RESPONSIVE BUILDING ENVELOPES;
Active Apertures for Chinooks

by

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A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the
degree of
Master of Architecture

In

(M.ARCH.) Professional

Carleton University
Ottawa, Ontario

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RESPONSIVE BUILDING ENVELOPES

ABSTRACT

This thesis is an investigation into responsive architecture, specifically within the building envelope. It seeks to respond to local environmental conditions and enhance sensual qualities to generate a unique architectural environment by engaging interaction between people and the building's skin. By analyzing the wall assembly as an aperture for responding to the peculiar weather conditions in Calgary specifically Chinook winds, the responsive envelope will engage air, light and water movement to harness energy and create a site specific building envelope.

This thesis develops from an exploration and investigation into flexible, adaptable, transformable, dynamic and interactive elements in architecture that have allowed structures to achieve movement. Investigations into types and reasons for movement and their transitions will lead to experiments into the phenomena of this choreography and the delights and experiences that arise. While traditional buildings are often regarded as static entities this thesis will show that they do indeed address dynamic and ever-changing factors. The contemporary design of buildings which can respond to environmental changes and building use enhances both the quantitative and qualitative aspects of the building.

Through analysis of existing research and documentation, this thesis presents the research and design of an 8890m² Arts and Culture Incubator and residential building in downtown Calgary that explores the concept of the responsive building envelope to environmental conditions, building program and urban context.

Illustration 1: Responsive Environments
Fran Castillo

RESPONSIVE BUILDING ENVELOPES **ACKNOWLEDGEMENTS**

This thesis is dedicated to my family who has constantly supported me throughout my life; the distance from home has never encumbered their encouragement. Without their support I could never have conquered any of my struggles or succeeded in my accomplishments. I would like to thank my mother for her objective and optimistic support, helping me to remain focused despite all the chaos and whose diverse interests established my love of learning; my sister for always inspiring me with her passion and dedication to every task she takes on; my grandmother for her patience; and my grandfather for his dedication to quality work and the beauty of the English language. They are the foundation of my work and the core that always holds me together.

I am sincerely grateful to the professors at Azrieli School of Architecture and Urbanism who constantly challenged my limits and always gave me a new perspective. I would like to express deep gratitude to Sheryl Boyle for her insight and direction throughout my thesis.

I would like to thank all my family and friends who always made me laugh and kept pushing me to better myself. I am eternally thankful for your support.

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RESPONSIVE BUILDING ENVELOPES: PART I INTRODUCTION

Rudimentary forms of responsive architecture can be seen throughout history starting with the movement of a simple pivoting door to contemporary retractable roofing systems which allow for a complete change in environment and conditions.

Responsive architecture is used across the world especially in the Middle East and Europe where climatic patterns and temperatures allow for a more open and free relationship between the interior and exterior.⁽¹⁾ The word *responsive* can be defined as a quick and positive reaction.⁽²⁾ Responsive design is a broad field covering the choreography of movement, functional movement, environmental responsiveness and aesthetic purposes. Its goal can include making buildings more useful, more energy efficient, and contributing towards richer, more aesthetic and more delightful experiences. The benefits of responsive architecture can also include prolonging the life of the building by being more adaptable and accommodating to users. Advanced technology and new materials have produced sensational responsive building envelopes, achieving optimum building efficiency and a quality of experience unique to its users and context. These factors enable architecture to have distinct phenomenological aspects, which connect people and place. Movement can generate extraordinary moments or make people more

Illustration 2: A Retractable roofing system for the University of Phoenix Stadium, Peter Eisenman, Arizona

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INTRODUCTION

aware in an experience by playing with light and shadows, repetition, balance etc and engaging the imagination.

This thesis investigates methods to use responsive architecture appropriately and effectively in Calgary, Alberta, to create a symbiotic relationship between architecture, its inhabitants and the environment. Typical building design takes into consideration dynamic factors such as solar patterns, wind variation, seasonal change and user needs while remaining primarily static in form. This often creates a disjuncture between the building and its environment at specific times of year. To explore this disconnection, this thesis seeks to investigate conventional and traditional movements found within the building envelope, such as windows, oculi, chimneys and doors and reinvent them to provoke phenomenological experiences dependent on unique weather conditions, in addition to standard considerations.

Calgary is a young city with dynamic and quick changing weather conditions. In particular Chinooks, which are a unique weather condition to Calgary, can shift temperatures by 30 degrees in a few hours, providing a glimpse of spring in the midst of winter. Calgary is also one of the sunniest cities in Canada; enjoy 2396 hours of sunshine each year.⁽³⁾ The building envelope in this thesis is designed to

RESPONSIVE BUILDING ENVELOPES: PART I INTRODUCTION

embrace these unique or dramatic qualities and to enhance the life and use of the building.

Responsive architecture relates to elements that are moveable or transformable in terms of their purpose, their composition, their form and their meaning without reducing the overall structural integrity of the building.⁽⁴⁾ Responsive architecture is associated with a variety of terms and styles including: dynamic architecture, kinetic architecture, adaptable and flexible architecture, smart architecture and bio architecture. Responsive architecture incorporates some aspects of all of these design principles and is defined as a reaction to environmental conditions and user habits.⁽⁵⁾ This thesis focuses on movement of the building envelope, one of the most detailed and articulated parts of a building. The building envelope provides the first impression and interaction users have with a building. This thesis explores movement within this interstitial space between exterior and interior as a series of zones which informs the building program, layered spaces and overall form. This thesis examines the elements within the building envelope, exploring the concept of a door, window, oculus and chimney. The project building itself does not move or shift and movement is limited to the building envelope. The project also examines possible programs within static interior wall cavities of the building as well as programming the interstitial space.

Illustration 3: A proposed rotating dynamic tower in Dubai by David Fisher

RESPONSIVE BUILDING ENVELOPES: PART I

THE SKIN OF THE BUILDING

The building envelope is often referred to as the skin of the building that protects the core from environmental damage. Physical skin is one of the most versatile human organs aiding the metabolism, immune system, protecting the body from bacteria and regulating body temperature.⁽⁶⁾ The skin is a flexible surface, allowing movement and simultaneously acting as a surface for sensory perception (touch). Composed of a variety of complex systems and layers the skin acts as an active boundary between the inner core and the diverse environment outside. The building envelope also separates and protects juxtaposing environments but allows required transitions between the two spaces. The building envelope is also the first image of the building which is viewed from both outside and inside, similar to the skin of people. It is a surface that is judged by occupants and the community. The composition of the façade has a direct influence on the interior environment affecting comfort, energy and durability, productivity, as well as occupant and visitor happiness.

This thesis will explore the building skin as an active boundary between the core of the building and the exterior environment. *In Performance-Oriented Architecture- Rethinking Architectural Design and the Built Environment* by Michael Hensel, the building envelope or enclosure has four physical function; support,

“For physicists, a boundary is not an entity but an action; an active transitional zone where energy transforms from one energy state to another. A boundary is a lively zone of arbitration rather than of delineation”

-Hensel, Michael.
*Performance-oriented Architecture
Rethinking Architectural Design and the Built
Environment.* Chichester, West Sussex: Wiley,
2013. Page 58

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THE SKIN OF THE BUILDING

control function, aesthetic appeal and distribution functions.⁽⁷⁾ Michael Hensel describes these functions as follows:

- 1) Support Functions: The building envelope must be able to stabilize, resist, transfer and accommodate all dead and live loads forced onto the building which are required to make the building stable. The structural function of the skin can be performed by the whole envelope or a part of the envelope.
- 2) Control Function: The building envelope must regulate and mediate conflicts between interior and exterior loads, including the flow of moisture (rain, snow, water vapor), airflow; thermal control and energy (heat, sound, fire, light, solar heat, daylight, UV control), insects and vermin, pollution and allow for access and egress.
- 3) Distribution function: The building envelope can circulate services and utilities such as power, communication lines and water throughout the building and,
- 4) Aesthetic Function: The building envelope should present the building to the public realm through shape, colour patterns, reflectance etc with appropriate materials.

