B. Dave, A. I. Li, N. Gu, H.-J. Park (eds.), *New Frontiers: Proceedings of the 15th International Conference on Computer-Aided Architectural Design Research in Asia CAADRIA 2010*, 155–163. ©2010, Association for Research in Computer-Aided Architectural Research in Asia (CAADRIA), Hong Kong

# SCALABILITY

*Parametric studies from exoskeletons to the city*

BEN COOREY
*University of Technology, Sydney Australia*
*bpcoorey@gmail.com, Benjamin.Coorey@uts.edu.au*

**Abstract.** This research will explore and provide an initial study into the diversity of contemporary computational design methodologies emerging in the field of architecture. It will rely on modern philosophical and mathematical ideas as a resource to integrate a seemingly disparate set of design techniques into a unified framework for architectural design. The explorations in this paper will demonstrate a preliminary study into various methods of operating across this framework through a series of parametric design experiments that span across multiple scales. The result indicates new techniques and skills that are becoming increasingly important for architectural design.

**Keywords.** Parametric; generative; systems; interface; design.

## 1. Background

This research is rooted in the domains of philosophy, mathematics and computation as they relate to new frontiers in architectural design. The research will draw on the philosophies of Deleuze (1987) and De Landa (2006, 2002), specifically the concepts of multiplicities and their relation to manifolds and dynamic theories. It will demonstrate an alternate way of understanding design, avoiding essentialism and objective qualities in exchange for design through morphogenetic processes and systems thinking. This will be linked to emerging computational techniques to create a process of design that embraces the virtual and the actual, in an attempt to understand design trajectories emerging in this field of design.

### 1.1. PHILOSOPHY, MATHEMATICS AND SCIENCE

Multiplicities are at the core of the philosophies of Deleuze. This research will both explain and explore the idea of a multiplicity, and its potential applications in an architectural context. The idea of a multiplicity contains traits evident in the closely related mathematical concept of manifolds. Manifolds belong to the discipline of differential geometry; an alternate geometric language to the traditional three-dimensional Cartesian space architecture typically operates in. The importance of this shift in language is the possibility of now studying geometry without any reference to a global space. Friedrich Gauss studied the two-dimensional manifold proving that a surface becomes a space in itself and can be studied entirely through local information without the need for a Cartesian description. His successor Bernhard Riemann successfully developed the more general notion of abstract n-dimensional surfaces or spaces.

To understand these abstract spaces relating to material objects or physical systems, we refer to theories of dynamical systems, where the manifold dimensions are used to represent various properties of a physical process. The dimensions map degrees of freedom, which are the relevant ways an object can change. Using differential calculus, we can capture the state of an object at any given single point in this n-dimensional manifold which can now be defined as a state space of possibilities for that object. The exciting potential of such representation is the ability of an object's state to change, describing trajectories of behaviour over time. Hence, the state space not only captures an object's instantaneous state, but how its properties can change over time; it captures processes. The processes, or trajectories, can be studied directly with the mathematical resources developed in the field of topology. In particular, we can study topological features called singularities which exist in manifolds that determine recurrent or typical behaviour common to many dynamic models and hence many physical systems. Depending on the initial conditions and the deterministic laws of the manifold, there will be a multitude of trajectories, each specifying a possible history of the physical system.

Critical to this research is the notion of progressive differentiation. To understand this theory, we need to rely on a separate field of mathematics; the theory of groups. Geometry can be transformed in various ways, and if this transformation leaves the object visually unchanged to an observer, we can state that it is invariant for this transformation. An object's degree of symmetry relates directly to its invariance, a sphere being more symmetrical than a cube under the rotational transformation. Describing an object by its degree of symmetry classifies an object relative to a transformation and not by its intrinsic properties. It is possible to imagine a process where the cube could become the sphere by losing invariance through a symmetry breaking transition. This form of transition is called a bifurcation and can apply directly to the topological singularities discussed previously.

An important revelation comes from Felix Klein who realized that all geometries known to him could be seen in a hierarchy, each level possessing more symmetry than the level below it. Hence the hierarchy of geometry (topological – differential – projective – affine – Euclidean), indicates that metric geometry emerges out of the topological and differential geometries of manifolds into real space. The undifferentiated intensive space of manifolds hence forms a real dimension of the world, a non-metric continuum that can progressively specify the discontinuous real spatial structures familiar to us in metric space through a series of symmetry breaking bifurcations.

