Agility in Interior Architecture

An investigation through Prototypical Design for Interactive Spatial Dynamics
Agility in Interior Architecture

An investigation through Prototypical Design for Interactive Spatial Dynamics

Exploring spatial articulation for a kinetic and dynamic architectural language; developing unique ephemeral relationships between space and its users. Utilising precision fabrication workflows creating a modular construction system for interaction and manipulation of interior spatial conditions.
To Mum and Dad, Your unwaivering support is invaluable, Thank You.
Abstract

This paper identifies and discusses designing interior building dynamics that, through user interaction, can be physically manipulated and maneuvered to suit a changing situation in spatial requirements/preferences. Designers have partially realised this architectural vision through both mobile and dynamic interior elements, and relocatable construction systems. Here lies the potential for a digitally manufactured modular system for spatial dynamics, providing interactive interior architecture with embedded spatial fluidity. Providing occupants of these interior spaces with the capacity to determine the spatial conditions how and when they require. Leveraging modern digital fabrication techniques like CNC timber milling and consideration of factors such as assembly/disassembly, this thesis explores ideas of tactility and kinetics of interior space and how the user interactions can exact spatial change. This research develops a modular tectonic language, with low operational - mechanical and construction - complexity. A manipulatable interior tectonic such as this would be possible to complement existing structures or other fixed designed architectural elements to provide an enhanced level of building function through a immediately influenceable spatial conditions. The research undertaken explores a series of experimental modular prototypes, each a unique response for spatial dynamics.
# Contents

Abstract vii

Preface xi

Chapter 1 - Research Agenda

Introduction 3
Glossary 4
Methodology 5
Methodology - Ideology and Synthesis 6
Methodology - Design 7
Interactions through Architecture 8
Project aims 10

Chapter 2 - Ideology

Agility in architecture 14
Key Theorists 18
Responsive Architecture - Digital Kinetics 20

Chapter 3 - Synthesis

Process 26
Categorization 27
Case Studies 28
  A. Digital Fabrication 28
  B. Kinetic Facade 30
  C. Responsive Installation 32
  D. Augmented Reality 34
  E. Virtual Reality 34
  F. Holographic/Laser Projection 36
  G. Arduino 38
  H. Kinetic Sculpture 40
  I. Responsive Building Performance 42

Chapter 4 - Design Investigation

Design Aims + Objectives 46
Design Investigation Framework 47
Prototype 1 - Binary 50
Prototype 2 - Chain 60
Prototype 3 - Rope 66
Prototype 4 - Pivot 80
Prototype 5 - Cascade 94
Prototype 6 - Drift 102
Fabrication Findings 118

Chapter 5 - Expression

Conclusions 122

Bibliography 126
Preface

Primarily, this 'research by design' thesis is operating within three different fields of the designed environment. Each of these subcategories, that the research is situated within, carry their own significance relating to both my personal process and the desired design outcomes. These areas were defined as: Digital Fabrication, in particular CNC milling for timber elements; Kinetic Design; and Flexible, Adaptable Interior Architecture.

Flexible and Adaptable architecture has for a while been an interest of mine, seeking alternative interior architecture solutions responding to challenges of spatial inefficiencies, generic notions of fixed architecture and providing additional functionality for otherwise dormant spaces. These are some of the challenges which interior architects still wrestle with today to enhance the buildings and spaces we occupy. Through the twentieth century and to today architects have pitched ideas, some limited by the mechanical/technological state of affairs - whose visions for mobile interior spaces were hindered by overcomplexity of fabrication and assembly.

With the aim of picking up on the virtues of what these designers were striving for, citing these over complex mechanics, utilising precision techniques for digitally controlled manufacturing and fabrication, through this thesis I investigated how these digital fabrication methods can be leveraged to reduce design complexity.
Chapter 1
Research Agenda
Introduction

Within the realm of kinetic sculpture and architecture, designers have sought to create dynamic and active relationships between the constantly moving forces of the world and their own physical interventions.

This art manifests the motion of the world around us into emotive and apparently cognizant abstracted expression, reacting in unison with its evolving environment. Some kinetic sculptures seek to visualise and formalise otherwise hidden or obscured forces, while there are kinetic artists who attempt to create a medium which reflects or responds to how people or the environment display.

The underlying aim of this thesis and investigation is to explore how the virtues of kinetic art can be interpreted within the context of interior architecture, primarily to explore how interior architecture can embody this idea that kinetic art will manifest actions that ‘breathe life’ into the interior spaces. Adjacent to this, exploring the notion of manipulatable spaces which rely on user interaction to provide a greater flexibility and fluidity of space.

In the twentieth century architectural theorists proposed that the ideas of enhanced actuation and articulation of space were compromised by the feasibility and constructability of over complicated mechanism and technological/material restrictions. Jumping into the twenty-first century digital fabrication has opened a new door in terms of precision manufacturing for new kinetic relationships within an interior built environment.

Through digital fabrication processes - ie CNC routing - for simplified mechanism, modular construction this thesis aims to create playful and responsive passive dynamic interior conditions.

My process identifies mechanisms which to create this kinetic condition.
**Glossary**

**Collaborative**  Two or more people or entities working together to achieve some common aim.*

**Deconstructable**  Retaining the capacity to be disassembled and reassembled again after the initial construction.

**Digital Fabrication**  Digital fabrication is a design and manufacturing workflow where digital data directly drives manufacturing equipment to form various part geometries. This data most often comes from CAD (computer-aided design), which is then transferred to CAM (computer-aided manufacturing) software. The output of CAM software is data that directs a specific machine, like a 3D printer or CNC milling machine.

**Immersive**  Providing, involving, or characterized by deep absorption or immersion in something.

**Interactive**  Involving the actions or input of a user

**Kinetic**  Of having movable parts activated by motor, wind, hand pressure, or other direct means and often having additional variable elements, as shifting lights.

**Responsive**  Responsive architecture is defined as any building or building component equipped digitally to designed for adaptation to changes in its surroundings.

**Shared**  Used, done, belonging to, or experienced by two or more individuals.*

**Tangible**  Of, relating to, or being the sense of touch.

**Virtual Space**  Virtual space is defined as an environment or platform within which users can interact, independent from a real location or environment, facilitated by a network of computers. Virtual space can be situated within real space as an additional virtual layer.

* The distinction in this context between shared and collaboration is shared is to experience and collaboration is to influence
**Methodology - Ideology & Synthesis**

In order to situate my design ambitions, an account for the history of dynamic interior architecture was taken. For this, I identified the industries and design fields which I associated with these initial design ambitions. Through this synthesis phase I have focused on discussing interaction and architecture. This first of two phases of this thesis is to gain an understanding of how different types of architecture can respond to changing use, operation and location. This covers interactions in digital space, active intelligent responsive architectural design, how digital fabrication facilitates adaptable design, and passive kinetic design applications. Recognising how users interact with architecture, how users interact within architecture, how the environment can influence architecture is an important component of this research as phase 2 - the prototype design phase - is initiated.

