Signal Systems: Experiencing Ecological Reconnection Through Communicative Biomimesis

Elizabeth Simonson
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School of Architecture
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Doctorate Project Committee:
Spencer Leineweber, Chairperson
Andrew Kaufman
Elizabeth Song Lockard

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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in fulfillment as a Doctorate Project for the degree of Doctor of Architecture in the School of Architecture, University of Hawai`i at Mānoa.

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To my mother and brother, for your love, encouragement, and patience. You have walked with me through this journey, and supported me during the most trying times. I owe you my deepest gratitude and appreciation.

To my committee, Spencer Leineweber, Elizabeth Song Lockard, and Andrew Kaufman, for your wisdom, guidance, and tireless efforts. I am truly grateful for your insight and direction.

To Ardison Garcia, "you're my river running high, run deep, run wild." You have inspired me throughout this journey and have kept me afloat. Thank you for your unconditional love and support.

To my friends, "we are all a little weird, and life's a little weird, and when we find someone whose weirdness is compatible with ours, we join up with them and fall into mutual weirdness and call it love."

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I. ABSTRACT

Throughout the evolution of mankind, technological advancement has supported rapid urbanization and the development of modern convenience. As societies develop, a detrimental shift has occurred in human cultural evolution. While urbanization has led to comfort and convenience, a change has also occurred in the way people relate to their built environment. Human cultures have long been based upon the natural environment in which they are encompassed, but as populations move away from the natural environment, cultural development hads detached from its natural basis, thus severing the co-evolutionary process between man and nature. Built environments have digressed from occupiable spatial supplements within the natural environment, into structures which hinder any connection between nature and humankind. This has in turn detached much of the human cultural connection to the natural environment.

To remedy this detachment, this research focuses on the development of a biomimetic design methodology that employs spatial experience as a means of communication. This design methodology is then applied to three densely urbanized sites through the insertion of a footbridge overpass. Toronto, Singapore, and Perth, are each located in varied climatic regions, providing highly varied biota from which the biomimetic design methodology is based. Each overpass, features five spatial components, each communicating specific environmental status levels taken from the immediate surrounding natural environment. Each overpass is then analyzed in terms of how effectively the five components perform spatial communication. Possible improvements are explored, both in terms of spatial communication, and coherence of the biomimetic language. Projected future applications are considered, and explorations of alternative uses are analyzed.

II. INTRODUCTION

Design should follow, not oppose, the laws of life. Biological equity must determine design. Design must reflect bioregionality. Projects should be based on renewable energy sources, design should be sustainable through the integration of living systems. Design should be co-evolutionary with the natural world. Building and design should help to heal the planet; design should follow a sacred ecology.[1]

This research hopes to establish a method of reconnecting our urban and natural environments through the design of communicative space. Communicative spaces have the means to convey information integrated within the design language, allowing users to gather knowledge while experiencing space. By experiencing this space, users will regain an understanding of their dependency on the natural environment, a notion that has dissipated as urbanization has progressed. The reinstallation of natural dependency within humankind's cultural values will promote progressive cultural evolution fully integrated with the natural environment. Culture, as defined by Michael Weinstock, author of *The Architecture of Emergence*, "is the evolved system of transmitting increasingly complex social and ecologically contextualized information down through the generations, the means by which each generation is bound into society and through which they contribute to it."[2] Urbanization has caused a shift in this "ecological context," and cultural development has become detached from the natural environment. To successfully reconnect human culture and the natural environment, this study conducts several analyses in order to define any cultural digression that has occurred from the disconnection.

2.1 PURPOSE OF THE PROJECT

Ideally, urban environments of the future shall be integrated with the natural landscape. This requires a regional identity reflective of the natural surroundings which exists in all urban systems, including social, economic, and cultural. The qualities and processes of these systems should relate back to the immediate surrounding natural environments. In order for this to occur, the functional and aesthetic aspects of built developments will need to slowly morph towards complete cohesion with local natural ecologies. To establish a cohesive reconnection, a shift must occur in the way the natural environment is perceived, and the elements that embody the basis of human culture. The phasing of the urban environments towards an integral relationship with the natural environment will remedy the current social, political, economic, and cultural qualms,

[1] Stephen R. Kellert, *Building for Life: Designing and Understanding the Human-Nature Connection. 1 ed.* (Washington, DC: Island Press, 2005), 97.
[2] Michael Weinstock, *The Architecture of Emergence: The Evolution of Form in Nature and Civilization.* (Chichester, U.K.: Wiley, 2010), 19.

as well as ensure future stability in what is currently an unstable situation. This stability will only be achieved through the recognition of the need to reintegrate with the natural environment, and the allotment of total dependency on local natural ecologies. This dependency reassures an emotional and psychological relationship with the natural environment that is currently absent or weak in many modern societies.

Along with stabilizing the urban environments, the relationship formed will be interdependent, wherein the natural environments will better benefit from humankinds existence as a species. This newly developed, highly evolved design methodology will produce built environments that will act as a device to translate and hopefully amplify efficiency and productivity in both the human-built and natural environments. Current modern spatial typologies are regionally explicit. Urban frameworks are inhibitive of relationships with nature, thus constricting human understanding of an ecology's vitality, which humans are directly dependent. Because of the current constriction and isolation cause by the design and development of disconnected spatial enclosures, humans are unknowingly exposed to various negative repercussions. These repercussions exist at both an individual scale, such as one's psychological state, as well as at a societal scale, for example resource management. The reconnection of human culture and the natural environment through a spatial application can aide in the remediation of these repercussions.

As well as reconnecting and unifying built and natural environments, this study will focus on the remediation of recent cultural homogenization that has occurred on an international scale. The phasing towards an environmentally dependent urban framework will also provide a sense of identity drawn from the uniqueness of the immediate natural surroundings. Eventual urban integration with the natural environment will aide in the continued development and solidification of effectual cultural evolution. The ability for cultures to connect and experience exposure from the natural environment plays a major role in its development. In the book, *Understanding Meaningful Environments*, it is stated that "There is growing recognition of an inextricable link between biological and cultural diversity, with many areas of mega-biodiversity being sites of high cultural diversity too. With the loss of cultural diversity, important knowledge on sustainable ways of living in particular places is being lost."[3] The recent detachment caused by increasingly isolating urban environments has allowed for an occurrence of cultural disintegration. Less

[3] A. Guney, and K. Moraes Zarzar, *Understanding Meaningful Environments: Architectural Precedents and the Question of Identity in Creative Design - Volume 4 Research in Design Series.* (Amsterdam: IOS Press, 2008), 66.

urbanized societies and cultures are easily overshadowed by cultures with further international establishment and technological advancement. This disintegration has occurred internationally, because societies bother urbanized and undeveloped lack definitive sources with which to draw a cultural basis of identity.

While cultural aspects were once the primary sources of architectural typology, modern urban identities are shaped by economic and political aspects as well. As modern political, and economic structures constantly evolve at paces of intermittent ebbs and flows, identity basis from these aspects becomes unstable. A methodology for the supplementation of this "identity basis" is therefore crucial. The natural environment, with its stable and constant evolutionary progression, is a viable source of stable identity supplementation. To achieve a method of implanting this nature-based identity into a modern cultural establishment, the development of a means to spatially supplement modern cultures is vital. This study focuses on the reconnection of human cultural systems with the natural environment through a spatial need, rendering social spaces as the primary concentration in terms of design and phasing.

By phasing this reconnective, environmentally expressive identity into the social spaces within a modern urban environment, these areas will represent the immediate surrounding natural ecologies. As cultures develop and evolve through the exchange of social activity, the spatial quality of the areas in which social exchange occurs will function as incorporative devices that instill environmental awareness into cultural evolution. Through the process of biomimetic design, the social spaces will absorb and exude a regional identity based on the surrounding natural environment, which will in turn feed into cultural evolution. Biomimetic design, or biomimicry, is a design process which addresses a design challenge by mimicking the solutions found in nature.[4] The insertion of biomimetic design elements taken from the immediate natural environment will provide these social spaces with efficient systems performance, a regional identity, and a strong connection with nature formed through a unique language. The phasing steps proposed will act as an external force that will push human developmental evolution in an efficacious direction. If left unaltered, the current, ecologically detached evolution of spatial typologies could lead future built environments without a stable design basis. The lack of a stable urban design basis will hinder the forwarding of cultural, social, and economic evolution.