### 1.2. PARAMETRIC DESIGN

The introduction of parametric associative modelling software into the field of architecture has instigated the opportunity to embed these theories into a new understanding of design. Parametric software empowers an ability to describe objects by parameters and relationships to each other. The designer has to consider design not as a static object, rather a flexible system that has varying degrees of freedom and the capacity to produce divergent possibilities. To construct an architectural system computationally, there needs to be consideration of the data structure (which will influence the search methodology); the degrees of freedom and parameters; the relationships between the parameters; methods of searching the solution space and criteria to evaluate the appropriateness of the solution.

A critical piece of the puzzle revolves around methods to search these complex solution spaces. Search algorithms are commonly studied in the field of computational science seemingly with a focus on search efficiency. The most basic search methods are uninformed and face difficulties when dealing with large search spaces. Terzidis (2006) describes a stochastic search procedure that randomly places objects within a site so there is no overlap. The process is inefficient and relies on chance; for a simple search space an uninformed solution will be less likely to produce an acceptable solution in comparison with more advanced techniques. To improve the search process, algorithms can incorporate heuristics and data structures that are easily traversed. For example, graphs are data structures that have a variety of search algorithms that have been explored extensively and appear commonly in most computer science literature. Frazer (1995) and Bentley (1999, 2002) describe an evolutionary approach to search algorithms, uniting the neo-Darwinian model of evolution with computer technology in an attempt to solve complex ill-defined problems. These algorithms differ from traditional search algo rithms by considering populations of solutions at once. This methodology implements various types of genetic algorithms, all with an underlying architecture that allows the evolution of solution populations through the processes of reproduction, evaluation and selection.

Janssen (2004) makes a distinction between two modes of evolutionary design; parametric and generative. The parametric approach takes a predefined design and searches for optimal solutions by adjusting smaller parts which have been parameterised, hence systems that have strong relationships and minimal degrees of freedom. The generative approach is useful for complex ill-defined problems, relaxing the constraints and allowing a much larger search space with differing criteria in an attempt to produce novel or unpredictable results.

Janssen refers to the paradox that emerges from the two alternate approaches as the variability problem. As the criteria are relaxed, designs evolve that are unpredictable and creative but often unintelligible or difficult to evaluate. The parametric approach is useful for optimizing solutions; however it is unlikely to provide novel unpredictable solutions. I would argue that there is no formal difference between the two methods, simply a difference in the initial construction factors of the system; that is the degrees of freedom and strength of relationships between parameters. Focusing our attention to the logic of multiplicities, topology and dynamical systems may reveal more similarities between design methods. Hopefully this research will demonstrate that the divergent modes of design that are currently being explored are intrinsically linked via a virtual continuum. Understanding the relationship of existing designs and my own work to this virtual space could describe trajectories to provide clarity and an origin to a seemingly diverse and divergent set of working methods. This will provide an opportunity to see the field from a unique perspective and perhaps highlight potential future trends that will only be evident from this new viewpoint.

This paper describes three distinct parametric explorations conducted during the Masters of Digital Architecture at the University of Technology Sydney. The work is unique in the sense that it attempts to understand some very diverse design systems implemented across multiple scales through an all-encompassing framework, identifying a proposal for a unique understanding of architectural design. The key drivers for architectural design can be replaced by the degrees of freedom a particular system may have, the number of dimensions for the state space of possibilities, and the methods of designing and parsing through this virtual environment. It must be understood that the metric result or output of the system is intrinsically linked to the virtual realm of possibilities. This research will demonstrate various strategies for exploring design across multiple scales and material systems. Each system will be discussed by describing both the logic of the virtual system and the associated metric forms. There will also be a dialogue about the various experimental techniques to search the complex design spaces that are now being presented to emerging designers.

## 2. System design

Following is a series of parametric explorations spanning multiple scales; from material systems to the city. These will demonstrate an initial attempt at understanding a logic and framework for design using virtual systems intertwined with various geometries as a methodology for architectural design. The key elements of this framework (figure 1) involve data storage capabilities, relationships (geometrical and data), user interface and methods to search the possible solution space. As these are a work in progress, the various case studies explore individual parts of this framework. With further progress, it is foreseeable that each of these case studies could implement the full framework.