The key areas of interactive architecture identified as being precursory to this design research being, as I have categorized them, are: Digital Space; Kinetic Design; and Digital Fabrication Prototyping. It is important to distinguish the variations that exist within the area of Kinetic Design. I have grouped these into Responsive Kinetic Design and Physical Kinetic Design. The distinction between Responsive and Physical, respectively, being digital means of awareness and actuation, and mechanisms initiated by a force, typically human or environmental, influencing motion. As my research is endeavouring to find architectural solutions within at least two of these categories, it is vital to clearly define a collection of terms which pertain to the design process and design outcomes. Key terms such as responsive, kinetic, tactile, interactive and articulation have specific context and therefore specific definition within this thesis. From literature and case study these terms began to feed into my particular design goals and design aims moving forward - pairing the case study evidence with the literature’s findings. This developed the framework which I was to work within the prototype design phase.

**Methodology - Design**

Essentially, the framework existed as a wish list for what the investigation aimed to accomplish. The intention was to develop a number of prototypes, each achieving some of the criteria which I set out in the framework. The series of prototypes explores the ideas of digital fabrication, assembly, interaction and fluidity of spatial conditions.

The design phase began with sketch iterations looking into how flexible partitions could lend towards adaptable space. The primary tool for developing these prototypes for the modular construction was Autocad. In Autocad I developed and tested each prototype initially as 2D geometry. Autocad was the primary design tool utilized because of its capacity to work with manipulatable and parametric profiles with the end goal of being able to transfer the CAD files to the software for the CNC milling robot.

Each prototype was developed in an iterative process, developments coming out from the previous prototypes. The iterations can be split into two categories based on the type of spatial dynamic they are accomplishing. Each prototype succession builds on the previous iteration, usually increasing the capacity for spatial change or simplification of fabrication/assembly but through this further development findings could be retroactively applied to the earlier iterations.

The iterations are named for a key characteristic of the motion/relationship of the modules. Binary, Rope, Chain, Pivot, Slide, Cascade and Drift are the results of this thesis, presented as potential wall module prototypes for interactive and manipulatable space.
Interactions through Architecture

This portion of the thesis analyzes the different relationships that exist within architecture, specifically the ways architecture/design responds to users and the environment, how users can adapt architecture and how architecture/design can enhance interaction and facilitate collaboration between users.

Building on the initial literature reviews, a fairly wide scope of potential design aims for this thesis were established. Citing the academic work of Leatherbarrow, Kronenberg and Kolarevic, the scope for the design research included building dynamics, flexible architecture, kinetic sculpture/architecture and responsive architectural systems. Robert Kronenburg’s synthesis on this field was distilled in his comments about flexible buildings and how they should ‘respond to changing situations in their use, operation and location’. To define the scope further, this investigation set to find a solution for the first of these three conditions; use. At this junction the question being posed to be answered by the design research was essentially “how can interior architecture respond to changing requirements for use?”.

There was a curiosity in the hypothesis and synthesis phases, while the particular methodology was yet to be defined, to first explore a variety of different vehicles that could potentially be used to communicate interactive design. As a part of the AMPD Lab there was interest to find a way to research the underlying design-based motivations of the investigation, user interaction and kinetic qualities within a digital context.

Digital Space encompasses a portion of architectural solutions for interactive architecture. Through an in-depth case study of different digital architectural spaces, I explored some of the ways that people could interact with digital spaces and interact with each other in digital space. Initially the focus on digital space was proposed as a communication tool for potential interior architectural interventions. The case studies in this phase were used to define the different types of interactions possible within different digital spaces currently available/hypothesised. Augmented Reality (AR), Virtual Reality (VR), Projection, Holographic/Lazer Projection and Responsive Design (infrared sensor based) were the main classifications made for the examples of digital spaces. Each of these classifications dealt with user/digital space interactions, environment/digital space interaction, and user/user interaction within digital space in different ways.
Project Aims

The aim of this thesis was to explore interaction, agility and adaptability within interior architecture. Opening with a literature and case study, the synthesis phase collates the previous research by architectural theorists and built examples within the designed environment. All of the case studies selected capture the ideas that the theorists discuss, covering both digital and non-digital responsive architecture and design.

Following the synthesis phase, the design investigation phase presents the design-led research undertaken that builds on the previous research for interactive and agile interior architecture. This phase presents a series of experimental prototype designs that address short term agility; exploring tactility, kinetics, and spatial fluidity, and long term adaptability; through fabrication and construction.

How can adaptable and interactive interior architecture embody kinetic principles and facilitate spatial dynamics?
Chapter 2

Ideology
Agility in Architecture

In an attempt to enrich the temporal experience of interior space, how can kinetics bring about more meaningful experience/connection between users and the spaces they inhabit?

Flexible buildings are intended to respond to changing situations in their use, operation or location. That is architecture that adapts rather than stagnates; transforms, rather than restricts; is motive, rather than static; interacts with its users, rather than inhibits. (Kronenburg 49)

Cedric Price with reference to his Fun Palace - "It was an era that considered the fantastical opportunities for buildings to accommodate the needs of users, versus the more typical arrangements whereby people are shoehorned into spaces. The vision [was to] create cities, buildings and spaces that reacted in real time, that altered composition based on conditions, and pushed and pulled according to the compositions."

What does architecture look like which is some kind of 'fluid fabrication' so that the hardware of its architecture become responsive in real time to environmental influences and live inhabitation? One of the limitations within this field of architecture will be if it can evolve alongside technology and culture.

"There can be no excuse for creating architecture that fails to cope with current variations and future change, as the reasons for designing with flexibility as a priority are more important than ever before, and the technical ability to do it is more readily available." (Kronenburg 41)

Whether it's foreseen or not, a building's lifetime will be defined by its capacity for change. Some buildings need much more thought and effort put in to recycle and adapt them for a new purpose. Over a built environment's life, adaptive reuse will inevitably occur, responding to the changing social and physical conditions. Any building or element which is deemed unsuitable for repurpose get disposed of. It remains unknown if the architecture of today will be more capable of adaptation and repurpose when the time comes and the social expectations and physical requirements demand change. Sustainability calls for flexibility over adaptive reuse due to these inevitable shortcomings.

"The functional and operational failing of inflexible buildings indicate how designers' knowledge and objectives have become separated from the user's experience and needs." (Kronenburg 41)

If architects are aware that adaptation is likely to be a part of their building's timeline, there is potential for this to be considered and designed for. Increasingly, architecture is being designed for a particular purpose with less discussion on how it could be repurposed years down the line. It's unknown if this will result in longer lives for buildings, or if there is a missed opportunity to be prepared when societal or environmental changes seek response within the built environment. To try to predict the future adaptation is to predict the ways people want to use buildings in the future, what we will expect from our built environment, and how the natural environment will influence and interact with the building and its systems. There's argument that today's new architecture should be the most able to respond and remain fit throughout the impending environmental changes our world is likely to experience. Adaptability doesn't have to mean one size fits all.