Several grounding theories and prevalent lines of thought have been used to compile this study's research documentation. There are three subtopics that dissect the critical

[4] Janine M. Benyus, *Biomimicry: Innovation Inspired by Nature*. (New York: Harper Perennial, 2002), 7.

points of thought within this document. The first focuses on the importance of the human-nature connection, and the ways that we depend on the natural environment. The second focus point deals with the disconnection that has occurred through urbanization and technologic convenience. Lastly, the current design methods for restoring the human nature connection are examined. The following literature review briefly summarizes the grounding theories of each key topic within the research documentation portion of this dissertation.

2.2 THE HUMAN NATURE CONNECTION

Ecologies of the Heart: Emotion, Belief, and the Environment: While this source does not related to the study of architectural space in relation to the natural environment, it is prevalent to this dissertation because of its outlining of human psychological and emotional needs in relation to the natural environment. The author, E.N. Anderson, explains in chapter six the intricate mapping of relationships between basic human needs and the natural environment. Anderson explains that all needs must be satisfied by the environment, but in humans, in comparison to other life forms, emotional needs are far more constrained to fulfill because of their complexity. Human emotions are subject to cognitive construction, as we think and dwell on human emotions. Moreover, Anderson explains how cultural traditions further influence human feelings, as we are taught how and when to feel particular emotions. As cultural construct is dependent on the regionally specific natural environment, emotional tendencies are also regionally specific, in correlation with the immediate natural environment.

Ecosystems and Human Well Being: Our Human Planet: A series of five books, these works go into great detail all areas from which humans benefit in relation to natural ecosystems. These benefits range from resource, as ecosystem services are examined. Fresh water, food, timber, fuel, nutrient cycling, medicine, waster processing, and cultural amenity services, are a few of the outlined resources. Text book like in structure, this source follows ecosystem resource and degradation from the perspective of four main millennium ecosystem assessment scenarios. These scenarios, TechnoGarden, Global Orchestration, Order from Strength, and Adapting Mosaic, each approach future ecosystem management from different perspectives. While the four perspective methods aren't carried through in this study, the elements from within each of the perspectives are, mainly in the resource outline portion of this study, as well as the development of the systems analysis used for the case studies .

2.3 GLOBALIZATION, URBANISM, AND THE DISCONNECTION

Diversity, Globalization, and the Ways of Nature: This source, by Danilo J. Anton, conducts a thorough analysis of the manner in which the natural environment has responded to recent globalization of human social, ecological, and cultural aspects. These three systems are examined from a variety of perspectives. As this global phenomenon has affected the natural environment at a planet-wide scale, human well-being at a socio-economic scale, the modern urban environment, and several ecosystemic typologies, such as grasslands and aquatic environments. Anton outlines the degradation that has occurred within the natural environment, and analyzes its causes in terms of the rapid development of human economy and society. The information revolution, global financial markets, transportation networking, and free markets are all aspects that effect the natural environment in an unconscious manner.

Crucial to this study are the parallels that Anton draws between biological diversity and cultural diversity. A large portion of this study will deal with the ways in which biodiversity and cultural diversity are intertwined. The various occurrences that cause a bridging between the two are outlined, and important to this study because they are keys to the reconnection. Anton explains the concept of biodiversity as including both the range of living beings and their relations among themselves and with the physical environment. This type of biodiversity is ever changing in a cyclical manner through evolutionary means. Human societies are not isolated from the natural environment, and so they are closely interconnected with it and derive their means of existence from it. From this, the main bridge drawn between human and natural environments are the culturally unique management systems developed through processes of trial and error. These ways of existence performed by different peoples in their perspective natural environments is a key example of regional identity based on immediate natural elements.

Building for Life: Designing and Understanding the Human-Nature Connection: This work, by Stephen R. Kellert, examines several vital aspects of the human-nature connection, and the role that the built environment plays in this ever changing relationship. Much of Kellert's analyses deal with the manner in which human society and the natural environment have disconnected, and the negative ramifications that have ensued because of it. Kellert discusses the impacts of the neglect modern societies have placed on the natural

environment. The impacts occur in two realms, outlined in separate chapters. The first several chapters discuss the ways in which modern human societies have severed connection with the natural environment, and the psychological and physical result. Kellert examines the human perspective, and the ways in which the presence of the natural world has been an unquestioned constant for much of human history, generally noticed only as an adversary or appreciated only when no longer accessible. Also examined, are the manner in which the impacts affect all of mankind, as only recently has he encountered nearly ubiquitous environmental damage and a feeling of alienation from nature produced by huge human populations, consumption, urbanization, resource depletion, water generation, pollution, and chemical contamination. Kellert's analysis of the human-nature relationship qualms contribute significantly when reconnection is brought into consideration throughout this study.

These two opposing thoughts form a dynamic throughout this work, which is further investigated throughout the chapters. On one side, there is the widespread belief prevalent in many rapidly developing countries, that the successes of the modern world depend on the control and conversion of nature. This perspective sees nature as a tool that can be furthered through human ingenuity, and the application of technology to maximize productivity in natural systems. The opposing premise stipulates the maintenance of diverse natural environments because of their positive impacts on the human physical, mental, and even spiritual well-being. Kellert then examines the supposition that through a new design paradigm, deficiencies in modern life can be ameliorated. This design paradigm, restorative environmental design, focuses on the manner in which humans as a species can avoid excessively consuming energy, resources, and materials; generating massive amounts of waste and pollutants; and alienating the populace from the natural world. Kellert defines the current relationship people share with the natural environment as a design failure, and stresses the need for the design of the built environment to provide sufficient and satisfying contact between people and nature. Elements of restorative environmental design are relevant to the goal of reconnection within this study.

The Architecture of Emergence: The evolution of form in nature and civilization: In contrast to Kellert's rigorous dissection of the connection between human and nature, as well as the tangible manifestations that have resulted and are apparent in modern human society, Michael

Weinstock approaches the relationship between human and nature in a much more theoretical manner. This study defines all forms of nature and all forms of civilization as having 'architecture,' and arrangement of material in space which overtime determines their space, size, behavior and duration, and how they come into being. Energy information and material flow through all the forms of the world, and human forms and culture have coevolved and developed within those flows.

Weinstock examines the human-nature relationship from an international scale, and points out that the landscape of the world had been as much shaped by the cultural history of human interventions as it has by climatic effects such as glaciers, and by geological processes of uplift, erosion and deposition. From this perspective, he explains the metabolic processes of living forms, and how they produce changes in the natural environment, which modify the local regime of natural selection. This organization of whole ecological systems emerges from multiple interactions which occur between the aforementioned metabolic processes, and all the forms of life that coexist within it. The generalization of nature into a working system is analyzed in a correlational manner alongside human cultural development. The Architecture of Emergence is an important source to this dissertation because of its analysis of human culture and the natural environment from a more theoretical standpoint. The cohesion established between culture and nature is achieved through the stabilizing element of systems mapping. The standards at which Weinstocks flow mappings are established weigh heavily in this dissertations case study analysis. Weinstock declares the importance in understanding that ecological and cultural systems are inextricably connected, so that the transition of one system through its critical threshold will provide positive feedback on the others, and has the potential to initiate a cascade of changes in all other systems.

2.4 BIOREGIONALISM AND METHODS OF RECONNECTION

Cities as Sustainable Ecosystems: Principles and Practices: This source outlines the possibilities of redesigning entire urban environments in conjunction with their surrounding natural environments through the mimicking of ecosystem function. Authors Peter Newman and Isabella Jennings examine the many parallels that exist between natural ecologies and built urban environments. While many of the infrastructural and tangible elements of an urban environment are taken into consideration, for instance, the ways in which

transportation systems can be more closely linked to similar systems within the natural environment, the intangible elements of urban environments, such as establishing a viable "sense of place," are also touched upon. The belief throughout this source is that sustainability can only be achieved through a design approach in which systems and components within them are in ecological balance with one another. This source examines the lessons from sustainable ecosystems and addresses the unsustainability of current city ecosystems. It offers solutions to the current predicament and provides a framework for action and ecological restoration within the city and its bioregion.

