highlights the first topic for further research in forming a better analytical base through a sound
understanding of the analytics of design, generally summarised as types and typologies.

Critique has also been directed at methods of parametric design that attempt to capture both normative and analytical intelligence in a single ‘black box’ generational tool. These tools inevitably lead to over-aggregate design process and solutions that rely on pre-scripted assumptions to be made by the generative system. This is once again symptomatic of the normative/analytic debate but more specifically determined as a lack of understanding when it comes to computational and design scale. This argument forms the basis for the second area of research into methods for the scalar defragmentation of design problems in order to mitigate the design assumptions made by the generative system alone.

The second part to this discussion (chapter 3.2.2, pg 49), explores the highly controversial claims that parametric urbanism is a new design ‘Style’. The chapter acknowledges that as a system, parametric modelling does lend itself well to advanced and organic form-making exploration, which in turn, has a stylistic consistency in its outcome. Despite these stylistic consistencies, it is argued that a design style requires more than just recognition of formal qualities produced by a constant medium. In addition to this, other critics raise concerns over the way in which parametric modelling is being employed as a form-making tool to dictate the geometry of urban environments. This provokes parallels to the egotistical design programs of modernism and questions of whether parametric generation of design artefacts is in any way desirable to the end user. The third area of concern is identified from these
arguments surrounding the type of model that is produced as a digital artefact and how this is both applied and communicated. This argument is essentially based around a scepticism of current parametric output modes and whether we sufficiently control the end product through due consideration of the input data. This concern is with the type of data being used as well as the interface language that controls it. This flags the fourth area for further research, which is concerned with the diagramming language we use to communicate ideas.

6.1.3. Outcomes of the Design Studies

The following chapter discusses the outcomes from the practice based development and application of the problem centric method for parametric urbanism. This is described in two sections that summarise the individual benefits and downfalls of the problem centric systems design process and the method of parametric urbanism. This description of outcomes is based on observations from its use and feedback from the design team as this system was applied to design projects under practice constraints.

Observations from the Problem Centric Approach

The problem centric method for parametric urbanism aims to counter the technically led design process at a systems design level. This suggests that design systems should be less prescriptive in themselves but designed with an understanding of the design context, tasks or problems. This approach can be used to then combine the strengths of both human and computer counterparts to deliver the optimal digitally base workflow to produce a solution. The proposed model requires the domain user to handle the
qualitative and subjective judgements while the computational system is used for quantitative generation.

This development and application of this form systems design theory was a result of two things that can be largely credited to the existing operating practices of Grimshaw. Firstly, the practice is highly focused on emergent technologies, understanding the full design potential and dedicating resources towards becoming proficient in these areas. Secondly, the practice philosophies on design process were naturally aligned to a problem centric way of thinking. Understanding a design from its first principles, strong diagramming as well as clarity in architectural expression and project delivery was naturally synergetic with the theories and aims behind this research. Bob Ivy, former editor of the ‘Architectural Record’, further validates this with the term ‘Embedded Intelligence’ which he coined to describe Grimshaw's approach to design. This means that in every beautiful detail or aspect of a design, there is a clearly understood problem and a well-executed solution. This, in part, helped shape the research program and the way in which the method has been structured. As a result, the problem centric approach ensures that the problem is understood, requirements are determined and the method is devised between human/computer capabilities. First and foremost, this is about understanding what those capabilities are. These are generally understood and described in chapters 2 and 3 but will have a different weighting depending on a person, team or practice’s individual capabilities. In this, the problem centric approach is a systems design version of the embedded intelligence design philosophy.
The problem centric method for systems design is an ideal aim that saw different levels of success and failure in practical application. It was discovered through the practice studies that despite a promising trend of new, parametrically savvy graduates coming into practice environments, that the problem centric systems interface model is largely unattainable. The majority of practitioners are still not at a level of expertise to assume a direct and dynamic interface with their digital working environment. It was, however, concluded during the design studies that design teams could attain a level of problem centric systems design as long as one member was accomplished in parametric programming. This removed the pressure for members to develop their own working system and allowed for a more balanced approach to problem focused system design. Although this places the responsibility for systems interface on the minority, the key benefit was in the shared design thinking about how a problem could be solved and the best way to structure the working environments to facilitate the desired outcome. The result was that no system or workflow was designed in a bubble with the blinkered view of technical problems overshadowing the design outcomes. Although not fully attaining the ideal of problem centric design, the team scenario worked to the advantage of the systems design as the team kept the programmer on task with a higher-level, holistic view of the prevailing design aims. This group model still relies on the rest of the team to readjust their thinking towards the new potential that parametric logic and generation offers. Problem centric digital design thinking was, therefore, successfully implemented through this embedded research program.
Outcomes of the Design Method