"How can housing that is unfit for habitation by its adherence to a stylistic genre rather than the requirement of its inhabitants be justified? Or "iconic" arch that is more concerned with its symbolic presence than those who will use it be relevant?" (Kronenburg 41)
How can architecture be designed to allow for a range of possible unique timelines?

In order to facilitate this kind of repurpose or adaptation the design must acknowledge that when it’s constructed it’s not complete. Permanence and durability are realised in time, not the day they are handed over. A building or interior is going to survive if it remains relevant and adheres to the condition

'We tend to believe that work is complete when its construction, layout and look have been brought to the state that was specified in design. From that moment onward we expect the work to stay as it first was, suffering but enduring the effects of inhabitation and environmental influence.'

Can we think of design as unfinished? How can we design for unfinished architecture which is readily in a constant state of change?
Key Theorists

David Leatherbarrow is a Professor at The University of Pennsylvania School of Architecture and author of the paper Making Space for Time. Leatherbarrow poses the question “How can we design for unfinished architecture?” and I believe he’s contemplating an architecture which is not incomplete, but an architecture that is intrinsically flexible and will be continually adaptable and adapted. With the critique he offers on today’s architecture - typically suffering although enduring the effects of inhabitation - this question which he poses seeks a solution which goes beyond facilitating inhabitation, instead proposing how architecture can become a live entity designed and programmed to be adaptable and responsive to the needs and desires of its occupants.

Branko Kolarevic co-directs the Laboratory for Integrative Design (LID) and co-edited Building Dynamics with Vera Parlac. Kolarevic argues that architects should see themselves as ‘programmers of spatial change’, rather than just a producer of unique 3d space. While he acknowledges the challenge that the majority of systems being inherently inflexible in architecture, he is fixated by the potential for responsive architecture to develop beyond a fascination for mechatronics - he discusses a vision for kinetic responsive architecture where the change in environment, or actions of the users directly influence the architecture in a non-digital way. Kolarevics thinking about the role of architects has developed into my second project objective.

Robert Kronenburg, is a Professor at Liverpool School of Architecture. His research focuses on creating innovative forms of architectural design - ‘Mobile, Flexible, Filmic and musical’. He has authored journals, papers and books on the topics of portable architecture and responsive built environments. He articulates his position in Flexible: Architecture that Responds to Change, published in 2007, “Flexible buildings are intended to respond to changing situations in their use, operation or location. That is architecture that adapts rather than stagnates; transforms, rather than restricts; is motive, rather than static; interacts with its users, rather than inhibits”. Kronenburg’s definition of flexible architecture is the prompt for the third project objective.

Each of these three theorists addresses the potential they see for architecture of change. All of these authors articulate themselves within the field of dynamic architecture in a similar way, and provide unique perspectives on what change really means for buildings, how architecture responds to change and how future architecture will ultimately generate spatial possibilities rather than fixed conditions. The way that their shared philosophy has manifest into my project objectives has derived from how their thinking has made me approach the subject of programmable architecture, kinetics and dynamics. I want to use responsive architecture as a vehicle to understand more about how building performance could be enhanced, what real time response looks like in the built environment, and how flexibility and programmability change the way we use space.
Responsive Architecture

Digital Kinetics

In 2017 Naglaa Ali Megahed produced a report titled “Understanding kinetic architecture; typology, classification and design strategy”. The report explored how developments with kinetics, robotics and computation have played a role in digital design processes, construction and fabrication methods along with intelligence and automation within the contemporary architecture industry. Out of all these different categories which kinetics is associated with, adaptability and flexibility are currently most influenced by ‘embedded computation intelligence’. Today’s knowledge in structural, mechanical and material engineering as well as developments in information communication technologies have had a great effect on kinetic design (Fox & Kemp, 2009). ‘Interactive Architecture’ is an article written by Michael Fox and Miles Kemp. They describe this kind of architecture as ‘environments that not only facilitate interactions between people but actively participate in in their own right’. Kinetic or Interactive architecture has only been born out of the other emerging industries of construction and computing such as CNC fabrication or virtual reality (Fox & Kemp, 2009). Since the concept of kinetics has existed for decades there are plenty of definitions available, but it is important to give it a contemporary standing. Fox and Kemp offered this definition: ‘Kinetic architecture is defined generally as buildings and/or building components with variable mobility, location and/ or geometry’.

Megahed claimed that responsive and kinetic design now offers a wider range of possibilities for architecture. The possibilities for kinetics which have the largest influence on interior architecture are the ability for human and environmental stimuli to trigger automatic changes to reorganise and respecialize space (Megahed, 2016). Bharati (2017) thinks that ‘kinetic elements should not only be integrated into the system of a building, but should be flexibly embedded into the fabric of that building’. Responsive kinetic architecture relies on not only an infrastructure of dynamic physical and electrical (audio, visual, lighting) elements, but has to have a receptive network built in which can recognise the stimulus and react with the motion of said physical elements.

Digital kinetic architecture offers opportunity for interior spaces to have embedded intelligence and recognition in order to transform the space, layout or components. If there a changes in the user’s behavior or there is an environmental change, a digital kinetic system can optimise the interior conditions to best suit the function, and through this a variety of functions can be performed within one space. Traditional architecture does not typically give spaces multiple functions and multi-functional design is most often afforded by a secondary method such as furniture. Digital kinetic architecture can achieve integrated multifunctionality without relying on the physical manipulation and interaction between the user and the elements of an interior. For public and private spaces this can be a useful design strategy for spaces which require innovative organisation and need to accommodate many users and many functions in a compact environment. Fox thinks that this technology still presents the most practical opportunities for unique and difficult scenarios, but is mostly unexplored when it comes to solving problems around today’s dynamic and flexible lifestyle of the human and the building, alike. (Fox & Yeh, 2000) (Bharati, 2017)
Currently, there is a lot of research going into interactive environments, so a lot of these projects are focused on gaining the most interactions they can at once. Corporate settings for architectural projects, because their intended audiences are that of a large number of users, typically exist in larger corporate settings, stores, or in densely populated urban contexts. Such projects are developed with the intention that they will be used by multiple users at once. (Fox & Kemp, 2009)

Because of this, corporate projects are operating on a much larger scale than most interactive architecture projects. With the intention of maximising the number of users, the research gains valuable exposure which has translated into greater experimentation of these interactive architecture prototypes. With such a large scale, this experimentation has disadvantages with connecting and responding to individuals, instead ‘they often employ interactions or general interactivity based on very general or nonspecific data’ (Fox & Kemp, 2009). Corporate initiatives like this are concerned with developing their unique corporate identity, with the personality and quality instilled in brand. As their architecture becomes communicative and smart, and can embody a corporate identity ‘then it can facilitate a whole new level of accessibility and personal attachment to a particular brand.’ (Fox & Kemp, 2009)

Another commercial workspace concept which is gaining traction in company around the world is the idea of nobody having a set workspace dedicated to themselves. With the systems to keep their work portable - an intuitive laptop/cloud connection and good old fashioned paper - employees can set up anywhere in the building to carry out their daily tasks. This creates opportunity for employees to share the resources of the company, making use of what they need when they need it. Spaces like conference rooms can be repurposed if they are not required and other larger spaces can be used for effective individual work or a big open platform for meetings, communications, and conferences to be held. I think that this concept can tie in with adaptive architectures; if the users are happy and encouraged to be fluid through the building, the interactive architectures job is that much easier.