Earth at a Crossroads: This source runs the closest to the ideas discussed within this paper. The author, Hartmut Bossel, questions the possibility of reaching a future that is both environmentally and socially sustainable. The structure of this source, and the elements examined, are pertinent to both the research documentation of this dissertation, as well as the compilation of elements used to analyze the three case studies. Bossel offers a holistic systems view of the development of human society within the natural environment, and stressed the dynamic nature of interconnected feedback processes. Also, similar to Cities as Sustainable Ecosystems, but more in depth, this source traces the possible future paths of societal development and their impacts on the natural environment. The whole-systems approach of this book was a valuable model because of its incorporation of all societal elements, not just the architectural environment. Bossel lists the main facets of sustainability that must be developed in order to maintain a sustainable way of life into the future. These include ideals such as the need to develop a system of society that is both physically and socially sustainable, that is able to accommodate the ethnic and cultural spectrum of humankind, in all its diversity, and that moreover permits change and human development 'indefinitely.' He also stressed the need to understand that there is no unique state of sustainability: either vast wasteland at minimal existence, or fertile landscape with an ecologically benign civilization, as well as the fact that we cannot control "flows" restricted by conditions on earth, and by the laws of nature. Flows required by a given demographic, technological, and societal development path may or may not be physically possible.

Understanding Meaningful Environments: Architectural Precedents and the Question of identity In Creative Design: This source discusses the use of precedents and the development of understanding identity throughout the progression of design evolution. It is relevant

to this dissertation because of its analysis of identity. As this study hopes to conclude a means of defining identity through the built environment, this study discusses three different types of identity, and their role throughout design. Legitimizing identity, resistance identity and project identity are all relative due to the ways that this source traces their origins. Origin of identity, and how identities are derived from architecture is a key focus of this dissertation, but geared more towards the relationship humans have with the natural environment. This source will help to supplement the development of a methodology that can derive a unique identity from the natural environment.

2.5 UNIQUE ASPECTS OF THIS STUDY

Previous design methodologies established are similar in that all have the intention of both restoring the human connection with the natural environment, and enforcing a distinction between regional identities in the built form. These studies primarily focus on inserting supplanted patches or bands of the natural environment into the urban environments, in hopes that a relationship and interdependency between man and nature can slowly evolve over time from mere exposure. Small scale urban interventions and subtle approaches to the current urban framework are currently the most prominent methodologies existing to dealing with the issue of detached urban frameworks.

Currently, these urban interventions of green belts, blurred urban edges, and restoration of biospheres do not take into consideration the human perspective of these proposed green environments. As resources become scarcer, the priorities of this species could potentially result in the deepening of naturally detached urban arrangements. This detachment has developed through a change in perspective of the natural environment. While once viewed as an integral part of human society, the natural environment has now been reduced to a necessity purely for resource needs, and is treated in a mechanized and detached way. Resource is taken in an interjectory manner, without consideration for the effect that this depletion has on the health of natural systems. The future relationship with the natural environment is only lightly touched upon, and ways in which humankind's modern societies could potentially exist alongside ancient natural systems has not yet been well defined.

This thesis approaches reconnecting human and nature relationships from a cultural basis perspective. While other studies attempt reconnection through different levels of exposure, this dissertation focuses on reconnection through reinstalling awareness of human dependency.

The newly designed social spaces will communicated with its in habitants, and will accurately represent the natural environments status. This thesis focuses on the future potential of a mutualistic symbiotic relationship between the natural environment and the urban metropolitan environments. Mutualistic symbionts exist in correlation with one another, where efficiency is heightened through the adapting of one symbiont to the other. Roles such as the processing of resource into energy are carried out by one symbiont, and subsequently shared. The other symbiont is then free to evolved specializing in another role, such as defense. Each symbiont is thus specialized in its role, and much more efficient at performing a task, when compared to a solitary being, which must perform all tasks singularly. An idealistic future is to be realized, and through futurist processes such as back casting, steps can be laid out in order to bring the urban environment closer to this ideal society, in conjunction with future advancements in technology. The implementation of this design methodology will be highly dependent on the forward evolution of sustainable and ecological construction techniques, as well as the current preservation of the scarce natural environments remaining. While the existing methodologies for human-nature integration deal with mostly functional improvements, such as the guarantee of resource and preservation of regional economies, this study hopes to add the more intangible component of identity.

The reintroduction of nature-based dependency that is to be developed through the gradual phasing of urban developments are holistic, in a sense that we will eventually base all elements of the urban society off of the immediate natural ecologies. Biomimetic in all aspects, the ideal future urban landscape will act as a built ecosystem that parallels the natural, and draws identity, structure, and function from the surrounding natural ecosystems. The sense of regionalist identity will then be further reinforced and stabilized because of the identity's reintroduced dependency on the natural environment. Cultural evolution can then be set to evolve naturally in a stable environment that provides sufficient connection to the natural environment. The assumed preservation of natural environments will also promote the development of biodiversity, which will in turn, help to establish cultural diversity.

2.6 SCOPE OF THE PROJECT/METHODOLOGY

In order to develop a design methodology that can successfully bring all aspects of an urban environment to complete cohesion with the natural environment, several understandings much be achieved. Firstly, this study will define the importance of the human-nature connection, its role in the development of human culture, and the role of the built environment as a connective device. Secondly, the manner in which a disconnection between humanity and nature will be analyzed, wherein the changing stature of the built environment will be examined. This study will then briefly outline some of the current architectural design movements that are focused on revitalizing the human-nature connection through built typology.

From the initial research documentation, a means for conducting case studies will be outlined. Three case studies will be carried out, where parallel systems mappings throughout three differed environments. The systems mapped will indicate past, present, and potential deficiencies and strengths in the overall human connection with the built environment. The strengths outlined in the case studies will then serve as the foundation for an ideal future urban environment. After establishing the fundamental qualities this ideal futuristic environment will posses, this study will uncover a method to actively coerce the urban environment back into a relationship with nature, through the redesign of social spaces. As culture develops through the exchange of information in social environments, the spaces in which these social exchanges occur should impact cultural development through their form and typology. A social space that is designed to represent the immediate natural environment will impart a sense of awareness and connection within its inhabitants. This awareness is then carried through the development of culture that occurs within this space through the process of human to human socialization.

One of the main grounding theories of this study is relying on the ability to map ecological patterning in built and natural environments. An understanding of pattern mapping and language extraction is to be earned, primarily through conducting qualitative research on the works of Christopher Alexander, Anne Whiston Sprine, and Hartmut Bossel. Through conducting case studies on different societal relationships to ecological typologies, which are to include a historic society, a modern urbanized society, and a forward looking bioregional society, systemic structures are to be extracted, and compared to one another. A new pattern, comprised of elements from the three ecological typologies will be compiled, and applied to the design of social spaces. This new structure will be supplemented by the anticipatory inclusion of nascent technologies.

Once the new design structure is established, a phasing plan that will bring the current social spaces to an idealistic state as aforementioned will be mapped in steps to accommodate technological advancement. The biomimetic design methodology for social spaces will ultimately be applicable to all current urban environments. While urban infrastructural systems are an important element of an urban pattern, due to the physicality and tangibility of its nature, this thesis focuses primarily on the phasing of the non-infrastructural elements of an urban framework, most importantly, the social, and cultural evolution of future humans in the idealized ecosystemic environment. The future aspect of this study requires some creative estimation of how the world will potentially look. The final product will take form in the shape of an urban intervention, that both unites the urban population with the immediate natural surrounding environment, as well as makes users aware of the current environmental status.

III. RESEARCH DOCUMENTATION

3.1 RESEARCH OBJECTIVES

This documentation intends to analyze three main sections of the dynamic relationship between man and nature. The first section revisits the historical importance of the connection between man and nature, and how culture had developed through this connection. The second chapter focuses on a breaking of this connection that has occurred, and the changes in basis of both human culture, and the built environment. Lastly, this research documentation examines the existing proposed methodologies for reconnection human culture and the natural environment. This information will be utilized in the development of a new design methodology. This design methodology will focus on reconnecting human culture and the natural environment through initiating a change in the way social spaces are designed. This new design method for social spaces will warp the role of social spaces, providing them with the ability to communicate to its inhabitants the status, identity, and efficiency of the immediate natural surroundings. As cultural evolution occurs within social spaces, it will be prompted with this addition of information that will enclose the exchange of information from person to person.