Within this context of systems design, there were four aspects of operating parametric programs at an urban scale that came into question. It was concluded that a greater focus is required on the parameters involved with parametric modelling and the subsequent means of communication. This returns to the typology discussion and the aspiration to implement analytically derived design logics. The conclusions to come out of this were that every design practice has an understanding of parameters, be it formally recorded or intuitively understood. Every aspect of design is based on parameters affected by any number of locally specific variables that lead to the realisation of a final artefact. The ideal is to recognise them as such and determine how they can be quantified for digital applications. Through the design studies, it was demonstrated that defining parameters as prime relationships in diagrams is highly intuitive for architects and designers. This formed the basis of the representation and communication systems described in this research. This was not intended as a means of promoting existing working methods and adapting digital systems to suit. To be true to the problem centric model, the research took the core of intuitive representation as it currently exists in practice and adapted the process of drawing as an interface with digital systems. This still required a shift in thinking and a change in working methods, but it was less intrusive than transplanting an entirely new system with unfamiliar workflow requirements.

Through this embedded research program it was determined that an operating design practice can produce long term benefits from the short term investment in adjusting their working practices to encompass new forms of
digital design thinking. As discussed in chapter 4, some tools were more successful than others. A number of points in the development, application and outcomes of the tools determined this success. Firstly, the simplicity and usability of the tools inputs and the benefits any results had to the design decision making process. The term ‘simplicity’ is used in reference to the usability and accessibility of a tool and method, not the sophistication and complexity of the problem or the outcomes from its use. Simplicity was critical under the time constraints of ‘in project’ development where results were needed quickly to inform design decisions. It is an easy trap to fall into assuming that a complex system is required to solve a complex problem. This research demonstrated the opposite to be true. The most effective tools were those developed around an explicit understanding of design objectives and the defragmentation of the steps required to develop and validate a design response to those aims.

For the second measurement of success, accessibility of the tool was important in the communication of parametric design capabilities. Although not directly a part of the design or systems development process, it was critical to have an established means of communicating new design capabilities to the wider design practice as new tools and methods were produced. No method or tool that was developed could be fully utilised unless design teams understood its aims and potential outcomes. This was achieved through email news releases, wiki style blog entries and practice presentations that allowed the potential of a process to be understood and integrated into other projects. This is described in greater detail in chapter 6.2.2 (pg 224).
The final measure of success was in the adaptability of the tools to be applied to problems of a similar nature. It was rare to find the same problem with the exact parameter requirements recurring on multiple projects. It was, therefore, more successful to have flexible tools that could be easily adapted to new project requirements. It was important to allow as many team members throughout the practice to make these adjustments without relying solely on the original creator of the tool.

**Outcomes from Applying the Four Rules for Parametric Urbanism**

*Diagramming*

The core focus of the diagramming language was to create more accessible and intuitive methods of capturing design ideas in a digital format. This requirement led the method to utilise well-established techniques of diagramming in Illustrator. There was already a knowledge base for digitally drawing lines and shapes that the parametric system could build upon. The system also took advantage of existing working practices that contained both implicit and explicit data classifications of objects that the parametric script could utilise. Additionally, this meant that diagrams that had not been intended for parametric use could be used as the base input for parametric optioneering. With only minor alterations to the parametric script, a wide range of projects gained easy accesses to generative optioneering without any specialised scripting knowledge themselves.

The use of .dwg file format was relatively stable in operating between programs. Despite the flexibility offered by this standard drawing format, DWG was not the native format of Illustrator, Grasshopper or Rhino making
some degree of misalignment or data loss inevitable. The level of accuracy required by the case study testing in this embedded research exercise, meant that this minor data loss was not an issue. The biggest impact the file conversion had on the design process was occasionally redrawing geometry that had become unreadable or buggy. Across a range of different types and scales of project, data loss was the exception rather than the rule.