Note: Hensel's view of the building is primarily technological but presents concepts that this thesis will consider.

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

The building envelope divides the interior from the exterior and plays a crucial role in mediating these two environments. Openings in the building envelope include windows, oculi, doors, and chimneys. The position and design of windows, oculi, doors and chimneys affect the floor plans and the elevations and respond to site conditions and community context. All of these elements are reacting to conditions or situations that require a response and their design completely affects the aura and the quality of the building itself and its relationship to the context. These elements frame, articulate, enhance, join and disconnect environments.⁸⁾ Architecture influences behavior and establishes the movement between environments.

Penetrations in the wall dramatically influence the character of the room inside and the relationship the user has with the interior and exterior, creating destination points. Doors, windows and chimneys are responsive elements in the building envelope and their role has significantly evolved overtime. Each has suffered with the advent of standardization and many varieties have been eliminated.

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

DOORS, WINDOWS, OCULI AND CHIMNEYS

The first responsive elements in architecture were the creation of operable windows and doors, chimneys and oculi. Where the function of the wall is to separate and divide, doors, windows, oculus' and chimneys allow passage. However these openings provide very different functions and means of passages customized to the elements in transitions. Doors offer a direct, interactive and immediate area of transition. The window is a portal composed of a complex assembly of parts, while an oculus is a window in the roof without glass. Chimneys are connected to the hearth of the structure, typically seen in vernacular architecture. The necessity to control exterior factors for protection against weather, elements, ventilation, security, visual sight and passage has been a requirement for thousands of years; however these practical desiderata are also places of introduction - where separated and often juxtaposed places and elements meet.

Metaphorically and physically, thresholds mark a beginning and an end. References to thresholds are found in the many rituals and ceremonies, symbolizing a fresh perspective, newfound clarity or a new start. These areas of transition have embodied meaning and emotion and are represented and depicted in ways to worship and connect to mankind's relationship with each other, the natural

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

world, time and even the heavens.

In Roman mythology, Janus is the god of transitions: a god of good beginnings and the result of fair endings.⁽⁹⁾ He is the porter to heaven and inaugurates the beginning of each year in January, the month dedicated to him. Janus is the guardian deity of gates and, similar to every door, Janus can see two ways: forward and backwards, past and future. Janus was worshiped or prayed to at beginnings: the start of harvest time, planting, marriage, birth or other life events. Cardea, goddess of thresholds, especially door pivots and hinges, was prayed to for security and health. These thresholds have altered the way people associate with each other and the spirits, dividing and connecting spaces and worlds. They have contributed to the separation and connection of man and divinity, the separation between public and private space and separation of environmental factors and weather conditions. Perhaps the decrease in the majestic personifications or ritualistic ceremonies has led to the increase of scientific and quantitative measurement of these elements, allowing man to perceive his control over his environment.

The first primitive doors and windows were simply holes in the wall, potentially covered in animal hide, cloth or wool and later adorned with shutters. One of the oldest doors discovered was found in 2010 in Zurich, Switzerland, dating back

Illustration 4: The Roman god, Janus; looking forward and backward on a coin

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

5000 years. It was constructed out of Poplar planks of wood with hinges to keep out the cold wind from the lake. ⁽¹⁰⁾

Windows, doors, chimneys and oculi also provide orientation: as one enters, they are immediately presented with new conditions of the space and provide a datum. Each element is embedded with meaning and symbolism and has a function. Their design includes the use of durable materials with precise assembly. *Dure*, a verb connected with the Middle English word, *Duru*, is defined as “to last, continue, endure.” ⁽¹¹⁾ These responsive elements are continuously tested, through repeated and constant use. Windows, doors, oculi and chimneys must filter environmental conditions. A screen on a door should allow ventilation while prohibiting insects to pass; a shutter blocks direct sunlight while allowing natural ventilation and a lock can stop unwelcome visitors from entering. These elements are intricately crafted and innovative pieces of technology. Doors and windows are pieces of technology within the building envelope, customized for specific program requirements or environmental conditions. Windows can hold certain gases, like argon, within the airspace between two or three panes of glass to be more efficient or have a low-e coating to reflect more radiant energy coming into the building. Some doors must be airtight and require seals to maintain security or serve to open automatically

Illustration 5: The remains of the oldest door discovered in Europe. The age of the door was determined by tree rings with archaeologist, Neil Bleicher speculating the construction date to be 3063 BC (same time as the construction of Stonehenge)

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

for convenience. Each element needs to be intricately designed for its purpose and proves to be an important aspect of the efficiency of the building. These technological systems are able to more readily adapt to change but has a reciprocal relationship to experience. Phenomenological experiences rely on this technology to often create new, awe inspiring environments.

These elements have evolved over time, as has expectations of the building inhabitants. People today demand direct control over building elements with instant responses. Storm windows, once prevalent, are now very uncommon. Their installation in the fall and detachment in the spring was part of the ritual of owning a house. The wood fire providing heat and a cooking area has been replaced by a thermostat and an electric cooktop.

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

DOORS

Doors contribute to the phenomenological aspect of entering and departing. *Duru*, of Germanic origin meaning door or gate is related to the Dutch *deur* and German *Tur* or *Tor* (door or gate). This is taken from an Indo European root shared by Latin *foris* (gate), Greek *thyra* (door), Gaulish *doro* (mouth).⁽¹²⁾

Doors can dramatically influence the atmosphere of the space depending on their scale, materiality, construction, geometry and relationship to the program of the space. Their presence can establish a certain aura or invoke a tacit response prior to entering. How one enters a church, a home, a hospice or a children's hospital is very different from how one leaves that space.

Doors allow for transition between exterior and interior, while also dividing and organizing space within the interior. Their position determines flow and connection between spaces, allowing for moments of interaction. In 16th century Italy, a convenient room had many doors allowing access to a variety of other rooms permitting flexibility of program; however by the 19th century in England, most rooms only had one door, often leading to a corridor of many doors (for the removal of traffic in the room).⁽¹³⁾ This strategy rearranged the entire design of

Illustration 6: Gates of Paradise Doors on the North Entrance of the Baptistery of San Giovanni in Florence. The doors were designed by Lorenzo Ghiberti

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

the house, often separating people of differing status and completely altering the pattern of domestic life. The passage was mainly for servants, in order to separate their domain from the gentlemen and ladies. Doorways are more than a divider or partition, they are symbolic in nature and are metaphors in other aspects of life.