3.2 METHODOLOGY

Human Connection with the Natural Environment: Biodiversity is an invaluable resource supplied by the natural environment that cannot be restored once gone. The link between the natural world and human development as a species has grown weaker as technologies have allowed further detachment and independence from nature and its ecological systems. As humans, we solidify our existence and success through forced guarantee of resource, and living in consumption of more than what is produced naturally. As technological advancement displaces human dependence on the natural environment, cultures reflect this growing disconnect, through the loss of a regionally defined identity. Human cultures have developed and evolved throughout history in conjunction with the connections made with the natural environment. There is a direct correlation, as aforementioned by A. Guney, and K. Moraes Zarzar, in *Understanding Meaningful Environments: Architectural Precedents and the Question of Identity in Creative Design*, between the prevalence of human culture and ecological health.

Several methodologies have been suggested in the hopes of restoring or protecting biodiversity in the natural environment. These methodologies include, the restoration and

maintenance of healthy bioregions through connected and representative systems of static and dynamic reserves within the city itself and its bioregion, through the conductance of bioregional celebrations and education, by reducing the ecological footprint of buildings, re-creating cities as biodiversity arks, and designing ecological architecture and infrastructure.[5] The importance of biodiversity in the surrounding natural habitat needs to be made apparent to an urban region's inhabitants because of the fact that cultural values and diversity originate and evolve through basic connections with the natural environment.

While few of these methodologies have been implemented, other strategies for the protection of biodiversity that have been suggested seem to fall flat of truly being capable of successful implementation. These ideas consist of the restoration of more integral ways of life such as urban eco-villages that encourage interaction between humans and nature in the metropolitan environment, as well as on a level of physicality, incorporated a system of nature reserves from the city into the bioregion, as well as ecologically designing a cities infrastructure, allowing biodiversity to flourish and evolve.[6] The issues that could prevent success in these methodologies of protecting biodiversity would mostly stem from the fact that they do not correlated in a close manner with the everyday lives of modern people. A change in lifestyle from submissive urban implementation will not occur, and instead, this study deals with the fact that this insertion of a bioregional dependency through policy is required. Complete dependency on an element not controlled by people is the only way to allow the natural environment to once again flourish and establish a successful means of existence.[7]

Human history is rich and diverse in that cultures have developed in direct correspondence with their immediate natural surroundings. The difference in terrain, climate, and biological diversity from region to region has resulted in distinct cultures that are connected through the natural regional. As well as cultural practice, our physical make up and anatomical structures also evolved in correspondence with our immediate surroundings. This region-based individualism allows for a variation of species types, all fine-tuned for existence in their perspective locales. All aspects of human settlements evolved from their initial connections with the surrounding environments. Social structure, cultural practices, and economic vitality continued to draw

[5] J Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices.* (Washington, DC: Island Press, 2007), 69.
[6] J Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices.* (Washington, DC: Island Press, 2007), 69.
[7] Kanchan Chopra. *Ecosystems and Human Well-Being: Our Human Planet: Summary for Decision Makers (Millennium Ecosystem Assessment Series.* (Washington: Island Press, 2005), 45.

origins from the influence of the immediate natural environment, which was reflected in the form and aesthetic of these entities.

A regionalist language is based off of several complex elements that constantly change throughout time. Heritage, local life-style, material availability, available labor and local craft skill knowledge, and existing construction regulations are just a few of the factors that compose a regions identity.[8] The built result is a physical embodiment of a precious and distinct vernacular language. This language is "regionally distinctive, regionally representative, and regionally understood," providing the local inhabitants with a psychological sense of familiarity and distinction.[9] From the vernacular language stems a regional "sense of place" with which people can familiarize and identify with.

Formation of Human Cultural Disconnection with Nature: Today, this "sense of place" is rare and indefinable in a majority of the developed regions. There are two main processes that occur over long spans of time which amalgamate several distinctive cultures into a blurred identity. "Cultural weathering" is the gradual layering of several cultures onto a region over time, and bits and pieces of separate cultures are sprinkled amongst one another, with overall definition lost.[10] Statues are a basic example of an individual "sprinkle," as they freeze in time a particular item of regional significance. Other evidence can be seen in "cultural hybridization," a complete blending of cultures into a completely different identifiable culture, which can easily be observed in the cuisine of a colonized region.[11] This transnational culture can be viewed in a biological sense, as stronger and more aggressive, with the capacity to infiltrate and replace more singular and unique cultural aspects, such as religion in an indigenous culture. North American culture for example has gorged itself and has a largely disproportionate influence in today's globalist culture.[12]

Dwelling spaces, responded purely to natural constraints and the fulfillment of human need, both in form and aesthetic. Cultural ornamentation of built surroundings was based off of practices and beliefs that stemmed from the human relation to the natural environment. As

[8] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 133.
[9]Kingston Wm. Heath, *Vernacular Architecture and Regional Design: Cultural Process and Environmental Response.* (London: Architectural Press, 2009), 3.
[10] Kingston Wm. Heath, *Vernacular Architecture and Regional Design: Cultural Process and Environmental Response*. (London: Architectural Press, 2009), 6.
[11] Kingston Wm. Heath, *Vernacular Architecture and Regional Design: Cultural Process and Environmental Response*. (London: Architectural Press, 2009), 6.
[12] Danilo J. Anton, *Diversity, Globalization, and the Ways of Nature*. (Victoria: Idrc (International Development Research Cent, 1994), 204.

technology advanced the progress of urbanization, and populations grew, social, economic and cultural establishments evolved to work in junction with the new human ability to take control over natural surroundings.[13] Human culture basis switched, as urbanization and technological advancement afforded a more convenient means of living. This changed the basis from which human culture is based, and changed it from a method for living in the natural environment, to a method of living in a human construct. This resulted in the corresponding detachment of a cognitive connection with the natural environment, as well as the understanding in human dependence.[14]

As technological advancement allowed for increased convenience, and cultural detachment from the natural environment increased, built reflected this "basis switch" seen in culture. Built enclosures decreased in having the ability to communicate to its inhabitants the realities of the surrounding natural environment. In the introduction to Dennis Dollens' Digital Botanic Architecture, Dollens addresses the current disconnect with the natural environment. "Architecture reduced to the concept of a machine or object has lost biologic connections that once adhered it to us and to nature as closely as shells, dens, nests, and boroughs to the species that respectively inhabited them. This current architectural disconnect fosters a false sense of humans as species-independent from our building and environment. In fact, architecture is part of an ecosystem and, more specifically, is a symbiotic growth dependent on human intelligence and muscle (or its mechanical replacement)."[15] This symbiotic relationship should ideally be between the built and natural environment, which results in the benefit of mankind. Instead, the relationship has switched and now exists between the built environment and man, which results in the disadvantage of the natural environment.

Many of the current basis for which modern buildings are constructed, are based explicitly off of human derived concepts of mechanism and space. The cultural lack of natural basis filters throughout societal systems and leaves built enclosures without a regional identity or a relationship to the surrounding built and natural environments. As such, the built environment is foreign and disconnected from the landscape. This in return disconnects the human inhabitants from the landscape, through a reinforcement of detachment in form a cycle of disconnection has therefore established itself and has maintained the disconnection between man and nature. What humans

[13] Danilo J. Anton, *Diversity, Globalization, and the Ways of Nature*. (Victoria: Idrc (International Development Research Cent, 1994), 205.
[14] Danilo J. Anton, *Diversity, Globalization, and the Ways of Nature*. (Victoria: Idrc (International Development Research Cent, 1994), 203.
[15] Dennis Dollens, *Digital-Botanic Architecture: D-B-A*. (Tokyo: Lumen Books, 2005), 12.

relate to directly on a daily basis does not allow for a connection with the natural environment, which in return, restricts cultural evolution to occur with nature. When human culture becomes neglectful of the natural environment, the realization of dependency on the natural environment is dissolved disallowing an understanding of human impacts on the natural environment.

While the detachment between culture and the natural environment has left the human race unaware of the necessary connection that is needed to be maintained with the surrounding ecologies, cultural detachment has resulted in an absence of cultural basis. Because the current cultural basis are on inwardly fabricated notions and constructs, such as a building design based off of a modern construction method, there is no resulting stability in the evolution of our cultural ideals. When human cultures were based singularly off of a relationship with the natural environment, cultural evolution progressed steadily and regional cultures maintained strong identities because of their connection with natural bases. In modern society, cultures are based minimally off of relationships with nature, resulting in rapidly evolving cultural constructs. As technological advancements and "global flattening" occurs, cultures are meshed and watered down, resulting in what is becoming a globally homogenized identity. [16] The rapid spread loose cultural basis has resulted in the loss of several valuable cultural aspects. Less established beliefs and ideals are easily consumed or absorbed by larger cultural constructs, and regional specificity is loosely varied.