The most common uses for responsive systems are predominantly found in facade design. The environmental implications and building performance are enhanced through smart facades which can detect sunlight levels, heat and ventilation requirements and adapt accordingly. In Paris the L’Institut du Monde Arabe has a facade which can detect daylight levels and direct sun levels and adjust apertures within the building to allow for ideal interior lighting levels. This application for responsive design is important for learning how a system can take simple cues and even learn how to best serve the users through their actions and interactions with the intelligent system. Currently the most common types of adaptive interactive interiors are based on a soft system of walls and other elements. Ghislaine Garcia developed a list of stationary and adjustable elements within a home for a study on the responsive home. Only the rooms with plumbing/ventilation - bathroom and kitchen - and the structure were the elements which were deemed stationary, with all other elements considered fluid; including apertures, lights, roof and user, as well as all other physical elements mentioned earlier. (Ghislaine, 2017)
Chapter 3

Synthesis
Figure 1: The complicated process undertaken to arrive at the synthesis of design framework, locating all of the different case studies for interactive architecture. Each of the case studies falls under at least one of the four different domains which I have chosen to investigate: Prototyping, Physical kinetics, Responsive Kinetics, and Digital Space. Case studies which represent two of these domains can be located at the crossroads within the abstracted representation of this phase of the project.

These descriptors are used throughout the case study portion of this thesis to categorize the different attributes of interactive design.
A. Digital Fabrication - CNC

Computer-numerically-controlled milling is a modern digital fabrication technique for translating digital three-dimensional computer models directly to physical manufactured components. 3-axis CNC milling facilitates prototype manufacture where pocketing, milling and cutting.

X-frame is a construction system devised by Ged Finch as the topic of his PhD. His design leverages the precise and scalable nature of CNC milling as a means of fabrication for floors, walls and ceilings. The ‘flatpack’ system takes sheet timber material and cuts out components for a construction system which slot together, as an alternative to traditional timber construction methods. Ged cites construction waste representing half of our dumped waste in New Zealand, and proposes X-frame as a zero waste alternative. This construction system is designed to be part of a circular economy within the built environment, with the capacity for disassembly, relocation and reassembly, without necessity for replacement or disposal of the structural or cladding materials. His work identifies issues with our current construction techniques that lead to high construction waste, namely contaminated chemically treated products, single use fixings, adhesives etc. As a flexible construction system X-frame has wide potential for configurations for door and window positioning as well as wall lengths and room volume requirements. (Fig. 2, 3)

Figure 2: (Above) Deconstructable X-frame prototype exhibiton.
Figure 3: X-frame prototype exhibiton, interior view.
B. Kinetic Façade

Ned Khan is an artist and sculptor whose work manifests and replicates environmental conditions through kinetic art. His work can be understood here as an artistic application of kinetic principles within an architectural context. (Fig. 4, 5)

Figure 4: Turbulent Line, 2012. UAP STUDIO + Ned Kahn collaboration for the Brisbane Domestic Airport Carpark.

Figure 5: Kinetic Façade - Turbulent Line, 2012. Wind creates ripples across the 117,000 shade aluminum panels.
C. Responsive Installation

Characterized typically by digital projection or mechanical actuation, this type of responsive design relies on motion detection through sensors or cameras. The installation translated some form stimuli into a change in the physical elements or projections. All the users can observe and influence the installation equally.

Nervous Structure (2011) is an interactive installation by Annica Cappetelli and Cristobal Mendoza that consists of a wall-mounted sculpture containing hundreds of vertical and parallel lines made of elastic cord that are projected upon with a computer-generated, interactive animation of a similar number of lines. The motion of these projected lines is ruled by a simulation, which makes them act like soft ropes, and said motion is influenced by a viewer’s movements as interpreted by a computer that surveys the scene through a video camera. (Fig. 7)

Figure 7: Nervous Structure, 2011.
D. Augmented Reality - Mobile

Multiple users can experience the same digital space simultaneously. AR combines digital elements with the real physical environment. In a collective experience, there is a platform for a collaborative digital space.

In 2017 Will Pappenheimer developed the AR installation Drawing Constellation, a participatory drawing installation.

The work uses a modified public AR app, Layar, to upload drawings to a constantly animated and evolving virtual “constellation” centered within an exhibition space by GPS location. Participants are invited to use their cell phones or tablets to create drawings with their own choices of color, brush size, etc. A single user can change the whole galaxy by creating multiple drawings in succession. Through the live phone or tablet views on site, the audience is immersed in their own swirling drawings (Fig. 8). In its simplest form Drawing Constellation is a communal drawing-sculpture for virtual space. (Will Pappenheimer, 2017)

Figure 8: Drawing Constellation, 2017. User created “galaxy” of drawings viewed through mobile Augmented Reality interface.

E. Virtual Reality - Headset based

Within virtual reality space, primary users can experience and influence the virtual conditions. This interaction is isolated to the primary user and often non-collaborative. With the digital space being independent of the real space, a secondary observational experience can be established with an alternative broadcast of the primary users experience on traditional display. Because of the nature of the equipment requirements, headset and controls, this restricts true interaction between users.
F. Holographic/Laser Projection

Umbrellium is a group formed out of architects and designers which seeks to ‘design and build urban technologies that support citizen empowerment’. Assemblance, a 2014 urban installation, is a full immersive augmented reality environment, lasers and lights respond to the motion and actions of people (Fig. 9). The lasers create three-dimensional forms which can be manipulated with movement, and the underlying principle of the project was to create a collaborative immersive environment. The characteristics which Kronenburg offers for responsive architecture, adaptive, transformative, motive and interactive are touched on here, especially in the ways it is interactive; people interacting with the architecture and people interacting with each other because of the architecture.

Figure 9: Assemble by Umbrelerium. Collaboration in an Immersive Environment.
G. Arduino

The open-source electronics programming platform Arduino was an opportunity to explore, on a small scale, how user or environmental influence could activate change in an architectural context.