In early Christianity, all worshippers entered through the west portal and made the voyage down the nave towards the altar in the east and towards the place of baptism and communion. The positioning of elements, commencing with the entry door, represents a progressive journey to immortality, rising or being resurrected to live for eternity through faith with Christ. In the Romanesque and Gothic eras, Church doors were positioned symbolically in groups of three, in association with the Holy trinity. The proportion of doors relating to the rest of the building was also identified in Vitruvius' *Ten Books on Architecture*, specifically addressing doors of Temples and was part of the perfect relationship between body and architecture⁽¹⁴⁾

Doors can now be made out of a variety of materials including wood, metal, glass, paper, leaves and hides, with the ability to swing, fold, slide, or roll in order to separate or open a passage. Evidence also indicates the Romans were using sliding and folding doors in 100AD; having slotted rocks for tracks and guides.⁽¹⁵⁾ Greek scholar,

"So I say to you: Ask and it will be given to you; seek and you will find; knock and the door will be opened to you."

- Luke 11:9

"I am the door: by me if any man enters in, he shall be saved, and shall go in and out, and find pasture."

- John 10:7-9

"I know thy works: behold, I have set before thee an open door, and no man can shut it: for thou hast a little strength, and hast kept my word, and hast not denied my name."

- Revelations 3:8-1

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<[www. BibleGateway.com](http://www.BibleGateway.com)>

RESPONSIVE BUILDING ENVELOPES: PART I THE FIRST RESPONSE

Heron of Alexandria, created the earliest known automatic door using steam power to open the door after lighting a fire.⁽¹⁶⁾ A door's components have drastically changed throughout time. Once dressed with detailed knockers, locks, handles, peep holes and elaborate hinges, the door has been stripped of its decoration and transformed into a technological instrument.

During the Industrial Revolution, doors became standardized and predictable for security. Their mass production drenched them in technology and endangered individuality. Some doors have even become untouchable: automatic doors and garage doors have replaced swinging doors and this change has altered the connection people have between the interior and exterior. Some public bathrooms now are door-less and use a corridor in order to ensure privacy and eliminate spreading germs. The most sanitary door has become no door at all.

Illustration 7: Heron of Alexandria's design for an automatic door. The system relied on heat and pneumatics to open the doors.

Illustration 8: Contemporary Automatic Doors

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

WINDOWS AND OCULI

Windows and oculi are defined as an opening in a wall or a roof to admit light and air. The idea of a window or a door is also used figuratively or poetically, referring to insight or opportunity. *To go out of the window*, refers to a person who is insane, tossed or wasted, while *the window of opportunity*, implies a brief moment that an opening exists.

The term 'window' has roots from Old Norse *vindauga*: from *vindr* (wind) and *augu* (eye). Wind was defined as "to blow" and indicates a window was a hole that allows passage. ⁽¹⁷⁾ *Vindauga* is still used in Norwegian Nynorsk and Icelandic languages. Initially windows were static and the response to retard the elements resulted from people filling the void with stone, wood or panes of glass, mica or paper. ⁽¹⁸⁾ The oculus derives from the Latin word for "Eye" as it resembled an eye. This described a small window often circular or oval in the roof. In Swedish, the term *Vindoga* is associated with window and defined as a hole through the roof a hut. The word window was first recorded in the early 13th century, referring to an unglazed hole in a roof, instead of a wall. Window replaced old English *eagpyrl* (eye hole) and *eagduru* (eye door). Many Germanic languages however used the Latin

Illustration 9: A modern steel curtain wall. The wall redefines the concept of a window and a wall, combining the elements for a panoramic view of the surrounding environment.

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THE FIRST RESPONSE

word: *fenestra* to describe a window with glass. Old English referred to window as an escape hatch of the imagination while old German literally translated it to “eye door”. ⁽¹⁹⁾

People depend on windows for ventilation, illumination, filtration, framing, sun protection, radiation, blockage, redirect light, fire barrier, sound boundary, thermal shield. Windows allow for visual connection to the exterior, providing light and orientation to the inhabitant while an oculus allows for a connection to the heavens. Both connect the user to different environments without having to leave the building.

Windows used to provide a specific view to the exterior or destination in the house. Factors to ensure the efficiency of windows include the size and the dimension of windows, the position and orientation of the windows (in relation to the orientation on site and to other windows), the effect of external obstructions, clarity or texture of the glass, canopy projections and quality aspects of daylight and glare. Windows provide a relationship with the outside, allowing a breeze, noise or smell to pass through; however it is a view of the world and not a full sensory connection if the window is not operable. The modern curtain wall has changed the definition

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of a window. The ability to increase the maximum size of glass paired with the innovative structural framing of the curtain wall allowed for a panoramic view to the outside. Windows are now everywhere and nowhere: their form has amalgamated with the wall and the mullions have become part of the structural grid. There is no longer a particular view chosen or highlighted but instead a continuation of the visual landscape.

Illustration 10: Mies Van der Rohe - Sketch of the German Pavilion in Barcelona 1929

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

CHIMNEYS

The hearth is the origin of civilization: people gather and dwell around the fire.

⁽²⁰⁾ The fireplace is comprised of the hearth and chimney, working simultaneously to allow fire inside the structure. The fireplace was ritualistic for birth, marriages and death. The hearth provided a variety of essential functions for the building: delivering light and heat for the structure, offering a place to cook and also a location where stories and tales were exchanged.

The word 'chimney' derives from Middle English, denoting "fireplace or furnace", from Latin as *caminus* "forge furnace," and from Greek as *Kaminos* meaning "furnace, oven, brick kiln." Each origin represents the word as a source of heat; while flue is taken from Old English *flowan*, to mean "to flow" or old French *Fluie* as "stream" and represents the path of travel from interior to exterior.⁽²¹⁾

Originally residences were heated by a fire, but lacked a chimney. Chimneys are required to control heat and airflow between inside and outside. They block physical elements from entering the building and keep heat inside, while expelling smoke. The invention of the chimney dramatically altered the design of buildings

RESPONSIVE BUILDING ENVELOPES: PART I

THE FIRST RESPONSE

allowing for lower ceilings and smaller rooms.⁽²²⁾ Without a chimney, the height of the room was taller as an oculus or hole in the roof allowed smoke to dissipate without being hazardous to occupants. Chimneys were also used in the hypocaust system in Ancient Rome, where the tubes or ceramic box tiles in the wall would draw smoke (produced by a fire in another lower room) out of rooms while still transferring heat around the building underneath the floors.⁽²³⁾ By the 19th century, heating no longer required a hearth and a chimney but was replaced by an automatic basement boiler where heat is carried by pipes throughout the structure. Lighting has also become automated and controlled, light bulbs disseminated in abundance in each room; stoves have replaced the need to create fire to cook; and televisions and cellphones have replaced the fireplace as the place for storytelling.

Illustration 11: Hypocaust System used in Roman Baths

RESPONSIVE BUILDING ENVELOPES: PART I **DELIGHT**

“But “on the earth” already means “under the sky.” Both of these also mean “remaining before the divinities” and include a “belonging to men being with one another.” By a primal oneness the four-earth and sky, divinities and mortals-belong together in one....This simple oneness of the four we call the fourfold. Mortals are in the fourfold by dwelling. But the basic character of dwelling is to spare, to preserve. Mortals dwell in the way they preserve the fourfold in its essential being, its presencing. Accordingly, the preserving that dwells is fourfold.”

- Martin Heidegger, *Building Dwelling Thinking*,
Harper Colophon Books, New York Page 2

In Heidegger's: *Building Dwelling Thinking*, Heidegger acknowledges a basic sense of space but believes that *places* are created by something more than the act of building or shelter. There needs to be a deeper connection with the structure to bridge the phenomenological to human dwelling; a lived and experienced environment where people can strengthen their sense of self and reality.