Questions are raised concerning the importance of cultural consistency and the definition of place [fit these notes in better with the remainder of the section]. Kingston Heath, author of *Vernacular Architecture and Regional Design*, argues about the definability of place. "Place, however, is more than a geographically definable entity accentuated by historical and visual landmarks; and heritage is not the aesthetic replication of a selected past. On an emotional level, place is a mental construct different for each of us, and, in the case of childhood dwelling places, tied from youth to personal experience."[17] As well as the amalgamation of cultures, cultural homogenization occurs at the process level, in which a culture evolves differently without a strong environmental basis. Heath argues that "all cultural experiences are hybridized, and that all vernacular forms are transitional. Is consistency of spatial quality important in cultural definition? What is the time frame required for a space to remain consistent in order for it to

[16] Danilo J. Anton, *Diversity, Globalization, and the Ways of Nature.* (Victoria: Idrc (International Develop ment Research Cent, 1994), 203.
[17] Kingston Wm. Heath, V*ernacular Architecture and Regional Design: Cultural Process and Environmental Response*. (London: Architectural Press, 2009), 3.

become defining and recognizable. All cultures and vernacular languages evolve…at what rate is this evolution productive/unproductive?"[18]

This analysis of pattern language aims at forming the basis for a reconnective bioregional design method. This bioregional design, as aforementioned, will biomimetically draw identity from the surrounding natural environment. This methodology will be applied to social spaces, where human culture is cultivated. Cultivation of culture in regionally expressive enclosures will supply a reintroduction of nature into human culture. The way in which urban and natural frameworks are set can be measured and recorded through the categorization of their specific patterns. Patterns found in the natural landscape are often less visible or obvious than those found in our built environments, yet useful in establishing an understanding of the ecosystems which occur within a specific region. The mapping and understanding of natural patterns found in the landscape can contribute to a standardization or classification of different bioregions. In a similar way, the mapping of urban landscapes plays an important part in classifying the ways in which they function, both systematically and in social aspects.

There are layers within the urban fabric that are laid upon one another, which result in the complete structure of a modern metropolis. While there is a tangible functional aspect of an urban framework which relates directly to a developments relationship with the surrounding environment in a physical manner, for example, the water distribution systems of a city that relates directly to a water source found in the natural environment, there is a layer of intangibility, when it comes to the human existential structures within these urban environments. The connections made with the natural environment in current spatial frameworks are strained and often non-existent. This is directly connected to the design of modern urban framework, which leaves the natural environment inaccessible and inconvenient to metropolitan inhabitants. Ultimately, a spatial design pattern will be developed that will allow for the social spaces within a larger urban context, to act as devices communicative of the surrounding natural environments identity and efficiency systems.

In deconstructing a patterned language, the ways in which landscapes are perceived must be altered. "Elements of landscape language are like parts of speech, each with separate functions and associations. Flowing, like a verb, is a pattern of events expressed in both water

[18] Kingston Wm. Heath, *Vernacular Architecture and Regional Design: Cultural Process and Environmental Response.* (London: Architectural Press, 2009), 6.

and path. Water and path, like nouns, are action's agents and objects; like adjectives or adverbs, their qualities of wetness or breadth extend meaning."[19] In built urban environments, the way in which the construct has developed is of great importance, as it is a determinant of systematic construct, as well as they ways in which social structures inhabit within the urban structure. Christopher Alexander discusses the differences in different urban frameworks, and how that has become apparent in the resulting social and economic structures, the intangible structures of an urban society. Alexander calls out another issue beyond the lack of connectivity between the natural and built environments. "It is more and more widely recognized today that there is some essential ingredient missing from artificial cities. When compared with ancient cities that have acquired the patina of life, our modern attempts to create cities artificially are, from a human point of view, entirely unsuccessful."[20] In this sense, there is value placed in the long evolution of an urban environment, when compared to our quickly erected modern societies. Alexander divides urban spaces by developmental form, noting two structural differences. One structure he denotes as a tree, while the other is a semi-lattice. When the structure meets certain conditions it is called a semilattice. When it meets other more restrictive conditions, it is called a tree.[21] The dimensionality of the two differs when the resulting social and economic structures are examined. This structure is applicable to all inner workings of the urban environment, from economic to social structure. The overlap in society is an element important in developing richness and integration, as well as solidity to the urban fabric. When comparing the social structure, we can get a better understanding of the differences between tree and semi latticed urban structures. "In a traditional society, if we ask a man to name his best friends and then ask each of these in turn to name their best friends; they will all name each other so that they form a closed group. A village is made up of a number of separate closed groups of this kind.

But today's social structure is utterly different. If we ask a man to name his friends and then ask them in turn to name their friends, they will all name different people, very likely unknown to the first person; these people would again name others, and so on outwards. There are virtually no closed groups of people in modern society. The reality of today's social structure is thick with

[19]Anne Whiston Sprine. *Language of Landscape*. (New Haven: Yale University Press, 2000), 85.
[20] Christopher Alexander. "RUDI: Bookshelf: Classics: Christopher Alexander: A city is not a tree part 1." *Pattern Language.com*. http://www.patternlanguage.com/archives/alexander1.htm (accessed October 17, 2010).
[21] Christopher Alexander. "RUDI: Bookshelf: Classics: Christopher Alexander: A city is not a tree part 1." *Pattern Language.com*. http://www.patternlanguage.com/archives/alexander1.htm (accessed October 17, 2010).

overlap - the systems of friends and acquaintances form a semilattice, not a tree."[22]

How the urban structure relates to the social structure correlates in the relationship between natural and urban environments as well. Our modern "tree" structured urban environments related to the natural environment in the same way that their social networks are established. Detachment and segregation from elements on the interior and exterior of the urban framework are resultant from the fundamentally heterotrophic design of our cities. As we provide ourselves security by leeching off of distant regions, we simplify our urban pattern language. This one dimensionality of connection hinders our awareness of the natural surroundings. In semilatticed structures, the crossing of connectivity in social, economic, and cultural aspects allows for tightness in society, and greater awareness for all urban elements.

The current urban metropolitan typologies have adopted a parasitic existence, in which the ability to self sustain has long past, and the need to look beyond a bioregion to support itself is required. This exploitation of resource from another region is often the only way a modern urban environment can survive. Los Angeles draws water from the Colorado River and Northern California, exterior regions, and can only sustain its population girth from parasitic practices.23 There are two types of ecosystems that our urban frameworks are generally modeled after. Autotrophic and heterotrophic ecosystems represent two ways in which the loop of resource travels through a particular system.[24]

While in an autotrophic ecosystem, the chain of energy distribution is looped, and for the most part, run off a base of photosynthesis. In these ecosystems, the looping of energies, from the smallest microbes to the largest vertebrates is evenly recycled and redistributed throughout the region through a complex system. "These systems generate all the energy needed and through a framework of hierarchical food webs, the nutrition is spread." [25] These ecosystems do not require any resource outside their ecological region, and are self sustaining. As well as living in a self reliant manner, the ecosystem does not grow to a volume larger than the natural resources can support.