**Scale**

One of the main benefits of this design method to the practice based projects was in the flexibility afforded by scalar defragmentation. The process did not have to be applied in a linear, top down approach with each new phase dependent on the results of the last. The defragmentation of both scale and problem tasks was key to this success. Additionally, the process didn’t limit the act of urban design to just ‘Masterplanning’ at the higher levels of scale. Assumptions at finer scales could be jumped ahead in testing to validate aggregate assumptions before they were integrated into the high-level design plan. One of the issues in this process, and one discussed in Recommendations for Future Research (Chapter 6.4: pg 228), is the continuity of data. This affects all phases of the design system and needs to be robust enough to minimise data loss, assumption and the ability to reintegrate working or output data into other aspects of the design process at any time. This is particularly exposed when working across a broad range of scales, particularly in how aggregate diagrams communicate or translate into finer grain block or building testing models.

During the practice testing it was acknowledged that diagramming, by its definition, is reductive. This is inescapable and only compounded at the urban
scale. The scalar defragmentation approach helped, but as a further measure of mitigating over-assumption through aggregation (or disaggregation) design engagement with specialists and stakeholders was critical to the process.

The method outlined in this thesis tackled the issue of aggregate diagramming through simplifying the diagramming language and sketch process in Illustrator. This was countered with sophisticated input parameters and robust, deterministic parametric generation. Although this system was largely successful, the simplicity in diagramming was a double-edged sword. The drawing system was simplified to be widely accessible while still placing the highly differentiated tasks in the hands of the designer and not the computer. The counter argument to this process was that it did not yet utilise the parametric generation to its full potential. The sophistication in this system was in the analytical database and parameter formation as opposed to the scripting that controlled form generation. This was a deliberate line to walk for the development of a governing method.

**Type**

Unlike some urban design systems, this technique does not need an extensive list of generic, prescriptive and universally applicable types and typologies. The benefit of using precedent data means that a given design problem can be analysed to determine the scope requiring testing. This informs the scope of data required to construct a recombination of types and type sets. The flexibility in this method worked particularly well in practice testing. Databases of explicit data meant that there was less pre-learned specialty knowledge required to use the system. The system was also more closely aligned with more familiar and traditional methods of informing design
through precedent studies. This was particularly true for the qualitative indicators, which gave the designers a better understanding of the quantitative data and the potential outcomes from its use.

It does have to be recognised that the definition between quantitative data and the qualitative indicators is ambiguous. It is relative to the research that has been conducted in that, on the surface, quality can be subjective. With further research into a given topic, subjective aspects can be rationalised thus rendering them quantitative.

Another important point in this process was divorcing the precedent data and typological data from the generative system. Foremost, this allowed the generative system to be relatively open to accommodate a broader scope of variable input within relatively simple parameters. The result of this was a minimised construct of preconceived assumptions in the input logic, allowing the more intuitive precedent database to govern the analytical rationale behind the generative system. This method responds to the argument raised in chapter 3.2.1 (pg 44) that describes the level of critique directed at methods of parametric design that attempt to prescribe analytical embedded intelligence into the generational tool.

Model
The model was, in a way, the hardest to define due to the ambiguity in its value as a communication tool. This factor of ‘value’ is largely dependent on how a model is perceived and understood by a third party. Functionally, the model(s) remained subject to the intentions outlined in this thesis that dictate that a model remains a passive recording of diagrams and different
defragmented facets of a design’s intent. The difficulty exists in the divide between the intention of the author and perception of the viewer. This is fuelled by the contemporary culture of communicating aesthetic through 3D renders. It is a danger that any 3D representation will be misconstrued as an aesthetic description of architectural artefacts. There is no definitive solution to the issue of external perception but one that was managed carefully throughout this research to maintain the appropriate representational language in the graphic of the diagram.

This issue of graphic perception also resulted in one of the main rules for models in this research becoming unattainable. The ideal for maintaining graphic continuity from working diagram to model to internal and external communication was diminished slightly with the need to rework graphics between working and communicating. Despite not fully realising the model as a communication medium, it was still a step closer than the traditional methods that were previously used in practice. As a result, efficiencies in the system were still achieved by reducing the amount of postproduction work between the working model and presentation.

The other key aim for this area was in the continuity of data with a particular focus on synchronous data formats and the ability to fold any part of the model back into the working process. As such, this was subject to the same issues of minimal data loss or redrawing described in the diagramming summary (pg 226).
6.2. Research Contribution

The following chapter will outline the outcomes and contributions to both practice working methods and the field of research.