Transformations that enhance a building's connection to the environment can also enhance the sense of place. A retractable roofing system allows fresh air and natural light into a sports field enabling grass to grow when the roof is open, while providing shelter and protection from the elements when it is closed. With a variety

RESPONSIVE BUILDING ENVELOPES: PART I

DELIGHT

of responsive elements such as this, architecture is able to go beyond past a visual connection to the environment and achieve a more fully sensual relationship interior and exterior.

“In the experience of art, a peculiar exchange takes place; I lend my emotions and associations to the space and the space lends me its atmosphere, which entices and emancipates my perceptions and thoughts. An architectural work is not experienced as a series of isolate retinal pictures but in its full and integrated material, embodied and spiritual essence. It offers pleasurable shapes and surfaces molded for the touch of the eye and other sense, but it also incorporates and integrates physical and mental structures, giving our essential experience a strengthened coherence and significance”

*- Pallasmaa Juhani, The Eyes
of the Skin; Architecture and the Senses, Wiley 2005 page 13*

In *Ecological Architecture*, James Steel states that the perception of control in buildings greatly influences the user's perception of comfort. Although recent technological advancements have allowed the world to be more automatic, people still need control or the idea of control. Offices have actually started to install fake thermostats to reduce complaints in buildings while the building manager can still

RESPONSIVE BUILDING ENVELOPES: PART I **DELIGHT**

control the actual temperature of the building. There is a huge demand for control despite technological innovations generating automatic and predictable schedules. People still want to participate in their relationship with the building.

The Phenomenological

Contemporary architecture relies on the combination of an intricately technical and calculated science designed as phenomenological experiences, gathered by the senses. This amalgamation of the phenomenological and technical generates a captivating, functional and safe enclosure.

Phenomenological experiences occur by engaging the senses; however senses do not function in isolation. Information from sight, smell, sound, taste and touch is continuously gathered, combined, and assessed to develop an overall awareness and comprehension of being and time. Each sense contributes to a larger understanding of other sensory information and the more senses experience, collects into a stronger aura of liveliness and delight. ⁽²⁸⁾ Wind chimes allow people to visibly see and hear the wind not just feel it blowing against their body. Phenomena can be influenced by architecture's ability to engage the imagination;

Illustration 12: The Thinking Hand by Juhani Pallasmaa

RESPONSIVE BUILDING ENVELOPES: PART I **DELIGHT**

creating extraordinary experiences and infusing a sense of awe or wonder for the user. Phenomenological architecture is able to augment awareness of experience.

The 8,3 meter oculus at the Roman Pantheon allows sunlight and moonlight to move along the interior walls and ceiling. This monument maps the sun's path and acts as a gigantic sundial in its dark interior. During the winter months, the beam illuminates only the vaulted dome, moving downwards to the base of the dome on the winter equinoxes and then begins moving along the walls. A ray of sunlight fully illuminates the entrance at noon around April 21, creating a spectacular phenomenon. As the summer solstice approaches, the ray of light moves across the floor, although it never reaches the center. ⁽²⁹⁾ The Pantheon has been described as one of the most unique and spectacular architectural pieces in the world, connecting man to the heavens through the oculus.

Artist, Ned Khan has frequently used responsive facades to accentuate the flow and movement of the surrounding environment. His works frame and enhance the perception of natural phenomena including flowing water, fog, sand and light to generate a complex and changing system or skin. Wind Veil is a façade that uses

Illustration 13: The Oculus in the Pantheon, Rome

RESPONSIVE BUILDING ENVELOPES: PART I **DELIGHT**

aluminum panels to create a visual dance with the wind, replicating water movement on the building's façade. Khan's projects work more than one sense by playing with acceleration, repetition, weight and balance and mystery and imagination. This delight enhances the sense of wonder.

Illustration 14: Wind Veil: a media facade by Ned Khan

RESPONSIVE BUILDING ENVELOPES: PART I

EXPLORATION OF MOVEMENT IN THE BUILDING ENVELOPE

Basic Types of Movement

Most moving components are defined in the field of mechanics primarily by solid matter, as opposed to a fluid or gaseous substance. Solid bodies can be categorized as rigid, elastic or plastic depending on their behavioural characteristics. Most common rigid bodies are connected by hinged joints or gears that allow for movement. ⁽³⁰⁾ The primary directions of movement are translation, rotation and scale. Translation is described as a movement of a component in a planar direction; rotation allows movement around any axis, and scaling is an expansion or contraction in size. These three can be combined to produce a more complex motion like a directional twist or roll. The actual movement of parts can have two main design intentions: ⁽³¹⁾

1) Movement to serve as a change of state: This involves a movement from one point to another, in which the start and end states are the key destinations and the cause of the movement. The transition between the two points is for the most part unimportant. An example of this type of movement is a door: it can either open or close. In this definition, the process of opening the door is unimportant or

RESPONSIVE BUILDING ENVELOPES: PART I

EXPLORATION OF MOVEMENT IN THE BUILDING ENVELOPE

irrelevant.

2) Movement is itself the intention: the sequence of the change of state generates a quality and a character. There is typically no clear start or end and follows a repeating pattern or rhythm. This planned and choreographed design allows the movement to become part of the character of the building, to be seen and experienced, instead of just completing a movement. Speed of the movement and weight of the assembly is also relative to the perception and character of the building. Some movement generates interest because people are unable to understand how the movement occurs.

Skin, Assembly, System

This thesis will identify three functional factors based on responsive architecture: the form of the moving element, its position in relation to the building envelope (internal, part of the skin, external) and the phenomenological experience of the response.

Responsive architecture implies elements in motion, ranging from interior

RESPONSIVE BUILDING ENVELOPES: PART I

EXPLORATION OF MOVEMENT IN THE BUILDING ENVELOPE

and exterior surfaces, to components and modules. Specifically within the building envelope, movement can occur as an independent skin, an assembly or a system. Surfaces can move to change the appearance or adjust certain properties to play and control lighting or heat gain. Internal surfaces can also be adjusted for framing certain views, for spatial arrangements and organization or to influence the ambiance of a room. Components and modules can respond as a physical reconfiguration shifting or blocking certain elements, to the needs of the user. The method of movement must be intended as a deliberate action, rotating, moving or repositioning itself.

For information on the components required to make objects move, as well as research conducted on various kinetic materials, and control options, please refer to Appendix 1

RESPONSIVE BUILDING ENVELOPES: PART I

CRITICISM OF RESPONSIVE ARCHITECTURE

Transformable, movable, adaptable, and interactive architecture have received criticisms for becoming obsolete, their maintenance issues, degree of responsiveness and people's relationship to this interacting architecture. Numerous buildings including Jean Nouvel's Arab World Institute have designed innovative responsive building facades that quickly became inoperable when they break and are too expensive or too inconvenient to fix. Responsive architecture needs to ensure that the ease of maintenance is considered in the design and that the benefit of fixing the system is worth more than abandoning the project and the system becoming obsolete.

People need to want to interact with the building in order to make the response successful. If there is little incentive to participate in the action, the system might not work as efficiently as designed.