In comparison, heterotrophic ecosystems are reliant on other ecosystems nearby for

[22] Christopher Alexander. "RUDI: Bookshelf: Classics: Christopher Alexander: A city is not a tree part 1." *Pattern Language.com*. http://www.patternlanguage.com/archives/alexander1.htm (accessed October 17,
[23] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 33.
[24] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 38.
[25] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 38.

resource. These are less common in the natural environment, and are found most often in rivers and watershed environments, where the organisms must wait for their resources to flow from an ecosystem at a higher elevation. The dependency that our modern urban environments have on distant regions "disconnects people from the impact of their consumption, disrupting vital feedback loops and undermining economic and social security."[26] All current cities are heterotrophic, and cannot be sustained purely from the region in which they inhabit. It is possible through photosynthetic means, suggested by McDonogh and Braungart, that our future cities can potentially exist in an autotrophic manner.[27]

Indigenous cultures that practice a lifestyle more closely engrained with the natural environment have been able to sustain themselves in an autotrophic manner, while still retaining rich and comfortable lives. Modernity however, and the globalized city with cultures based off of other cultures, cannot so easily accept a purely regional connection. "These indigenous and traditional communities are able to achieve ecologically sound economies due to the embedment of life-affirming worldviews and ethics, which recognize the land as something that nourishes humans and needs to be nourished in return. In turn, natural, social, and economic capital are protected simultaneously, providing a genuine basis for social and economic security."[28] This success of indigenous cultures can be attributed to their connection with the natural environment, and the fact that "economic and social security arise from creating human communities and institutions that are equitable, resilient, psychologically fulfilling, flexible, and ecologically minded."[29]

Design Methodologies for the Reconnection Between Man and Nature: Today, a new trend in the design of our built environment is slowly becoming more and more popular. As realizations are made concerning the lack of a relationship with the natural environment, design methods are geared toward making stronger attempts to restore this connection. Much of this awareness for human-nature detachment stems from the current ecological disasters that have occurred. Global warming for example has been directly linked to human activity.[30] The

[26] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 37.
[27]Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 38.
[28] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 27.
[29] Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 37.
[30] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed*. (New York: Princeton Architectural Press, 2007), 135.

absence of an understanding of the impacts human activity is having on the natural processes has led to the decrease in natural efficiency, loss of biodiversity, weakening ecosystems, among many other negative impacts, are occurring. This lack of ecosystemic efficiency doesn't have an immediate effect on detached built environments, because technological advancements have insured for existence within a protective buffer unaffected, at least for a limited period of time, from dependency on the natural systems. The notion of the effect of globalization on our urban environments is discussed in Understanding Meaningful Environments, as is it stated, "In the age of globalization, the importations of banal building types threaten to and have defaced many a city that had unique traditional urban fabric, while creating more environmental pollution as they are not well suited for the specific climatic conditions."[31] A recent increase in industrialization, for example the rapid urbanization of China, has led to an increased decline in the efficiency of natural ecosystems. As the comprehension of the human-nature disconnect and its ramifications comes to fruition, many new design methodologies have appeared with intentions to reconnect man and nature through the built environment.

As such, many architectural movements have been initiated, all of which fall under the umbrella concept of Regionalism. Regionalism as a movement focuses on the installation of a site specific identity and relationship which reinforces a uniqueness of regional specificity through both architectural form and function.[32] Within the realms of regionalism, many architectural thoughts have been developed to further enhance specific thoughts within the regionalist notion. On a building scale, movements such as Biophilic, Organic, and New Vernacular design have been developed, with the intention to restore a human-nature connection. Biophilic design for example, has the fundamental objective of eliciting a "positive, valued experience of nature in the human environment." In this movement, biophilia is set to be restored through high technological advancement in building types.[33]

As well as Biophilic design, Organic architecture is "architecture that, in unity and continuity, merges the elements that respond to different functions, as they occur in living organisms. In particular, it merges the dichotomy between the supporting and supported elements

[31] A. Guney, and K. Moraes Zarzar, *Understanding Meaningful Environments: Architectural Precedents and the Question of Identity in Creative Design - Volume 4 Research in Design Series*. (Amsterdam: IOS Press, 2008), 23.
[32] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 133.
[33] Stephen R. Kellert, *Building for Life: Designing and Understanding the Human-Nature Connection. 1 ed*. (Washington, DC: Island Press, 2005), 124.

in a single continuous element, and taking in to account, organic design is also defined."[34] In these two movements, the connection with the natural environment is not strong enough to re-instill the essential sense of dependency we have on the natural environment. While they have the capacity to give inhabitants a sense of appreciation, these methodologies do not communicate the urgency of a need for comprehension of human dependency on the natural environment. These branches of regionalist design focus in a majority on the form and climatic response, rather than the establishment of interconnectivity with the natural environment.

More recently in the development of naturally related design methodologies, Bioregionalism has become a more tangible direction towards our need for establishing physical connectivity with the natural environment. "Etymologically, bioregionalism translates to life territory, place of life, government by life. A central element of bioregionalism-and one that distinguishes it from similar politics of place-is the importance given to natural systems, both as the source of physical nutrition and as the body of metaphors from which our spirits draw sustenance. A natural system is a community of interdependent life, a mutual biological integration on the order of an ecosystem, for example."[35] While organic architecture may look and feel as though it relates to a region, on an architectural scale, it is the form which relates a majority of the connection to the natural environment. Between a buildings shell and the natural environment in which it inhabits, Organic architecture falls short because of its similarities to common urban environments, which buffer and shield in habitants from their true dependency on the natural environment. Porosity in built environments, with which dependency is channeled and made prominent, is an occurring thought that resides in bioregionalist thought.

In bioregionalist practices, the defining of a bioregion is one of the main elements which determine the scale and type of built environment that can be supported. The regionally holistic technical aspect of bioregionalism is what sets it apart from other form based design methodologies that attempt at connecting us with the natural environment. In bioregionalism, the first step is to establish this regional boundary. "Physical Determinants: climate, topographic landform, and cultural determinants, such a distinct life ways, patterns of land use, and organization, finance, and interchange, language use and inflection (dialect), distinct modes and materials used in construction, and styles of architecture. Together or individually, these determinants form a

[34] Ignasi Perez Arnal, Dennis Dollens, Alberto T. Estevez, Joaquim Ruiz Millet, Alfonso Perez-Mendez, Ana Planella, and Alfons Puigarnau. *Genetic Architectures/Arquitecturas Geneticas. Bilingual ed. santiago.* (Lumen Books/Sites Books, 2003), 77.
[35] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 21.

boundary, or center by which the region is determined. Boundaries are often difficult to establish in centrally defined regions."[36] Interestingly enough, one of the main indicators of a specific bioregion is the watershed system which it relies on.[37] Watersheds all form differently, according to precipitation levels, topography, and elevation, which lends them to differentiate from one another, though they may exist in close proximity to one another. Bioregionalism differs purely from other socially based regionalist theory because of this determination of region. Pertaining to this study, and having Honolulu as a test site, the idea of a watershed-based region division is appropriate not only from a bioregionalist standpoint, but from a cultural standpoint as well. "Bioregionalists determine regional differentiation based on ecological parameters, specifically watersheds. In Kenneth Frampton's *Critical Regionalism*, a region's limits are defined by a culture's unique identity, manner of place-making, architectonic strategies, qualities of the environment, and possible tactile experiences."[38] Being that the territories were historically broken up by watershed, this initiation of bioregionalist urban design practice could also act as a re-installation of historical land treatments.

The installation of bioregional practice is one of the few methodologies that react to our current environmental woes, while through technical approaches, attempt to change the entire mindset of our urban inhabitants. Bioregionalist communities from an economic standpoint, "reflect the capacities and limitations of their particular ecosystems, honor the diversity and history of local cultures, and meet human needs as locally as possible. They practice minimizing dependence on imports while focusing on high value-added exports. Paradoxically, this gives them an important competitive advantage in a global economy, allowing them to trade on favorable terms without sacrificing their economic sovereignty."[39] Beyond form and human experience, bioregionalist theory makes itself responsible for social, political, and economic issues that all contribute to the vitality of an urban framework.

Now that the disconnection with the natural environment has been made more apparent, and the sustainable movement is starting to pick up speed, several design strategies have been developed and implemented in hopes of restoring the vital human-nature connection through

[36] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 18.
[37] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 116.
[38] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed.* (New York: Princeton Architectural Press, 2007), 118.
[39] J Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices.* (Washington, DC: Island Press, 2007), 39.

built form. These methodologies exist in terms of either form, or function based attempts at reconnection. Design methods such as restorative environmental design, biophillic design, organic architectural design, ecological design, and many others, all fall under the methodological umbrella that is biomimicry.