6.2.1. Contributions to the Field of Design Thinking

The main contribution of this research is in the field of design thinking. Mark Burry describes this field as one of the least defined in terms of contemporary digital design practices. In support of this, chapter 2 describes that strategies for computational design thinking are still not understood in their ability to aid in the augmentation of designers’ abilities and encourage computational structures that support design exploration.

Chapter 3.1 (pg 40) notes that to date, the field of digital urban research has been sporadic and disparate in its aims and methods. Consolidated theoretical methodologies are identified throughout this thesis as one of the main areas currently missing from the field of advanced computational design and more specifically, the emerging field of parametric urbanism.

The lack of definition within the field of digital design thinking is the main driver behind this body of research. It needs to be recognised that this is not a traditional scientific research structure but rather a program designed to explore parametric design thinking in practice. In this light, the primary contribution of this thesis is on the personal and collaborative level of a designer through the lens of design thinking and analytically derived approach to system theory.
6.2.2. Contributions to Architectural Practice Methods

Parametric design had a particular interest in Grimshaw given the natural synergies between the existing practice approach to first principle design and the formalisation of this process into explicit parameters. As a practice, Grimshaw had already made the decision to invest internal resources into improving the practice's capabilities in this area. The formation of the Design Technology Group (DTG) was in response to the growing awareness of the latent potential in the digital tools that the company was already beginning to use and awareness of emerging technology. This move was happening around the commencement of this embedded research. This was a large contributor to the acceptance of this PhD as a vessel to share the load and responsibility of research with Deakin University. This took the pressure off practice work and the associated fees to absorb the entire R&D portion of the exercise. The embedded research benefited from the guidance of a larger group of professionals while the DTG benefited from the PhD research underpinning the development of new areas of inquiry and development.

As part of the formation of the DTG, cluster leaders were identified in each of the offices who were responsible for consolidating and communicating the work of their teams. This was a good way to encourage a deeper understanding of the capabilities and strengths of different team members. It also allowed for greater efficiencies in choosing the right people for the right jobs. The arrangement helped to manage knowledge sharing across the global network, raising awareness about what has been done successfully and what new methods were currently in development. This communication network began as regular strategic planning meetings via video conferencing aimed at
planning further development for the DTG, individual R&D assignments as well as inter office sharing of resources on different live projects.

This led to the formation of a wiki style database of work that allowed members to write up descriptions and examples about certain computational tools, methods or strategies they had developed and implemented. Short descriptions made these readily accessible and easily categorised under a certain 'problem type'. The final stage of the communication network was to form a blog that provided a more casual and accessible format for discussions, shared brainstorming over problems as well as individual success stories. This method of communication was critical in the uptake of parametric tools in new projects.

6.3. Limitations of the Research

In addition to the initial scope and limitations outlined in chapter 1.5 (pg 12), the following areas have been identified throughout the process of applying this research framework.

6.3.1. Project Timelines

As previously mentioned, the projects did not allow for an extensive R&D aspect within their delivery timelines and their subsequent scope of fee. This meant that a large part of the development involved with this research was conducted outside of practice hours or within internally funded 'practice research' periods. The intention was that the need for a certain problem-solving tool would be identified within a project, developed in its own time and then reapplied and validated in another project of similar needs. In application this was not always the case. The case studies presented in the
thesis were selected because they were, unless otherwise noted, the most readily used and tested examples. There was a large portion of this research that was identified, developed but never had the right project or problem reappear during the embedded research period. This approach, therefore, demonstrates a limitation in the validation of all aspects of this research program. This has been mitigated in this thesis by only selecting the most thoroughly tested examples for presentation.

6.3.2. Judging the Success of Built Works

Although this research is based on project work within an active design practice, the scope of work has generally covered only the initial stages of design, anywhere up to planning stages and community consultation. Although this in itself is a validation of the design techniques and their general success in delivering design work, it is too compressed a time period to gauge the resulting built success of this research. To date, only one of the projects that utilised parametric design tools has completed documentation and gone to site. The remaining projects are either not progressing past feasibility stage or have yet to make it through to construction phase. Although this will happen in time and future research may be able to quantify the resulting success, or otherwise, this current body of work is limited only to the testing of planning phase design works. Although the projects involved with the embedded research are not built, they have covered all facets of scale, consultant and client body critique as well as varying levels of community consultation.
Although this is limiting to the validation of the design outcomes, this is periphery to the main focus of this thesis. The core contributions of design process and working methods have still been thoroughly tested across each of these and many other unreported projects. This work is pre site and can be judged independently to specific design decisions made within the general working methods.