Sara Nabil is a PhD candidate at Newcastle University. Her work is focused on interaction design, interior design and physical computing. In 2019 she designed the ‘ActuEater’ (Fig. 10), which is a table runner that can move and morph depending on the interactions you make with it. Her research has developed this using a combination of thermochromic fabric (colour change), SMA wires (shape and motion) and e-textiles (sensing). The ‘ActuEater’ is an example of how everyday objects can be given intelligence within an interior context. This particular project provides some context into targeted to discover how the ‘hardware’ of interiors, i.e. objects, furniture and space, can become interactive and intelligent, and how they can be used to adapt space for the user. (Fig. 10)

Figure 10: ActuEater, 2018. Arduino controlled interactive table runner.

Figure 11: ActuEater development. An array of vertically moving actuators responsive to light and pressure manipulate form.
H. Kinetic Sculpture

Characterized by motion that brings new meaning or experience.

An excerpt from The Morphology of Movement: A Study of Kinetic Art, George W. Rickey, 1963:

Any particular instance of movement takes place in its own time and becomes, for the artist, what a color or a shape is to the painter. In this measuring of time, the “interval” becomes all-important and it assumes many forms.

It can be very short, even instantaneous, in the measurement of velocity or acceleration, or almost interminable in the measure of a long journey into deep space or of the duration of awareness as compared with a momentary recognition. It can be interrupted, as in rhythmic sequences, and, if the intervals are short enough, can take on a new continuity as “pitch” or, in visual terms, the blur of rapidly oscillating objects. Chance may be introduced either by the movement of the observer, which the artist prepares for but does not pre-determine, or by incorporating in the object itself, some factor of fortuitousness.

Motion can equally reveal (or transform) structure, not only in the obvious way of showing cause and effect in a machine, such as the meshing of gears, the pushing of a crank, or the linkage of a typewriter key, but rather in the more intimate revelations of the link-to-link relationship of a flexing chain, the arching, resistance, recovering, and natural period of oscillation of a bouncing leaf spring, or the surface to surface zigzags of a beam of light. (Rickey, 1963 in Art Journal, Vol. 22, No. 4)

Figure 12: Grass by Len Lye, 1960. As an example of Lye’s Kinetic art, Grass imitates the chaotic nature of external environmental.
I. Responsive Building Performance

Building performance is a common justification for implementation for digital kinetic architectural systems; Controlling interior conditions, namely air quality and temperature.

The Media-TIC building designed by Enric Ruiz-Geil in Barcelona was built in 2011. The building was designed to regulate sun shading and internal heat gain through inflatable ETFE air cushions on its sun oriented facade. The reason this case study has been selected is because although it is using a highly demanding pump system to keep the air cushions inflated, there is an actual change in the composition of the building materials, as the system responds to the internal and external conditions. As the sun strikes the west side, the air cushions filled with a nitrogen/oil vapour mix which switches the facade from transparent to translucent. The way the Media-TIC building was designed for physical manifestation through digital means to essentially employ a passive energy solution, is an early example for how passive building performance can be revolutionized with intelligent systems. Although this does not exactly fit the definition for passive energy, it presents an opportunity for responsive architecture to utilize monitoring and computing to provide more than typical building services, which basically keep inefficient buildings on life support. It addresses my second project objective because its executing a physical change to the building, essentially adapting the materiality of its facade, to improve the interior conditions and energy performance requirements, if it were not for the cooling effect of the changes the building would be putting energy into cooling. (Fig. 13)

Figure 13: Media TIC by Enric Ruiz-Geil, 2011. ETFE ‘air cushions’ of the South sun facing facade.
Chapter 4
Design Investigations
Design Aims

The principal aim of this design led research investigation is to explore how interactive interior architecture and kinetic design can marry to bring about a new, interesting and dynamic interior language. Bringing interior space to 'life' with kinetic tectonics of dynamic elements with parametric digital fabrication;

1. To investigate how digital fabrication can be utilised for modular and parametric interior architecture.

2. To explore the design implications and requirements of dynamic interactive interiors; spatial arrangements, fenestrations, thresholds - as well as assemblability and integrity.

3. To investigate how interior architecture can embody the virtues of kinetic sculpture - ‘obscured’ characteristics unlocked through interaction of users or other energies.

The principal aim is intended to build upon previous research on flexible interior architecture, kinetic building systems, and interactive modular spaces. Transformable furniture and building elements have been increasingly incorporated in interior architecture to alleviate the pressures of small spaces. This research will explore how digital fabrication can be leveraged for precise construction, testing a series of designs of dynamic modules for a kinetic interior system.

Design Objectives

Tactile; of, pertaining to, endowed with, or affecting the sense of touch. perceptible to the touch; tangible.

Contextually defined as the ability for users to personally or collaboratively (active influence) interact with the space and influence the spatial outcomes.

Kinetic; relating to, characterized by, or caused by motion.

In this context defined as the ability for introduced conditions, environmental or user (passive influence) to give rise to ephemeral spatial outcomes upon interaction or influence - often unpredictable, unexpected.

Spatial Fluidity; the ability for the space to be rearranged, for variations in volume, division, light or colour.

Construction; the capacity for the design to be assembled and disassembled, and reassembled again.

Fabrication; an assessment of the manufacturability of the design, the efficiency of manufacturing process and materials, complexity of components and number of unique components.

Each prototype design was developed in consideration of the framework, but through the explorative design phase, some of these prototypes naturally had a stronger association with some of the framework criteria than others.

Design Investigation Framework

This framework has been established to both guide and assess the design prototypes. These summarize the qualities which the design prototypes seek to accomplish, in respect to the design goals I've already established. The design framework identifies specific attributes which answer pragmatically if the design is achieving what I set out to achieve.
The following design phase explores a series of prototypes for a modular wall construction system. The prototype designs that are presented in this phase demonstrate a collection of dynamic tectonics, and how those tectonics give rise to spatial fluidity. The findings of fabrication testing are discussed here, being an important component of this research, to understand the viability of CNC as a mass production module manufacturing process, also as physical testing of the geometric CAD development.

Demonstrating spatial fluidity through a series of plan, elevation, sections and perspective drawings, a number of configurations are presented to exhibit the spatial characteristics of each prototype. Rotational motion and linear motion are the fundamental mechanics that facilitate the spatial fluidity of a full assembly of these prototypes (Fig. 14).

To present and compare the prototypes they are explored through similar configurations, each arranged in walls of approximately 2 metres in height and spanning approximately 4 metres. For the wall prototypes that explore that rotational motion the plan drawings are most effective tool for communicating the intrinsic spatial fluidity. Exploring linear or directional motion the plan is also an effective tool; the use of elevation drawings in this section is more informative in communicating the flexibility and variation that is possible for these prototypes.

Figure 14: Plan development of a mobile flexible wall prototype.