Illustration 15: Jean Nouvel's panel on L'Institut du Monde Arabe

RESPONSIVE BUILDING ENVELOPES: PART I

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RESPONSIVE BUILDING ENVELOPES: PART II

MANITOBA HYDRO PLACE

Architect: Kuwabara Payne McKenna Blumberg (KPMB)

Date: 2010

Program: Office Building

Location: Winnipeg, Manitoba, Canada

Type of Movement: Movement as part of a system

Manitoba Hydro Place has a unique curtain wall system that has a double glazed outer façade and a single glazed inner wall in order to insulate the building. The space in between the double glazed façade and single glazed façade creates a programmable buffer zone, used as a lobby and seating area. Automated louver shades in the cavity control glare and heat gain while motorized operable windows on the exterior open and close in response to changes in light and temperature. The façades form part of an integrated design for the entire building, incorporating geothermal wells, natural humidification, dimmable lighting, raised floor plenums, radiant slabs, solar chimney and an advanced building management system. The façades achieve energy performances that the company reports are consistently about 60% lower than comparable but conventional constructed building. ⁽³²⁾ Radiant floor slabs heat and cool the building and therefore the building eliminated the need for HVAC systems, mechanical floors, dropped ceilings, air shafts and fans. The interstitial space of the buffer zone is usable throughout the entire year, creating an environment that

Illustration 16: Dynamic Buffer Zone in the Manitoba Hydro Place

RESPONSIVE BUILDING ENVELOPES: PART II

MANITOBA HYDRO PLACE

uses responsive architecture to increase the amount of daylight into the building when required to provide a better quality of environment to occupants. The building however is not as stimulating as other responsive building envelopes and is more practical than experiential. The building serves to create a healthy working environment but does not stimulate or engage the viewer to experience or enhance new sensations.

Illustration 17: Manitoba Hydro Place Detailed Building Section

RESPONSIVE BUILDING ENVELOPES: PART II

INVESTMENT COUNCIL HEADQUARTERS TOWER

Architect: Aedas +Arup (façade Consultant)

Date: 2012

Program: Commercial Office Building

Location: Abu Dhabi, United Arab Emirates

Type of Movement: Movement as a skin

A set of twin towers dressed with a crystalline honeycomb shell protects the building from the sun, serving to reduce heat gain and glare. The pattern of the skin was a mathematically pre-rationalized form (a dynamic Mashrabiya) that opens and closes in accordance with the sun's path. This advanced mashrabiya is made of translucent PTFE coated fiberglass mesh. The building uses linear actuators and input from the building's control system to individually shift the skin panels to five positions, between fully open or closed as the sun moves across the building. It is estimated that the screen reduces cooling loads by 25% and between 20-50% reductions in solar heat gain compared with other traditional curtain wall buildings.

⁽³³⁾ Looking up through the façade cavity, there is a 2 meter gap between tripod arms that are staggered on each floor. The three Y- shaped structure arms extend to support brackets that tie back to the curtain wall, although overall it is structurally independent of the curtain wall. Wiring to the actuators, which are concealed in the tripod, runs along the support brackets and the Y- shaped structures. The tripod actuator pushes a pinhead connection out to collapse the six fabric panels inward

Illustration 18: Interior view of the structure of the Investment Council Headquarters Tower

RESPONSIVE BUILDING ENVELOPES: PART II

INVESTMENT COUNCIL HEADQUARTERS TOWER

to pin the mashrabiya.

The response of the envelope generates a wave of movement as the sun hits the structure; however the façade remains static until the skin is programmed to move. The façade also appears quite light on the exterior but its bombarded with the Y- shaped structural arms that block and disconnect the occupants on the interior to the exterior environment.

RESPONSIVE BUILDING ENVELOPES: PART II

L'INSTITUT DU MONDE ARABE

Architect: Jean Nouvel, Architecture Studio

Date: 1987

Program: Cultural Center

Location: Paris, France

Purpose of Movement: Movement as an assembly

The Cultural Center's southwest facade mimics the lens of a camera or an eye in order to control light into the building. The motifs on the façade have photosensitive apertures which open and close in order to control light penetration.

⁽³³⁾ The sensors are based on dynamic weather inputs to reduce energy demands but only when necessary so that visual demands are also met. The area of the façade is divided for several sensor readings: the movement within each square is a contraction and expansion of material influenced by climate while each bay is individually controlled by the occupants. The overall composition and design allows a rich playful façade. Although the façade has been criticized for being too responsive, too noisy or even unresponsive, it begins to explore how a building envelope could respond to elements and change interior conditions. The façade creates a dance of light and shadows in the library, stimulating occupants within the building as daylight filters through the dynamic mashrabiya screen. The façade engages the users to interact with the bay of panels but for the each square of the panel to respond to the climate. The degree of movement is small but effective in continuously changing the environment through elegant and playful ways of filtering light.

Illustration 19 : Interior view of L'Institut du Monde Arabe

RESPONSIVE BUILDING ENVELOPES: PART II

WIND VEIL

Artist: Ned Khan

Date: 2000

Program: Parking Garage Façade

Location: Charlotte, North Carolina

Type of Movement: Movement as a skin

Ned Khan creates performance façades that incorporate flowing water, fog, sand and light to generate a complex and changing system or skin. Khan examines the patterns that emerge from how things flow and expresses them by making the façade a media phenomenon. His façades generate a phenomenological experience through a media performance façade, playing with the elements to create a constant changing façade. ⁽³⁵⁾

Wind Veil creates a visual dance of the wind as flaps of thousands of aluminum panels move with the lively changes of the wind. The wind movement against these small flaps of aluminum replicates water movement on the building's façade. Viewers are able to see the wind through his installation, combining the senses to provide a more developed awareness of the site. The dynamic façade is mainly for experiential purposes but it contributes to reducing solar glare and heat gain in the parking garage, a program that does not require typical building systems permitting the façade to effectively shelter the cars from weather or environmental conditions.

Illustration 20: Wind Veil Installation on a Parking Garage.

RESPONSIVE BUILDING ENVELOPES: PART II

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RESPONSIVE BUILDING ENVELOPES: PART III

THE PROJECT

RESPONSIVE BUILDING ENVELOPES: PART III

THE PROJECT

This Thesis proposes the design of an Arts and Culture Incubator for Calgary, located adjacent to the city's downtown core in an area of promising growth socially, culturally and economically. The project aims to enrich the vibrant area and further develop its cultural and creative persona. The Incubator will provide 50 residential units on site in addition to the incubator areas.

The structure is wrapped in two building skins: a traditional curtain wall (mainly on the west and north façade) with a second skin which sweeps around the building to mediate environments and enhance specific areas of the building. The skin of the building is porous; a physical space and an area of transition. It incorporates characteristics of the oculus, door, chimney and window into one entity. The building envelope sweeping around the structure is called Janus, referencing the god of doors and transitions as the envelope connects and divides the secular interior, the earthly exterior and the heavens. Acting as a zone around the core, the building design interchanges the traditional definition of elements; the operable window becomes the skin, traditional walls act as doors and chimneys and the oculus becomes a solar chimney. The design also embodies the idea of "good beginnings" as occupants enrich their knowledge and expand their creativity in the

RESPONSIVE BUILDING ENVELOPES: PART III

THE PROJECT

arts and culture incubator and embrace the future with innovative achievements.