6.3.3. Limited Exposure and Testing

Although this research was conducted within an international design firm, the exposure of this embedded research exercise was limited predominantly to Australian projects. Of these, the majority were in Melbourne. This limits the contextual validation of this research as a globally relevant means of urban design. The research draws knowledge from Grimshaw’s previous and current experience with international urban planning and design. This experience and consideration has come through the people involved with the DTG to directly affect the parametric tools, methods and outcomes as well as the project team leaders and members who controlled the project design vision and processes that governed the work. Although this added to the diversity of the contextual experience that fed into the formation of the working methods, the process was not tested directly within any international projects.

As mentioned in chapter 1.5 (pg 12), a further limitation in the scope of validation has been the process of conducting this research within only one architectural firm. This provided exposure to a diverse range of project typologies that helped to shape the theoretical design method presented here. However, the limitations to this approach were in the singular practice
philosophies that also helped to shape the outcomes of the research presented in this thesis. As such, the presented work is limited to a single philosophy of design, defined in chapter 5 as ‘All of a Piece’. This is a limitation of the testing field but not of the potential application of the proposed method. This has been designed as a flexible construct that prescribes systems, relationships and workflows that could be more widely applicable than the cases presented here.

6.4. Recommendations for Further Research

This thesis outlines a theoretical proposal with a focus on system design thinking towards parametric urbanism. The holistic approach of this research towards problem centric systems design as well as each of the four rules for parametric urbanism suggests a number of different avenues that require further and more focused research. As new trends and technologies emerge, the areas identified will evolve in their requirements. This is relevant for attaining a truly problem centric approach as well as refining the 4 rules for parametric urbanism. There are also much greater body(s) of research required in exploring synergies between digital design thinking and areas such as System Design and Cybernetics. In addition to the further development of technical elements within this research, a number of parallel areas were noted throughout as having direct relevance to this body of work.

Data mining for desirable information is a significant area of computational research that can benefit the parametric design tools. Each of the phase 1 analysis tools required some extent of searching, sorting and reorganising specific sets of data. The process described in this thesis involved the manual
sorting of data into a project specific format and database. This could benefit greatly from more automated data mining techniques and requires further research into potential methods for achieving this.

The third phase design tools described in this thesis have been flagged as requiring further research. As mentioned in chapter 5, this phase is the least prescriptive of the three as it is subject to external program requirements. Further research is required to explore a more seamless interface between certain external software and the phase 1 and 2 computational tools. This research would focus on transitional interface methods and systems such as Geco (Food4Rhino (c)) that allows Grasshopper geometry to be analysed through Ecotect in its natural format or Hummingbird (Food4Rhino (d)) that acts as an interface between Grasshopper and Revit. This process is aimed at minimising dead end processes that produce unreadable data and the potential for misinterpretation in the translation back to the design standard format.

Another area that will benefit from further research is the database of precedent information. Specifically, how the qualitative and quantities data is collected, tagged, cross-referenced and searched. With further research, this has the potential to become a much more sophisticated system driven by a tailored search engine capable of collecting data based on specific criteria which would allow a user to instantly compare comparable data across a range of projects. This system would be aimed towards a more focused and effective means of forming parameter sets from the widest range of relevant analytical data.
6.5. Closing Statements

Urban design is a highly complex, multifaceted and often very personal process. As designers, we are bombarded with opinions on what makes great spaces and the 'correct' ways to go about achieving them. Largely missing in this discussion are the relationships between normative and analytical design processes and the methods that are used to employ them. This thesis argues that we need consolidated work surrounding the governing methods we employ in digital design. In other words, digital design thinking. The discipline of Parametric Urbanism has suffered from disparate and ill-defined approaches to design thinking and an absence of any rationalised methodology underpinning its application in both research and practice.

In order to address some of the problems currently encountered in the practice of this discipline, we need to rethink the drivers behind the design process itself. It is argued throughout this thesis that architectural and urban design disciplines currently have their priorities backwards and that current applications of parametric urbanism have been led by a fascination with geometry and the technical mastery of computing. Although the pure expression of complex ‘parametric’ form has immense significance in its contribution to design exploration, it is still misused as a functionally hollow driving force behind digital design.