Biomimicry is a method of design and technological development that is more recently gaining attention, though the initial idea has been around since the 1870's, when the development of machinery was compared with devices found in nature.[40] It looks towards nature as a device with which to model after, measure against, and seek out as a mentor.[41] Janine Benyus, founder of the biomimicry guild and the first person to have coined the term "biomimicry," explains natures method of design as an ultimate goal, in which every element "runs on sunlight, uses only the energy it needs, fits form to function, recycles everything, rewards co-operation, nature banks on diversity, demands local expertise, curbs excesses within, taps the power of limits."[42]

The application of a biomimetic language to an existing region could not only add further definition and clarity, but provide new solutions to existing problems by basing solutions off of biota that have evolved to deal specifically with regional issues. In nature, through the process of natural selection, evolved techniques that do not most effectively adapt become extinct, and in this manner, can assure the most adequate natural techniques off of which a language can be derived.[43]

The manner in which biomimicry is carried out varies drastically, and wavers between a literal and metaphorical translation of biological processes. While most effective translations are literal, modern technology is often found insufficient, and we are left to what can be labeled as "primitive" solutions when compared to those found in nature. For example, photovoltaic panels are mere metaphorical translations of the photosynthetic processes found in leaves, but we have been able to literally translate the sun-honing abilities of sunflowers, and applied them to our solar-concentrators. These design tactics are the 6th Principle to Sustainable Design, which calls for a respect of nature's wisdom.[44] As for biological diversity, the trend isn't specifically distinct from one cultural region to another, and instead follows latitudinal trends. Isolated areas such as Hawaii, will have the most readily available distinct biota from which to base

[40] Philip Steadman, *The Evolution of Designs: Biological Analogy in Architecture and the Applied Arts*. 1 ed. (New York: Routledge, 2008), 153.
[41] Janine M. Benyus, *Biomimicry: Innovation Inspired by Nature*. (New York: Harper Perennial, 2002), 7.
[42] Janine M. Benyus, *Biomimicry: Innovation Inspired by Nature.* (New York: Harper Perennial, 2002), 7.
[43] Yoseph Bar-Cohen, *Biomimetics: Biologically Inspired Technologies. 1 ed*. (Boca Raton: CRC, 2005), 36.
[44] Jason F. Mclennan, *The Philosophy of Sustainable Design*. (Kansas City: Ecotone Publishing Company Llc, 2004), 33.

design supplementation, due to the high rate of endemic species that inhabit remote regions.[45] Biodiversity has a strong tie to cultural distinction, as it affects the way in which a specific culture interacts with its natural environment, further influencing beliefs, customs, and mythologies.[46] In this manner, biological basis is more than appropriate in the development of a language.

In the field of architecture today, biomimetic design principles are already starting to help in providing definition to specific regions. In Harare, Zimbabwe, the Eastgate Centre, designed by architect Mick Pearce and engineering consultant Ove Arup, was built to mimic the naturally ventilated mounds of an African termite species.[47] The result was a cost efficient and effective building that is playing a large role in the redefinition of the regions architectural appearance.[48]

The application of biomimicry as a language doesn't necessarily require a single basis within an entire project, and can instead exist in a compilation of several effective biological solutions. During a class lecture given by Joe Ferraro, the specific nature of applied biomimetics were explained. For example, the native Hawaiian Silver-Sword has great potential for regional basis. Not only is it an endemic species that survives in harsh conditions, but it acts as a natural solar concentrator. The silver leaves grow to form highly reflective parabolic arches that concentrate solar energy to the center of the plant during its reproductive season. This allows for rapid growth of a flower plume and eventual pollination. The species can only exist at a specific elevation, and when conservation efforts lead to the placing of this plant at a higher elevation, the proximity to the sun resulted in hyper-concentration, and the ultimate self-cooking of this plant.[49] Hawaii is home to an abundance of unique biological processes that can readily be applied to our built forms.

In relation to biomimicry, bioregionalism occurs at an urban scale, and is comprised of biomimetic principles at several different scales and levels. Vincent Canizaro defines bioregionalism in *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition*. "Etymologically, bioregionalism translates to life territory, place of life, government by life. A central element of bioregionalism-and one that distinguishes it from similar politics of place-is the importance given to natural systems, both as the source of physical nutrition

[45] Michael A. Huston, *Biological Diversity: The Coexistence of Species* (Cambridge Studies in Ecology). (New York: Cambridge University Press, 1994), 17.
[46] Danilo J. Anton, *Diversity, Globalization, and the Ways of Nature*. (Victoria: Idrc (International Development Research Cent, 1994), 203.
[47] George Baird, *Architectural Expression of Environmental Control Systems. 1 ed.* (Washington, DC: Taylor & Francis, 2001), 164.
[48] George Baird, *Architectural Expression of Environmental Control Systems. 1 ed*. (Washington, DC: Taylor & Francis, 2001), 164.
[49] Joe Ferraro, "Antarctic Research Station" (lecture, School of Architecture, Honolulu, HI, April 19, 2007).

and as the body of metaphors from which our spirits draw sustenance. A natural system is a community of interdependent life, a mutual biological integration on the order of an ecosystem, for example."[50] Bioregionalism can be equated to urban biomimicry of a natural ecosystem, where the goals are to achieve similar levels of self-sustainability as found in natural environments. The bioregionalist movement has great potential, in that it establishes methods of dealing with all aspects of society, not only the built environment. A regionalist economy, society, and cultural entity are all established outcomes of bioregional applications. Bioregionalism is the movement most successful in fully focusing on reestablishing a human-nature through the development of regional dependency.

[50] Vincent Canizaro. *Architectural Regionalism: Collected Writings on Place, Identity, Modernity and Tradition. 1 ed*. (New York: Princeton Architectural Press, 2007), 21.

IV. MAPPING OF COEVOLUTIONARY DEVELOPMENT

4.1 GENERALIZED SUBSYSTEMS ANALYSIS

These case studies will function as a means to better understand the ways in which human urban environments are linked to the natural environment. Ultimately, this study intends to generate a methodology that will allow future urban environments to establish a reconnection between human culture and the natural environment. Three case studies will be conducted, and from each, "flow or pattern" mapping will be extracted. Flow or pattern mapping in urban typologies will be used to gain a better understanding of the ways in which urban subsystems work. In each pattern mapping, a parallel subsystem, found in each of the case studies, will be extracted and translated to a level where connectivity with the natural environment can be communicated. The four subsystems to be analyzed consist of the following:

Social System

This includes cultural activity, and the manner in which people associate with one another on a day to day basis. From a cultural standpoint, how is information exchanged, and how often do people interact with the natural environment. What level is this interaction, whether it be, due to employment, or extracurricular activity? How dependent is the success or frequency of social interaction, on our interaction with the natural environment?

Policy: how are the laws and rules established in accordance to the natural environment. Is there any connection? Does natural law preside over human law, or does human law allocate a percentage of concentration towards maintenance of a connection with nature. How does the governing establishment interact with the natural environment? Where do dependencies lie?

Infrastructure

Perhaps the most tangible of the subsystems to map because of its physicality. How are the physical systems of the urban environment connected with the natural environment. Are they dependent at all on the surrounding natural environment? For example, the most common form of modern dependency is found in our need for stable fresh water sources. How do the form and function of the infrastructural systems relate to the surrounding natural environment?

Environment and Resource

The gathering of materials and goods (basic imports) from the natural environment, can come either directly from the same region in which he urban environment presides, or from another region far away. How is the exportation and importation of resource managed, and to what level does it involve the immediate natural environment?

After thorough analysis of each subsystem within its specific case, the flow mappings of each will be compared to one another, and to the mappings of a natural ecosystem. An ideal social space typology will be constructed through blending the flow maps from each of the case studies. The efficiency aspect of naturally occurring ecosystems, the high level of natural integration found in indigenous Hawaiian societies, Vand the current level of technology that modern bioregional communities are the three main areas that our current urban typologies are deficient. Technological extrapolation will allow for an understanding of possible future relationships and functional mappings. Using the way in which natural ecosystems function as an ideal model, the subsystems flow mappings can be phased towards an idealistic urban environment.

A few other aspects of each case study will be analyzed, but will not play major parts in the patterning for the ideal society, but rather, will act as supplemental elements to the patterns that will allow further success of the ideal society. These additional "pattern supplements" will be drawn directly from occurrences found outside subsystem patterning. Though they do not occur in all of the case studies, their occurrences will serve to benefit the design for an ideal urban society. The supplemental elements will be analyzed as follows.