Janus' design provides stimulating and sensual spaces that embrace the quirky aspects of the site , specifically the Calgary climate. Similar to most Canadian cities, Calgary is haunted with cold winters but distinctively enjoys numerous hours of sunlight and the phenomenon of warm Chinook winds in the winter. The building envelopes assimilate and frame several key views while exploring and dissecting architecture's basic and oldest elements -doors, windows, oculi and chimneys. The skin will reform these essential elements to fit with the surrounding site and climate. The concept of the boundary of the building envelope also encouraged questions concerning program and placement of activities within the space of the envelope. Each activity is coordinated with cyclical climate conditions in the various climate zones of the building.

In addition to using passive design techniques, the project seeks to propose a new innovative building envelope that will interact with occupants on the inside and the weather inside.

Initial sketch for responsive architecture

Interstitial and Core plan

RESPONSIVE BUILDING ENVELOPES: PART III

THE SITE: CALGARY, ALBERTA

The project site is currently surrounded by various commercial and residential infrastructures. Located adjacent to the downtown core, East Village, and the Stampede Grounds, the property is bordered by concrete surfaces which are used primarily for parking especially during the Calgary Stampede, a two week event held every year in July.

East Village is developing as a dynamic area in Calgary with the construction of the National Music Center, a new library around the historic King Edward (Eddy) Hotel, public art installations, new apartment complexes and restaurants as well as the development of a river walk around the area.

Many corners of the downtown core also exhibit sculpture pieces. Calgary's skyline has also become enriched with internationally renowned architects designing world class structures, including the Bow Office Building, the National Music Center and the Peace Bridge.

The site also runs parallel to railway lines which are used twice a day as part of the Canadian Pacific Railway transport of goods across the country.

Illustration 21: The City of Calgary with the Rocky Mountains in the distance

Illustration 22: Downtown Calgary with the project site highlighted.

RESPONSIVE BUILDING ENVELOPES: PART III THE SITE: **CALGARY, ALBERTA**

This thesis will contribute to the innovative and creative structures being built in Calgary to strengthen its design integrity and pride within the city.

Illustration 23:
A. Fort Calgary (heritage Site)

B. Stampede Grounds

C. Downtown Core

Illustration 24:
D. East Village

RESPONSIVE BUILDING ENVELOPES: PART III

CALGARY CLIMATE

Calgary is located at a high altitude west of the Rocky Mountains along the foothills that are active zones for large thunderstorms and gigantic hail storms. Alongside these dramatic weather events the city generally has a temperate climate with typically warm dry summers and cold winters and is known as one of the sunniest cities in Canada. Temperature changes range from an average of 23°C in the summer to – 15°C in the winter (without wind chill) with annual precipitation of 412mm.

A weather conditions unique to Calgary are its Chinooks. Chinooks are a wind phenomenon experienced when moisture laden air travels from the Pacific coast and rises over the British Columbia mountain ranges pushed by the prevailing western winds. Most of the moisture from the humid pacific air is lost as fog, snow or rain, cooling (at a specific rate) as the air climbs the western slope; however the remainder of this now dry air mass descends on southern Alberta, compressing and rapidly warming, just as the air hits Calgary. The fluctuations in temperature and humidity in the city during a chinook can be dramatic, with temperature changes of 30°C in a few hours and a record decrease of 43% in humidity levels. On January 11 1983, the temperature in Calgary rose from -17°C to 13°C in 4 hours. The First Nations have described Chinooks as “snow eaters”, describing the constant melting

Illustration 25: A chinook wind traveling from the Rocky Mountains.

RESPONSIVE BUILDING ENVELOPES: PART III

CALGARY CLIMATE

of snow as Chinooks come over the year. ⁽³⁵⁾

The results continuously affect the land with soil moisture content decreasing or soil loss (from extreme winds) and many trees like the White Birch and the Mighty Oak cannot survive the rapid temperature fluctuations. Trees often have begun to 'wake up' in the midst of winter and are often killed in the next frost.

Chinooks winds bring a release of happiness for residents of Calgary via a break from the cold weather. They bring citizens back outside often being imprisoned by the climate's cold winds and temperatures. Chinook winds often bring a horizontal blanket of clouds from the west that adds to the flat landscape of the prairies. These clouds sweep over Calgary in a striking arch and literally breeze over the city.

Calgary is also a very sunny city averaging 2396 hours per year, surpassed only by a few towns in Alberta such as Manyberries (300km southeast of Calgary) getting 2,567 hours of sunshine each year and Medicine Hat receiving 2513 hours of sunshine. ⁽³⁶⁾

"Those who have not felt the warm, invigorating Chinook winds of this country, cannot well comprehend what a blessing they are. The icy clutch of winter is lessened, the earth throws off its winding sheet of snow. Humanity ventures forth to inhale the balmy spring like air. Animated nature rejoices."

-Cameron, W "An Introduction to Chinooks"

Mountain Nature 2005

<<http://www.mountainnature.com/climate/>

Chinook.htm>

Illustration 26: Diagram of a chinook traveling over the mountains

RESPONSIVE BUILDING ENVELOPES: PART III

SITE CONDITIONS

Illustration 27: Wind Direction Distribution Diagram (in percentage); Average per year.

RESPONSIVE BUILDING ENVELOPES: PART III

SITE CONDITIONS

TRANSPORTATION STUDY

RESPONSIVE BUILDING ENVELOPES: PART III

SITE CONDITIONS

The two main entrances lie on the west and south façade while the secondary entrance (mainly used for residences) lie on the north façade. The South entrance looks out to the stampede Correll (a famous building for Calgary). The Fluctuating building roof on the west elevation directs visitors to a panoramic view of downtown Calgary, heightened in certain areas to reflect the skyline.

RESPONSIVE BUILDING ENVELOPES: PART III

PROGRAM

Program

To compliment the development of East village in downtown Calgary, this thesis will propose a design incubator as an ideal asset to the community. This facility will provide research and development labs and workshops for start-ups and artists to explore an idea. The goal of the program is to bring together creative minds to further enrich Calgary's cultural and creative sectors.

Art and Cultural Incubator Program

Objectives:

- Bring creative individuals and teams from diverse disciplines together to create a rich multidisciplinary workspace and social environment
- Provide digital and hand craft tools to create art and projects that enrich and benefit the community.
- Provide feedback sessions, demo days, public exhibitions
- Public programming and workshops: an interface between artist and audience
- Teach digital tools to support artists and technologists
- Provide an environment to solve problems in a creative and technological

Possible Spectrums:

- Visual and Media Arts
- Product Design and Hardware
- Creative Code
- Architecture and Urban Planning
- Civic Engagement
- Filmmaking and Photography
- Data Science
- Game Design
- Journalism and Writing
- Interactive Installations

Requirements:

- Lounge areas for meeting
- Lobby with outdoor seating
- 100 person capacity venue
- Immersive media venue
- Shared desks in open space
- private studios
- Conference rooms
- Digital media Lab
- Presentation studio

RESPONSIVE BUILDING ENVELOPES: PART III

SITE PLAN

RESPONSIVE BUILDING ENVELOPES: PART III

GROUND FLOOR

1:400

RESPONSIVE BUILDING ENVELOPES: PART III

SECOND FLOOR

1:400

RESPONSIVE BUILDING ENVELOPES: PART III

THIRD FLOOR

1:400

RESPONSIVE BUILDING ENVELOPES: PART III

FOURTH FLOOR

1:400

RESPONSIVE BUILDING ENVELOPES: PART III INTERSTITIAL SPACE

The building is divided into three zones to mediate inside and outside: the interior core, the interstitial space and the exterior. The core is fully heated acting as the heart and structure of the building, while the interstitial space acts as a programmable dynamic buffer zone between the interior and the exterior. The building uses a double skin façade with the primary layer sandwiched between the exterior and the programmable interstitial space and the second layer between the interstitial and the core. The interstitial space would be cooler than the core, as it is not directly heated but is a transition zone between the inside and outside.