Figure 15: Digital sketch development of binary wall prototypes, exploring relationship between formable wall radius and module connection angles.
Binary was derived from some of the early experiments on spatial rotation. The intention was to create a segmented wall, consisting of vertical sets of modules, connected end to end by hinges to allow each segment to pivot plus or minus 20 degrees against the next (Fig. 16, 17). Initial ideas were to allow the wall to be able to slide around two or more adjacent circular tracks or slots, and the wall segments would be able to angle, in plan, clockwise or anticlockwise depending on which way it was being taken around the tracks. The intention of this design was to be able to enclose different areas in plan, depending on the preferred configuration - which area you wanted to enclose.

One of the issues that arose with this particular version of the binary wall is the necessity for floor and/or ceiling tracks, and the intention of this design iteration was not to create a solid, heavier version of a curtain which would otherwise operate in the same fashion. Instead by pinning one or both ends of the wall either into the ceiling and ground, or extending past the end of a fixed wall, there would be less requirement for tracks to keep the wall upright. If each segment of modules could ‘grip’ onto its neighbouring segments the wall would be able to achieve stability by being locked, in plan, in a series of semicircular runs, each sequence of clockwise, or anticlockwise, section of segments would have stability. With one end pinned or fixed it would allow the wall to achieve a large level of variability, with the ability to enclose different size space, divide a large space into two in a variety of situations. The issue with this could be, even with the low tolerance achieved with CNC, over a large number of connections and the complete lack of integrity at the unpinned end there would be a tendency for the wall to ‘dog ear’ near to the end, which would be a significant stability concern. Also over a large length unsupported the wall would need to sit on the ground, either the base of the wall, or some sort of casters. The most structurally feasible option would be to pin both ends, or at points along the length. Multiple fixed points along the wall will create more stability at the expense of greater spatial variability.
Figure 18: 1:100 Plan experiments. Variations of configurations for Binary prototype wall. Fixed pivot on both ends. Continued Right.
The binary wall is based on a single repeated module, which can be stacked vertically to create the wall segments. The wall segments could also be assembled individually with more of a skeletal frame, rather than a solid stack of CNC’d components. Using proprietary hinges to link each segment there is an extremely limited range of motion between on segment and the next.

Ideally this would keep the wall upright at all points in between the fixed ends. The final iteration of the binary wall is where the notion of kinetics comes in. You are able to push or pull on a section, and each section should follow and sweep around, following the same arc controlled by the angled sides of the segments, rolling like a vertical wave from one side to the other.

Because the initial idea was about containing circular areas in plan, the segments took on a concavity to the longer, outward facing sides. This was done so that when the segments came to form a curvilinear wall the inner surface would be continuous and hide the hinges/joints between each segment (Fig. 21). This also created a different condition on the outer surface which became jagged and exposed the hinges from that side. Part of the ideas about kinetics is creating patterns and having these patterns appear and disappear as the wall is manipulated in such a way.

Also, as each segment switches from angling clockwise to anticlockwise, the noise of the new sides coming together reveal another unseen pattern of the design, and as you continue to manipulate the wall there would be a series of these little interactions and noises.

In terms of permeability this design would consistent, because the elements are not getting closer or further from each other. If the segments were solid or impermeable then no matter which way they angle or move there is no change to the amount of light smell or sound that can pass through the wall.

The way the wall is limited in its range of motion has a negative implication for spatial arrangement where it would not be able to cascade or ‘shrink’ or roll into itself. The diameter of the enclosure would be the only way it can fold.

An interesting exploration could be into variable sizes of the angle achievable between any two segments. Possibly if one end has greater range of motion it could roll up on itself in a controlled manner. I think there is also interesting implications for using varied angles to achieve some sections with less and some sections with more flexibility, done in such a way that there was some constraints and some ‘end positions’ where the wall would be maxed out in one direction or another, creating areas of smaller and larger diameter space. Users would be able to use the sections they wanted to control the intimacy of the area they choose to occupy.
**Figure 19:** Exploring relationship between S-shape plan and elevation.

**Figure 20:** Fabrication testing for the Binary prototype, positive and negative details for vertical stacking.
Figure 21: Fabrication testing, exploring the module hinge conditions assembled in series.

As the CNC is best working with sheet or similar materials, that is the motivation to create low profile stackable elements, either out of sheet material like MDF or ply, but here is potential also to use solid timber such as 45x90 or similar. Using solid timber is going to be both high weight and a lot of resources, making it costly to produce for manufacturing time and the amount of materials that would be required. Too much material brings more issues of stability and structure, but also would limit the usability of the design. If people could not interact with it the way it was intended it would fail to achieve what I set out to in terms of simple spatial manipulation. The connections between each segment would under a lot of stress and would give cause to mechanisms failing or it falling apart entirely. The idea of stacking and attaching segments is partly attributed to the desire for ease of assembly and disassembly.

Getting the components CNC’d for the binary wall doesn’t have to be concerned about the issues of tolerances, except for the end fixing points. Recesses for the hinges were manually made after the CNC process.

Adhering to the same geometric forms, but reduction in weight and materials would allow the wall to be more interactive for more people, potentially less time fabricating with less materials required. Hollowing out of segments could alleviate some of the weight and usability factors, but ignores the time implications of manufacturing. As mentioned earlier, there might be an argument for creating an easily assembled frame which achieves the same kinetic qualities.
Prototype 2: Chain

The chain wall is another different development on top of the binary wall. The focus on the chain iteration was to create continuous surfaces on both sides of the wall as its reconfigured. Unlike the binary and rope designs, the chain wall has overlapping elements which sandwich with the neighbouring module and an axel between them to allow each to rotate around a shared pivot. The design iterations led to the geometry to allow for the maximum angle of each point of rotation to be controlled, and not have any different visual implications of the connection. The chain wall was developed to mirror the fluid characteristics of a bike chain (Fig. 24). The individual components require the least time during digital fabrication, due to the removed requirement for pocketing. Pocketing is the partial depth material removal that creates the slots and extruding details of the modules.

The chain modules have a greater range of motion to the binary wall, giving it increased variation of achievable configurations. (Fig. 23)
Figure 25: 1:50 Plan Chain Prototype Wall. Variation of potential configurations. Experiments show Chain wall is capable of greater spatial variation in contrast with the Binary Prototype. Continued Right.
Prototype 3: Rope

Figure 26: Rope Prototype module relationship.

Figure 27: 1:5 Rope Prototype

Figure 28: 1:5 Rope Prototype

Figure 29: 1:25 Rope Prototype wall S-shape configuration.

Figure 30: 1:25 Rope Prototype wall double S-shape configuration.
The rope wall is the second generation of interactive wall designs, and looked to develop on what the binary wall was achieving. Through some scale physical testing, using similarly geometry for wall segments, instead connecting each to the next with rope or cable running from one end to the other, in between each lateral layer of the stackable CNC’d components. Unlike the binary wall the rope wall could be straightened and bent into other angles other than the prescribed radius of the binary wall components.