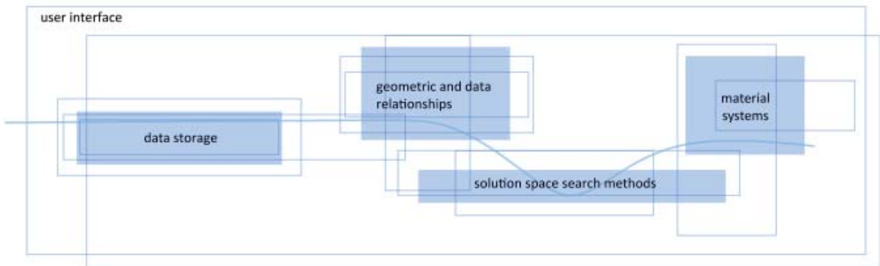


*Figure 1. Design framework*

### 2.1. EXOSKELETONS

The first system is constructed at the material scale; the metric reality becomes various facade exoskeletons primarily concerned with the control of environmental conditions through the manipulation and distribution of material across a building skin. A primary rig was constructed by modelling a series of deformable ribs with a network of fibres spanning between (figure 2). Each rib could be manipulated in multiple ways, including a change to the rib shape, rotation, number and density of fibre connection points and finally the scale of the rib. A typical system was constructed with multiple nested skins, each consisting of 15 ribs with six degrees of freedom, creating a large, complex state space of possibilities.

In order to intersect with the vast set of possibilities, a parameter control panel was setup which allowed the designer to manipulate the relevant param eters for each rib. The methods of operating the system were to manually tweak the parameters to achieve a solution. This worked because there was a capacity to map the transformations to physical effects. For example, a rotation of one rib would enhance an exoskeleton's structural capacity by developing a diagrid formation. Increasing the radius of a rib would spread the fibers out, allowing more ventilation through the skin. Decreasing the density at various points would allow more visibility and daylight into the space. The result was a highly controllable exoskeleton that could be manipulated and adapted into a divergent set of environments (figure 3).

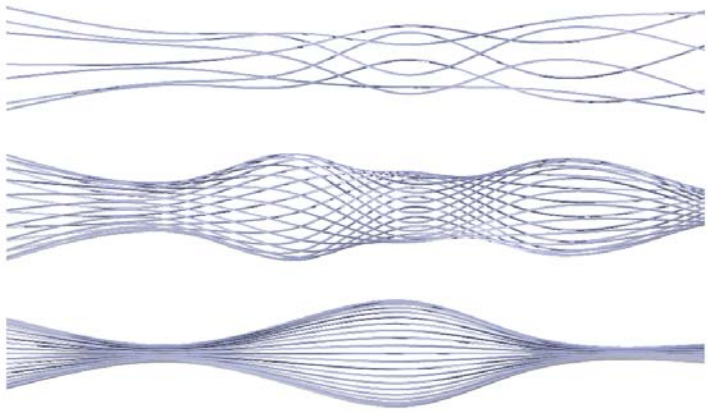

*Figure 2. Parametric rig control.*

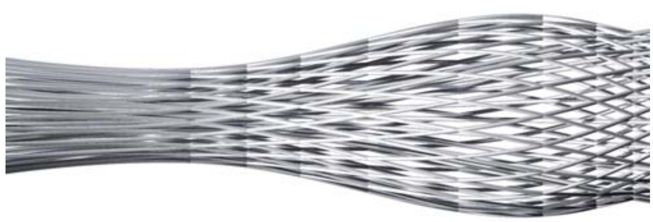

*Figure 3. Exoskeleton design.*

2.2. GENERATIVE MASSING MODELS

The second exploration is at the building scale, exploring the potential for parametric systems to assist in the planning stages of design. This exploration demonstrates that a more advanced yet similar logic to the first exploration can be used for building massing analysis and the generation of novel building designs. This exploration begins to also formalize this methodology for design. The design is broken down computationally into the following functions: storage of data, generation of solutions, optimization of solutions and geometric design. The separation of these functions allows for a division of workflow and focus for division of skills when designing this way.

This exploration used Microsoft Excel for data storage. This also provided a user interface that would allow the user to determine the amount of rooms, dimensions, location constraints and various relationships between the elements of the building. This was intrinsically linked into the generation module, where the building design data was interpreted and encoded into Generative Components massing features (figure 4). Using the constraints, multiple solutions can be generated and checked against the initial requirements.