RESPONSIVE BUILDING ENVELOPES: PART III

INTERSTITIAL SPACE

Programming of space was divided accordingly to pair with the temperature of the core or the interstitial space. The core holds the ground floor café, presentation areas, digital media labs, offices and studio space, and conference rooms - programs which require more heat as the body is subject to staying in one place for a longer period of time. Circulation, workshops, the gallery, the atrium, storage and maintenance rooms are located along the perimeter of the core as these functions often require a shorter stay or involve movement with higher body temperature or sweat. The exterior of the building also allows for a variety of events and activities to be held outside.

The concept of usable interstitial space is continued in the design of interior walls with a significantly larger width. This wall cavity provides storage space, room for utilities and plumbing noise and odor separation. Doors also become invisible as they slide directly into the wall cavity to allow for the space to be more open, more continuous and gracefully flow between spaces or, when the door is closed, completely separated for privacy. The walls effectively become zones of transition.

RESPONSIVE BUILDING ENVELOPES: PART III INTERSTITIAL SPACE

The interstitial space allow for the gallery art pieces to be highlighted and accentuated while still offering storage to the classroom behind adjacent to the gallery. The thicker walls also allows for a larger space between areas so noise does not interrupt people in the classrooms.

(Core)

RESPONSIVE BUILDING ENVELOPES: PART III INTERSTITIAL SPACE

The thicker walls provide a barrier between the small cafe and the more private areas of the building. These walls provide storage and provide a larger separation for noise and odor between environments.

RESPONSIVE BUILDING ENVELOPES: PART III

INTERSTITIAL SPACE

The interstitial space allows for storage to be hidden within the walls of the building and to provide better sound separation between environments.

RESPONSIVE BUILDING ENVELOPES: PART III **THE BUILDING ENVELOPE**

Janus, the unique building envelope, sweeps and wraps around the building highlighting views, controlling natural daylight and ventilation or serving to provide privacy for specific programs within the building.

West Elevation

North Elevation

East Elevation

South Elevation

The individual panels, named Cardea (referencing the goddess of thresholds and hinges), are 2438mm (wide) x 2743mm (tall) fitting between floor plates. The panels will have a programmed movement, acting through a series of destinations; moving from closed, to half open to fully open.

Closed panel

Semi open panel

Fully open panel

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE

Uniform pattern

Diverse pattern

The residents can choose the setting of the window, from materiality to how open or closed the panels are, which creates a unique and playful setting of shadows in their apartment. These panels then become a part of a bigger piece from the outside; their panels participating with the rest of the apartments panels for continuous dialog and movement of the skin.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE

As a cluster of panels, the façade becomes a dynamic undulating surface as the sun moves around the building. There is no definitive ending to the movement, although cyclically controlled by the building, occupants can override the envelope so the façade will constantly shift and move.

Different variations of skin patterns

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE

The façade has its own structural steel frame that attaches to the main structure of the building. The steel frame holds the panels and the mechanical requirements to move the panels.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: DETAIL

The overall construction for a single unitized Cardea panel consists of 4 individually framed plates, further divided in two sections for optimum sizing for manufacturing and ordering materials. These plates are composed of insulated glazing, ceramic fritted glass, trespa panels or translucent solar panels, depending on their required use and placement in the building. The panels when closed sit approximately 0.388 meters from the curtain wall and extend to 0.545 meters away from the curtain wall.

On each unit of the panel, the arms actuator rotates the torque tube, moving the panels simultaneously outwards (similar to a mechanical hinge). The sensors monitor solar gain, room temperatures throughout the structure and in the winter, dramatic fluctuations of exterior temperatures (to respond to Chinooks) and when natural ventilation is most desired.

- A: Ties to resist torque
- B: Glazing/ Trespa Panels/ Translucent solar panels
- C: Structural Frame
- D: Turbine structure
- E: Turbine node Pin
- F: Strut sleeves
- G: Actuator and power + control connector

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: MATERIALS

Cardea is covered in a variety of materials including translucent solar panels, customized trespa panels, triple insulating glass units with low-e coatings and ceramic fritted glass. These materials reflect the program of the space and are situated at specific locations depending on their orientation.

Illustration 28 : Transulent Solar Panels

Illustration 29: Triple Insulating glass

Illustration 30: Trespa Panels

RESPONSIVE BUILDING ENVELOPES: PART III THE BUILDING ENVELOPE

Direct sunlight warms the corridor on the south and west elevation of the arts and culture Incubator. Janus covers the residential tower also on the south elevation so residences can control heat gain and glare in their units. The building skin blocks natural daylight on the north elevation where most panels are inoperable and opaque to allow for regulation of the lighting in the art gallery and hides the maintenance storage areas. The East façade starts to curve and flow upwards, parallel to the movement of the sun to block glare and daylight where the building skin covers most of the residential units; then the panels descend to flow into the roof of the incubator, where it becomes an oculus that provides natural ventilation for the atrium.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: DOORS

Janus' panels surge and flow away from the ground surface at the South Entrance to shape a modern standard door. As people enter the building, the skin creates an elongated passage where the visitors enter into darkness filled with unique shadows from the panels above, into an atrium filled with light from the glass panels above. Janus enhances standard elements to create unique experiences as one enters the building.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: DOORS

On the North elevation, the doors would primarily be used for residents (to access to the park on the north side) and therefore the doors blend in with the skin, for a more private passage. The doors are 10 feet tall, conforming to the measurements of the panels but to still create a grand entrance into the building. The panels therefore become a door themselves.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: WINDOWS

The envelope challenges the grid of a traditional curtain wall, allowing for specific views to be highlighted and customized (depending on materials used) while still creating a phenomenal interactive experience. The panels can provide a continuous panoramic view if desired by the residents but play with repetition of shapes for unique and playful shadows.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE: OCULUS

Over the atrium and some of the workshop areas, Janus' panels become the oculus and will open and close depending on Calgary's weather. This allows for natural ventilation, eliminating stale air from the building and allowing inhabitants to enjoy the fresh warm air of a chinook in mid winter. Often people think of the building envelope as an entity that keeps the environment out, but in some cases it is magical to let the environment in. Most of Calgary's coldest days are often the sunniest and heat accumulation in the air space on these luminous winter days will supplement the unheated spaces still usable despite the exterior cold temperatures. In the summer, Cardea opens up to release this heat buildup and prevent an unbearable greenhouse effect.

RESPONSIVE BUILDING ENVELOPES: PART III

THE BUILDING ENVELOPE

“The shadow gives shape and life to the object in light.. in great architectural spaces, there is a constant deep breathing of shadow and light: shadow inhales and illumination exhales light. In our time; light has turned into a mere quantitative matter and the window has lost its significance as a mediator between two worlds, between enclosed and open, interior and exteriority, private and public, shadow and light.”

- Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses*, (Wiley Academy Chichester, 2005) page 51

RESPONSIVE BUILDING ENVELOPES **CONCLUSION**

Responsive architecture evokes phenomenological experiences and is often thought to be supported by innovative technology and enhanced building materials. With a deep investigation into the first responsive elements in architecture including windows, doors, oculi and chimneys, this thesis sought to dissect and rethink these primitive components together to reinvent them as part of a comprehensive building envelope.