I think if the wall has a lot of ‘slack’, the rope might not be enough tension to keep the wall upright, being much more prone to falling over in the middle, even when fixed at both ends again as seen on the last iteration for the binary design. Each module needs a system to ensure that its neighbour can not lean over away from it. Using a gear-like cog system and the tension (of the ropes) from one segment to the next.
Figure 32: Continued, 1:50 Plan Rope Prototype Wall. Variation of potential configurations.
A theme that is consistent throughout each prototype phase are issues about stability and weight. The focus of this phase is to hypothesize and develop designs for spatial fluidity and tactility rather than completely resolve all of the potential failings, these are discussed further.

The geometry of segments are such that, like the binary wall, when the segments are joined at the maximum angle, they create a smooth continuous surface, but unlike the binary, there's a degree of stability and structure when the angle is less than the maximum. Also while the segments are at a minor angle there is a gap between each between the gearlink at the top and bottom, revealing the rope connections and a fenestration through which does not appear in the binary wall. This is the only real notion of the ephemeral qualities - not strictly kinetic because the qualities are not a product of the motion.

The different modules can be CNC'd at the same time and the only other components are the ropes.

The end fixings would consist of a fixed pole or column that the end modules could slide down on. The tolerances for all these components are crucial for the success in terms of stability and usability. If they are too tight the smooth motion will not be attainable (or too tight they will not be able to rotate around each other at all), and if too loose this will give rise to potential for instability and, inevitably, failure.
**Figure 33:** Fabrication testing. Rope Module stacking tests and cog connection details.

**Figure 34:** Above, Connection testing with fabrication test models.
**Figure 35:** Below, Negative details for rope channel and stacking - test models.
**Figure 36:** Plan exploration of the range of motion between adjoining modules.

**Figure 37:** Exploring the range of motion between adjoining modules and interior edge join condition.
Prototype 4: Pivot

The pivot wall prototype is the first prototype which is intended to be able to be assembled without any other necessary fixings or other components. The individual modules have been developed to be able to stack on top of one another, similarly to a spaced running brick pattern. The lower side of the modules have a negative area that has been milled away in the CNC process. The upper side has the corresponding extruding area. The rotation of the modules against the modules it attaches to is controlled by the centre of the connection being cylindrical. An earlier development of this prototype was based on a connection system that only had these cylindrical connections. This allowed full rotation of the neighbouring modules. The final development of this included 'wings' on this cylindrical connection, with narrow wings on the positive details, wider wings on the negative details. These controlled the angle that the neighbouring module would be able to rotate to. This resulted in similar spatial opportunities to the prototypes that have already been discussed.
Figure 41: 1:50 Pivot Prototype Wall J-shape Configuration. Continued Right.
Figure 42: Pivot Fabrication Testing, Negative pocketed connection detail.

Figure 43: Pivot Fabrication Testing, Positive connection detail.
One finding from the CNC fabrication was that while the modules would stack and rotate as intended, the freedom of rotation was considerably lessened when compared to the other prototypes that operated in a similar fashion of rotation.

Out of these four prototypes discussed so far, this prototype iteration is the simplest to assemble, removing the need for other components or proprietary elements, credited to the connection system. Unlike the other designs already addressed, this is the first which does not provide impervious partition between spaces.
Figure 47: Pivot Fabrication Testing. Stacking pivot modules.
Figure 48: Pivot Fabrication Testing, Stacking modules.

Figure 49: Pivot Fabrication Testing, Modules assembled in series.
Prototype 5: Cascade

Expanding on the findings through the development of the Pivot wall prototype, the Cascade prototype shifted to a focus on a different type of motion. The prototypes all previously discussed realised spatial articulation though rotational motion. Cascade achieves its spatial fluidity through linear, or directional, motion. Namely, the cascade design allows a series of modular components to bank up into a straight solid wall, and each component in turn shifts horizontally to extend the length of the wall. A groove on one side of the component is shaped to guide a bar, or rudder, on the opposite half of the component to control the direction and rotation of the neighbouring module.

In this instance, the design of the Cascade prototype begins as a straight wall, and each sliding component moves out and rotates slightly as the elongated rudder slides along a curvilinear groove. Each section of the wall is made up of stacked modules, all joined vertically with a square pin; a set of simple digitally fabricated components. A base section fixed to the existing architecture, the cascading motion goes in and out in the same fashion each time. Each Module rests on the edges on the neighbouring modules that make up the next section. As each section slides out and rotates slightly the wall becomes longer, exposes new openings to eventually become a complete semicircular partition. Hereby turning a short solid wall into a new semicircular volume division.

Figure 50: 1:5 Cascade Prototype Module.
Figure 51: 1:100 Cascade Prototype configurations. Continued Right.
This wall prototype did not make it the digital fabrication testing stage. The nature of the design, that is to control motion though the groove and rudder system creates conflicting conditions between the function of the wall and the physical properties of the components. To manipulate the design the user must slide on component along from the next. For the beginning sections of the design this would be less conflicting, but as the length, and collective rotation that occurs in this semicircular design, applying a linear force to one end would be expressed as rotational force further along the wall closer to the fixed end. Because of this torque going through the relatively thin rudder of the module, and with some of the findings of the fabrication tests for other prototypes this wall design requires more research to be realised. At this stage, the research reaches a critical impasse between accomplishing the desired tactility through the CNC fabrication process.

Unlike any of the previous designs discussed, this is the first prototype which explored ideas of variable permeability, which was the primary motivation to create the Cascade prototype. It is interesting to explore the connection between the users ability to transform the space by extending a solid wall into a new different configuration. There is potential within a language such as this to create an interesting and playful relationship between users and the space they are interacting with by using different shaped grooves to lend itself to be capable of unforeseen configurations. This could create a sort of kinetic exploration or discovery that the users go through when they interact with the space.

**Figure 52**: Cascade perspective configurations - different stages of deployment.
Prototype 6: Drift

The final installment of the prototype series is the Drift wall prototype. This prototype responds to some of the complications and opportunities that surfaced through the previous experimentation, particularly the Cascade prototype. The Drift shifted back to a design that required a fixing method on either end of the wall assembly. Unlike all of the designs already addressed in this series, Drift explores variable spatial conditions and tactility through many individually mobile and interactable modules, in a way that leads to variable position and configuration of permeability.

Each module is stacked in a similar fashion to the Pivot prototype, the difference being the underside of the module provides two grooves, either side of the centre. On the upper side a positive detail, the width of the grooves is positioned on the ends of the long rectangular module. The positive detail fills about 2cm of the 15cm groove beneath it, allowing it to slide across the module beneath. As each module reaches the maximum position on its adjoining modules above and below, they too can move along and drag its adjoining modules.

Figure 53: Drift Prototype Module relationship.