This can be a case of not being able to 'see the forest for the trees' in that the designer’s closest to the production of parametric work often lack the perspective to see beyond the immediate technically based problems at hand. In architectural terms this has translated to complex expressionism and
geometric primacy with a reduced awareness of the final functionality as a built architectural outcome. This argument reflects one of the negative outcomes of Hillers criticisms of the normative dominating the analytic (Hiller 2007). In order to realign this approach to take advantage of latent computational design benefits, this thesis has reassessed the use of parametric programs and demonstrated a case for how they can benefit a more rigorously defined method for a problem centric parametric urbanism.
7. Bibliography


Food4Rhino (a), Hoopsnake for Grasshopper, accessed 18/08/13, http://www.food4rhino.com/project/hoopsnake


Food4Rhino (c), Geco for Grasshopper, accessed 01/05/15, http://www.food4rhino.com/project/geco?ufh

Food4Rhino (d), Hummingbird for Grasshopper, accessed 01/05/15, http://www.food4rhino.com/project/hummingbird?ufh


Krippendorff, K 1989, ‘Shannon, Claude (1916-)’, Annenberg School for Communication Departmental Papers (ASC), University of Pennsylvania. This paper is posted at ScholarlyCommons. http://repository.upenn.edu/asc_papers/213


Neoarchaic, Bumblebee Microsoft excel interface application for Grasshopper, accessed 18/08/13, http://neoarchaic.net/2013/05/bumblebee/


Parolek, D, Parolek, K, Crawford, P 2008, 'Form-Based Codes: a guide for planners, urban designers, municipalities and developers', John Wiley and Sons, Hoboken, NJ.


Pitts, Greg and Luther, Mark 2012, 'A Parametric Approach to 3D Massing and Density Modelling', the 30th Education and research in Computer Aided Architectural Design in Europe (eCAADe), Prague, Czech Republic, Vol 1, pg 157-165.


Stiny, G 1980, 'Introduction to Shape and Shape Grammars', Environment and Planning B: Planning and Design, 7:3, pg 343-351.

Stückelberger, J, Heinimann, HR, Chung W 2007, 'Improved Road Network Design Models with the Consideration of Various Link Patterns and Road Design Elements', Canadian Journal of Forest Research, Vol 37, pg 2281-2298.


White, M 2007, ‘The Plan is an Inadequate Tool for Planning: Enhancing the Urban Design process through the use of 3D+ digital tools directed towards sustainability’, Forum on the application of sustainable theory to urban development practice, University of Cincinnati, OH.


8. Appendix A

8.1. Publications Preceding this Research

8.1.1. Published Book Chapters

Pitts, Greg and Datta, Sambit (2009) Surface Geometries: experiments with constrained tessellation, in Gu, Ning; Ostwald, Michael J. and Williams, Anthony (eds), Computing, cognition and education : recent research in the architectural sciences, pp. 33-46, Australian and New Zealand Architectural Science Association, Newcastle, N.S.W. [B1]

8.1.2. Journal Publications


Pitts, Greg and Datta, Sambit (2009) Geometric and material constraints in parametric modelling: the design to fabrication process, International journal of digital media design, vol. 1, no. 1, pp. 3-14, Taiwan Association of Digital Media Design, Yunlin, Taiwan [C1]

8.1.3. Conference Papers


Pitts, Greg. Datta, Sambit and Kao, Kun-Tai (2007) Rapid manufacturing: torus geometry and surface tessellation, in Qiu, Yi Ren; Zhang, Deng Wen; Xu, Yong Yong; Chen, Nong Shi; Chen, Zun Hong; Yang, Jintan and Lai, Shuling (eds), DMD 2007 : Proceedings of the 1st International Digital Media Design Conference, 6-7
8.2. Recent Publications and Conferences

8.2.1. Conference Papers

Pitts, Greg and Luther, Mark (2012) A Parametric Approach to 3D Massing and Density Modelling, Education and research in Computer Aided Architectural Design in Europe (eCAADe), Prague, Czech Republic. pp 157-166.


8.2.2. List of Conferences Attended

Designing the Dynamic, City Dynamics.
RMIT, Melbourne. 2011

Book Publication from this workshop:

Smart Geometry, Material Intensities.
Rensselaer Polytechnic Institute, Troy, New York. 2012
http://smartgeometry.org/