Although the technology for responsive architecture is developing rapidly, components are criticized for requiring extensive maintenance and upkeep. This thesis proposes that the unique benefits of engaging the environment through an operable window style building envelope is to be embraced. These strategies can create a unique relationship between occupants and the building, providing a richer and stimulating environment.

This thesis explored responsive architecture specifically within the building envelope and designed a new building façade, Janus, which combined the function of windows, doors, oculi and chimneys and provided phenomenological experiences specific to site orientation and program. Janus marks a separation as well as passage; where

RESPONSIVE BUILDING ENVELOPES **CONCLUSION**

the solid face of panel can open and become a void; where people can connect themselves to the earth and to the heavens. This thesis project also sought to explore the potential of interstitial space, proposing new uses for wall cavities and air space within a buffer zone. Through these investigations and explorations, an understanding of the potential and the need for responsive architecture was established. Responsive architecture has the ability to reconnect people with their environment, to generate a more stimulating and enriching environment and provide delight in occupants' lives.

This thesis could be enhanced to include more technical support and facts, to pair the phenomenological aspects with a complete understanding of actual conditions occurring in the structure. Simulations can be run in order to further understand climatic characteristics and patterns on the site.

RESPONSIVE BUILDING ENVELOPES **APPENDIX**

TERMS:

System

A system relies on the connection of pieces to influence the entire body. Transformable structures involve the entire building working as a system, which changes over the longer term to adapt to economic demands, weather patterns, emergencies and other external factors.

Assembly

An assembly is specific pieces working together as a uniform body such as an intelligent surface and a media platform. While they might connect to other systems, it acts as an independent piece. Sensor based Responsive architecture includes dynamic facades, communicative building fabrics and intelligent independent surfaces. It is easy to distinguish the adaptive elements from the non responsive elements.

Skin

The skin acts as an additional layer to the building. Smart Materials are materials whose properties can be significantly changed in a controlled manner by

RESPONSIVE BUILDING ENVELOPES

APPENDIX

external stimuli such as temperature, magnetic or electric fields, moisture, or light.

Components

The term Automatic derives from the Greek Word Automatos, auto meaning “self” and matos meaning “moving by itself”. Presently, automation means a dynamic process in which speed, direction and efficiency are measured and controlled, so that these processes fulfill a given task or function on their own. Responsive architecture is dependent on certain components to function properly. These systems include sensors, software system and actuators.

Software

Building Management System (BMS) is a network of controls connected independently or centrally, to operate automatically and/or manually and measures and responds to both external and internal data. Some systems can measure rainfall, wind speed and occupancy density.

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Sensors

In order to react, there first must be an action to which to react. Sensors detect inhabitants' activities, environmental information and information about objects. Recently, sensors can also detect physiological data like heart rate, skin conductance, to then transfer data to actuators. Sensors have the ability to detect and measure air temperature, relative humidity, air pressure, air quality, light intensity, noise levels, fire and burglar alarms, wind and rain measurements, solar irradiation, pressure, force, revolutions per minute, torque, air speed, mass and volume flow, power consumption, energy consumption mechanical and electrical efficiency and the ability to switch to manual control.

Mounting sensors should be carefully placed in accordance with what they are measuring giving them enough space and size. Sensors are often placed in direct sunlight, instead of being placed on the north side with no direct sunlight for more accurate results. They require constant maintenance as they can produce errors from component aging, electromagnetic interference and/or environmental conditions.

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Actuation

Actuator technology encompasses all the components and mechanical elements required to set a body in motion: using mechanics with electronic controls. The main element consists of a power drive mechanism to convert energy into mechanical work. These include gears and transmission, electromechanical actuators, hydraulic and pneumatic actuators and micro actuators

Types of Actuators

Hydraulics and Pneumatics

Hydraulics and Pneumatics inflate with air pressure. Flexible or elastic materials are often used as a skin that allows air to fluctuate and extend the material. Deflation of the material can require little volume and be stored in a small place while inflation allows for desired spatial form.

Transmission- Gears, tension and cable.

This includes simple machines such as pulleys, gears and levers, combined with rigid frames or lightweight and folded structures. Transmission can also include the use of Cable Active systems to move a component.

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Electromechanical actuators

Electrochromic glass: changes the light transmittance in glass to moderate solar glare, solar gain and provides privacy in response to an electric current and natural light respectively.

Photochromic glass: reacts to light and not heat (significant amount of heat through solar gain would already be in the building before it blocks it out)

Materials

Certain materials can be actuators in a natural state: elastics, wood and zinc as their natural properties responds to different climatic conditions throughout the year. Smart materials have also been created to react to additional information

Smart Materials: smart materials have the ability to change their properties. Semi smart materials can change their properties once or a few times, however smart materials can have permanently reversible properties. The material's properties including form, colour, volume, can be changed by physical or chemical influences such as temperature, light pressure, electrical, magnetic or chemical stimulation.

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Thermobimetals have shape memory properties, using a thermo mechanical process. Above a certain temperature, the material exhibits a hard crystalline structure, however it changes as the temperature drops into a deformed or molded shape. It then can be reversed as the temperature increases. Shape memory alloys embedded in areofoil can consistently change shape. A team lead by Achim Menges at the Architectural Association School of Architecture in London, created a partition constructed out of wooden scales to react to ambient humidity levels, causing them to open and close, similar to the feathers of birds. Common metal compounds include: gold, cadmium alloys, copper zinc alloys and nickel titanium alloys (nitinol)

Elastic Materials: materials that resume original form after being stretched or compressed without the need for additional force. Often these materials are not used in an architectural scale as their deformation can not always be controlled.

Thermal Materials: Certain materials that change volume exhibit thermal expansion properties. Thermometers, heating vales and thermostats in taps and sprinkler systems are common examples of expanding materials. Phase change materials expand with an increase in temperature specifically assisting in thermal mass and storing of heat for partitions and flooring. The volume of the fluid expands

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accordingly to the temperature and then can trigger a piston or spring mechanism. If the temperature expands pushing a piston or the material cools and the piston is compressed back into the casing usually assisted by a spring mechanism

Material performance is dependent on the material assembly performance capacity, material assembly logic, material performance capacity, material behavior and properties and the material composition and structure.

Responsive wood architecture was studied at the Oslo School of Architecture and Design, specially analyzing the hygroscopic behavior of beech veneer, analyzing its elasticity and ability to warp without cracking, looking at the relationships between cut, fiber direction, and moisture content. The students looked at where the cracks occurred during drying and how elements shrank in relation to another. This would then increase tension in the assembly without cracking and increased structural capacity.

Types of Control

There are several methods to gather and direct information in order to ensure movement. The main methods of control are either indirect control, direct or internal control as outlined by Performance Oriented Architecture

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Indirect, Direct and Internal

- 1) Internal Controls (do not have any direct control or mechanism)
- 2) Direct control (where movement is actuated directly by an energy source external to the apparatus)
- 3) Indirect control (based on sensor feedback system)
- 4) Responsive indirect control; optimization of multiple feedback sensors
- 5) Ubiquitous responsive indirect control: a network of controls use predictive algorithms
- 6) Heuristic, responsive indirect control; algorithmically mediated networks that have a learning capacity

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