Figure 54: Drift Prototype Module.
To communicate the implications for spatial fluidity of this design, it has been employed in another semicircular configuration. Each module has independent freedom which has not been explored yet in this series; each other prototype relying on a connection of modules into a larger fixed component. As this design does not have the capacity to influence the volumes of space, the plan is a less effective communication tool to explore how this design can give rise to new spatial conditions. In this series the elevation drawings are the place to present different configurations.
Figure 56 1:50 Drift Prototype Elevation Configurations. Elevations reveal subtle differences achievable in shifting modules.
This prototype also requires less unique parts than most of the previous design explored here in this design phase.
**Figure 62**: Fabrication testing. Maximum overlap between modules.

**Figure 63**: Fabrication testing. Minimum overlap - Maximum separation between modules.
Figure 64: Fabrication testing. Minimum separation between modules.

Figure 65: Fabrication testing. Maximum separation between modules.
Figure 66: Digital Fabrication setup. Various milling tool path diagrams. Clockwise from top left: Ply Sheet Outline, Pocket Test for size, 10mm Pocketing, Full depth, 6mm Outline profile cut, 6mm pocketing.

Figure 67: Digital Fabrication setup. Outer Profile 6mm Depth tool path diagram.
Fabrication Findings

One of the most important conditions required for the designs on the whole was the tolerance and precision of the CNC milling process. For the “proto-paramacist” type design process to yield success through this method of digital fabrication, the precision of the modules that were being produced needed to reflect the precision of the CAD file which they are produced off of. One of the primary design intentions was for implementing a consistent modular assembly of identical/repeated modules.

Looking at the binary wall, rope wall, the significance of the tolerance for these versions was exploring the vertical nature of stacking the designed modules. Each single module has the lower pocketing/negative detail and upper positive detail in such a way that they should fit tightly into one another. The nature of the CNC milling process has an accuracy of ±0.125 mm, I have found, which with timber created some variation in the tightness/looseness of each connection. By designing for identical modules the goal was for a number of these modules being mass produced and the ability for them to be assembled in no particular way, each individual module would be compatible with any of the others. Aiding in assembly, disassembly and reassembly by removing the necessity for other fixings removable or otherwise.

The pivot wall, chain wall and slotted wall all dealt with ideas of the modules to be able to move in some fashion directly against the others that it was assembled with. Considering pivot and chain designs, the success was dependent on how one module would rotate around a point or connection with the neighbouring module. Again, highlighted in this section is the significance of the tolerance and precision. For the designs discussed above, the tolerance was intended for an absolute condition, essentially fixing one module to the next in a way that it would become one, larger, isolated component, but for the designs being discussed here, the other aspects of the design, in particular tactility and interaction, depend on the ability for these rotations/movements to be facilitated. When the tolerance of the timber CNC components was not accurate enough, the modules become immobile against the next, reducing the capacity for it to move independently from the neighbouring sections.

Considering the nature of the CNC milling, each of the design iterations relied on fabrication of a low profile module, extracted from the sheet material which was best worked with using this method. Because of this, each connection was repeated in a vertical fashion, and in the cases of chain and in particular the pivot wall, the repetition of the connection increased the chance that one of the modules would become stuck and hinder the success of the design in regards to the kinetic and tactile design ambitions.
Chapter 5

Expression
This research identified how digital fabrication methods can be utilised to manufacture architectural components to... Specifically, this investigation explored how a modular construction/assembly system for interior spatial dynamics would CNC milling of sheet timber products. Responding to a set of design criteria which were distilled and defined from the reviewed literature, a series of prototypes were developed. By employing a parallel prototyping design process, the collection of unique design responses that this thesis presents were each developed in tandem with the rest, in a collective feedback loop. In attempting to present a cohesive range of prototypes, experimentation that focused on one prototype often had ramifications for one or more of the other prototypes.

To investigate how digital fabrication can be utilised for modular and parametric interior architecture.

Because of this research method, generalized conclusions are that the success and opportunities associated with the selected manufacturing process - CNC milling - being a common factor across each individual prototype experiment.

One of the design intentions was to design a system of easily assembled, homogeneous components, while simultaneously a system where modular components would be able to shift, rotate or pivot in a restrained fashion so when they are all assembled in the intended fashion each module would move a small amount, amplified across a larger number of adjoined components. can mainly be attributed to one fundamental factor, revealed through the fabrication testing; the intensity/energy that kinetic sculptures operate on, manifesting forces of weather, is much less than the level of intensity of users interacting with the same interventions. With the intention to create interior architecture that users have control over, there needs to be a certain level of endurance so that the changes the user makes are not undermined by the natural forces acting on the intervention at the same time.

A limitation of the research undertaken thus far is in identifying the suitable balance between the freedom of movement between modules in the different axis which they are operating on. The CNC milling is capable of <1mm of precision, but the correct tolerance was not accounted for in this phase of the fabrication process. To achieve a balance between 1. freedom of motion, 2. structural integrity and 3. capacity for disassembly/reassembly, some further research to determine the appropriate tolerances allowed for should be undertaken.

To explore the design implications and requirements of dynamic interactive interiors as it pertains to spatial arrangements, fenestrations, thresholds - as well as assemblability and integrity.

To investigate how interior architecture can embody the virtues of kinetic sculpture - ‘obscured’ characteristics unlocked through interaction of users or other energies.

Through the variations in prototypes, this research has identified how such a system can achieve a variety of different means for users to manipulate the interior spatial conditions. These fluid spatial conditions that have been identified through this investigation are adaptable space and volume, and adaptable permeability. Half of these prototypes sought to find a solution to how such a system could create flexible partitions capable of bending and curving to allow for different spatial configurations and volumes, the other half responding to how these partitions could have potential to adapt the light and sound transfer from one space to another.

The second and third design aims were focused on what an interior architecture solution would be, that was capable of responding to an external influence. While the second design aim for interactive interior architecture was thoroughly addressed, the third design aim was not as well considered in the prototypes that this design research investigation produced.
How can adaptable and interactive interior architecture embody kinetic principles and facilitate spatial dynamics?

Answering the main research question, this thesis provides an analysis of interaction in architecture and responds with a series of design outcomes all of which are unique construction and fabrication methods for spatial dynamics. Combining the principles of dynamics and kinetics with tactility, interaction and manipulation has been expressed through these modular prototype designs. The marriage of these ideas is explored in a variety of ways to investigate different combinations of digitally fabricated mechanic details, styles of kinetic interaction and variable spatial conditions. The methodology adopted allowed the findings to be reflected upon throughout, feeding information back through iteratively, both in the design phase and synthesis phase.

Agility in Interior Architecture provides the basis for a new architectural language for interaction within interior architecture to empower users control over the surrounding spatial conditions.
Bibliography


Blackman, D. (2003). Housing : The ever-changing demand and requirements for housing mean that providing flexible, desirable dwellings is a major challenge for the future.


Homes for today and tomorrow. (1961) Great Britain. Ministry of Housing and Local Government; Morris, P.