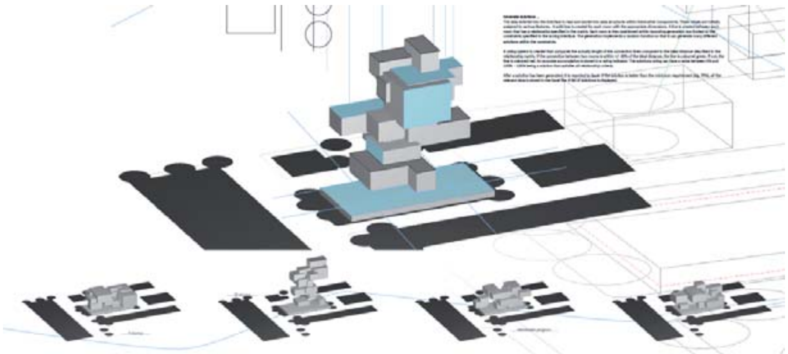

*Figure 4. Massing options.*

Preliminary optimization techniques were coded to increase the suitability of solutions. A locking mechanism was programmed to increasingly lock the positions of rooms that start to satisfy their requirements. The best solutions were then able to be saved into Excel spreadsheet for later viewing. The final stage was to embed an architectural language to the system. This is perhaps the most flexible stage, and is equivalent to the metric bifurcation of the virtual possibilities (figure 5).

*Figure 5. Design options.*

The system becomes more than the virtual manifestation of relationships; it becomes the metric object. Hence, the same initial system could be used to produce a divergent set of architectural designs. The metric emerges out of the virtual system.

2.3. URBAN PROXIMITIES

The final project explores the use of employing a similar framework for analysis purposes in the urban context. The task was to create an analysis tool that would produce a rated diagram of building sites based on multiple criteria. The initial driver for the project was to locate a site in Sydney that embodies a conflation of the surrounding city. The approach was to identify the important nodes of the city and develop a system to compare each building to the proximity of these nodes (figure 6).

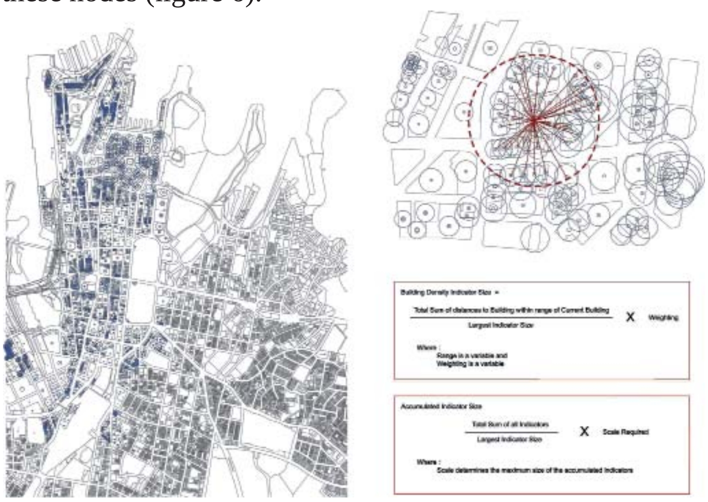


*Figure 6. Node proximities.*

The initial node data included train stations, bus stops, green space and building density. An advantage of using Generative Components was the ability to convert an entire map of the city into workable objects which could embed relationships. A custom function was designed to calculate a weighted response of each building to the distance from the various nodes. Once multiple criteria are integrated, the result is a unique diagram of the city tailored to the search requirements for your site.

This exploration implemented parts of the emerging design framework. Data storage and generation of solutions were critical in this work. The tool did not require a metric output, so the output was purely a representation of the virtual relationships and connections between components of the city.

## 3. Conclusion

The three projects outlined in this paper attempt to piece together a series of case studies with a priority of positioning them within a unified understanding of parametric design methods. The explorations demonstrate that a consistency in logic has been applied to a variety of scales and design requirements. Parametric design tools have proven to be an ideal tool for the construction of both metric and virtual spaces. This methodology of design allows the virtual and metric components to be developed separately yet be intrinsically related. More importantly, this paper has identified new skills and techniques that are becoming increasingly relevant in the design profession, including the need to understand data storage, search algorithms and system design.

## References

Bentley, P. (ed.).: 1999, *Evolutionary design by computers,* Morgan Kaufmann, San Francisco.

Bentley, P., and Corne, D. W. (eds.): 2002, *Creative evolutionary systems,* Morgan Kaufmann, San Francisco.

Deleuze, G. and Guattari, F.: 1987, *A thousand plateaus – capitalism and schizophrenia,* University of Minnesota Press, Minneapolis.

De Landa, M.: 2006, *A new philosophy of society: assemblage theory and social complexity,* Continuum, London.

De Landa, M.: 2002, *Intensive science and virtual philosophy,* Continuum, London.

Frazer, J. H.: 1995, *An evolutionary architecture,* AA Publications, London.

Janssen, P. H. T.: 2004, A design method and computational architecture for generating and evolving building designs, PhD thesis, School of Design, Hong Kong Polytechnic University.

Terzidis, K.: 2006, *Algorithmic architecture,* Architectural Press, Oxford.