System Cycles

Found primarily only in natural ecosystems, though sometimes found in a societies cultural activities, developmental cycles of destruction and renewal are a main element of self-governance, and constant refreshing that help to clarify a certain systems evolutionary progress. In natural ecosystems, such examples can include internal and external sources of destruction, such as a brush fire, or an overly reproducing parasite. The destruction portion of the cycle allows for the system to gain a higher level of efficiency after recovering from the destruction. Weak systems that cannot recover are destroyed altogether. In from a cultural aspect, Jewish societies had this type of regeneration phase, where every half-century a year-long jubilee was held, where all bondsmen were freed, mortgaged lands were restored to the original owners, and land was left

uncultivated.[51]

Panarchy

Similar to the notion of destruction and renewal cycles, panarchial theory describes a pattern of adaptive cycles that are nested within space and time. These cycles allow for greater connectedness which results from processes that disturb the system, stimulating release potential and reorganization. In this occurrence, "sustainability is maintained by relationships among a nested set of adaptive cycles arranged as a dynamic hierarchy in space and time-the panarchy. The panarchy represents the dynamic interplay between processes and structures that sustains relationships on the one hand, and accumulates potential on the other."[52]

[51] Hartmut Bossel,. *Earth at a crossroads: paths to a sustainable future*. (Cambridge, UK: Cambridge University Press, 1998), 67.
[52] Hartmut Bossel,. *Earth at a crossroads: paths to a sustainable future.* (Cambridge, UK: Cambridge University Press, 1998), 99.

4.1.1 Historic Mapping: Indigenous Culture and Society

Case Study 1: Ancient Hawaiian Ahupua'a and Watershed Ecosystems

Background Information:

The Hawaiian Islands had formed as early as 70 million years ago. After the arrival and eventual habitation of the volcanic islands by plants and animals, complex ecosystems began to form. Because of the islands isolation from all other land masses on earth, the ecosystems formed are both highly efficient and unique. Each element within these endemic ecosystems fulfills a specific need within the system, and as such, is one of the qualities which contribute to its vulnerabilities.[53] If one of the elements within the system is compromised, the entire ecosystem suffers great inefficiency. The links formed in the ecosystem through co-evolutionary symbiosis are highly specialized and less flexible than those found in less isolated systems. For example, if a species of endemic emergent tree, such as the Koa, is suddenly inefficient, due to fire or pests, the remainder of the ecosystem would suffer from the sudden absence of the Koa's high absorbency of heavy rain.[54] Figure 4.1 explains the integrated structuring of tree species that inhabit native Hawaiian forests.

Figure 4.1: Layers of plant species in tropical Hawaiian forests

[53] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.
[54] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.

Ancient Polynesians arrived at these islands somewhere between 1-600 AD.[55] From that time until 1778, the end of the pre-contact era, the Hawaiian society was able to evolve alongside the natural ecosystems that existed, and ingrain themselves within the system in a synchronized manner.[56] The successful coexistence of these two systems, the natural ecosystems and the human society, allowed the native Hawaiians to reach population of either 250,000 or 800,000. The amount of 800,000 is supportable on re-evaluation of the ethnohistoric evidence, and on a model of catastrophic loss of life after European contact.[57] The internal structure of the Ancient Hawaiian society was known as the ahupua'a, "the organizational structure whereby individual households were merged into a public economy—thereby permitting an intensification of rank and chieftainship."[58] The subsystems of the Hawaiian ahupua'a evolved alongside the natural ecosystems, and work in a symbiotic manner, with no external input from a disruptive source. The succinct coexistence of the Hawaiian people and the natural environment in which they live can be attributed to the interdependency and reliance the people placed on the surrounding ecologies. The following subsystems mapping will focus primarily on the extraction of key qualities of dependency that have rendered the ahupua'a system a success.

Social System:

The ancient Hawaiian social system was ordered by a strict caste system managed for the chiefs by a specialist class of managers, known also as the konohiki. The division of elite and commoners was fundamental in the determination of resource allocation and land management. However strict the political system was, it allowed for the equal uplifting of the importance of the natural ecologies.[59] The Hawaiian culture was oral, thus requiring memorization, and a high level of interlinking within the individual. "Native lore and historical accounts specific to every ahupua'a still conveyed by oral traditions and contained in numerous published and unpublished written documents, represent a rich legacy of traditional ecological knowledge."[60] Within the

[55] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 8.
[56] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 9.
[57] Patrick V. Kirch. "Archaeology and Prehistory in Kahikinui, Maui, Hawaiian Islands." (PhD diss., University of California, Berkeley, 2003).
[58] Patrick V. Kirch. "Archaeology and Prehistory in Kahikinui, Maui, Hawaiian Islands." (PhD diss., University of California, Berkeley, 2003).
[59] Patrick V. Kirch. "Archaeology and Prehistory in Kahikinui, Maui, Hawaiian Islands." (PhD diss., University of California, Berkeley, 2003).
[60] Kenneth Y. Kaneshiro et al., "Hawaii's Mountain-to-Sea Ecosystems: Social-Ecological Microcosms for Sustainability Science and Practice," EcoHealth Journal (2005): 4.

culture, religious beliefs about their origin of the people reinforced a connection with the land and the natural environment. This allowed for the people as a single body to experience a deep connection with nature, and the shared realization of their dependence on the natural ecosystem, as well as an understanding that the people as an entity, existed under the larger natural environment, as an integral part. Because the ahupua'a land division was so interconnected with the ecological environment, the cultural and political subsystems that stemmed from them shared the same reverence and understanding.[61] The interconnectivity between the cultural system and the natural environment stems primarily from the expanse of common knowledge shared amongst all. Environmental consciousness within cultural values ensures that as a people, who evolve socially together, priority on the natural environment is of primary concern, in all societal aspects.

Social interaction, cultural exchange, and political organizational subsystems were all evenly derived from the understanding of co-existential relationships between human and nature. Because of the shared basis between these three societal subsystems, the social, cultural, and political elements are intertwined, with a common respect for the natural environment. This shared dependency between all three subsystems in the social realm of indigenous Hawaiian societies allows for cohesive societal evolution with the natural environment, as well as a linking of awareness from generation to generation. As a people of the land, much of the social activity was accomplished out of doors,

Policy:

The caste system and dominance of high powered elite individuals within the political system of the indigenous Hawaiian society allowed for a tight control of resource. Water, being the most sacred resource to the native Hawaiians, was strictly monitored and controlled. This allowed the society to achieve high levels of efficiency within their infrastructural subsystems. Formal rules governed water distribution and discouraged waste. It was considered a grievous offense, and distribution was governed by the ali'i ai moku (district chiefs) as an instrument as a gods.[62] The Hawaiians were aware of their impact on the natural environment, and the fact that their usage of the natural resources was to a certain degree, environmental degradation. Therefore, laws are placed to compensate for the deficiencies caused by human use of the natural

[61] Kenneth Y. Kaneshiro et al., "Hawaii's Mountain-to-Sea Ecosystems: Social-Ecological Microcosms for Sustainability Science and Practice," EcoHealth Journal (2005): 4.
[62] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 9.

systems. Rigid schedules were set for the cleaning and diverting rivers and streams. The rights and privileges to water were earned, and not guaranteed, ensuring dedication to respect of the water systems. Farmers were expected to maintain clean taro fields that weren't ridden with weeds and clutter. They were also responsible to aiding in the cleaning of the communal streams and rivers, as their profit was most immediately affected by the water systems health.[63]

Punishment for disobeying the law concerning water was harsh. "Those who failed in either regard [maintenance and usage] were dispossessed of their land and banished. If a farmer dared to water his taro fields without the approval of the overseers, he was put to death. Disobeying water regulations jeopardized all; the gods were seen to be merciless in this regard."[64] The element that would render this process less effective today is the totalitarian mannerism of the Hawaiian society, as well as the religious belief systems which enforced reverence of natural systems deep within an individual's core. Though this political system is harsh in terms of enforcement, and wouldn't function in a society today, the elements that can be extracted from this subsystem are essential in how the realization in natural dependency is established. Having the ability for a shared social awareness of human effects on the surrounding environment at a level integrated with the political system is an important component of congruent human-nature compatible systems.

Infrastructure:

The ahupua'a system was structured around the water distribution system, and though a majority of the natural structure was kept, there were man-made alterations to the river systems that allowed for crop irritating. Figure 4.2 depicts the traditional configuration of the ahupua'a system, which were watershed-specific. In managing the waterways, high priority was placed on careful maintenance, as

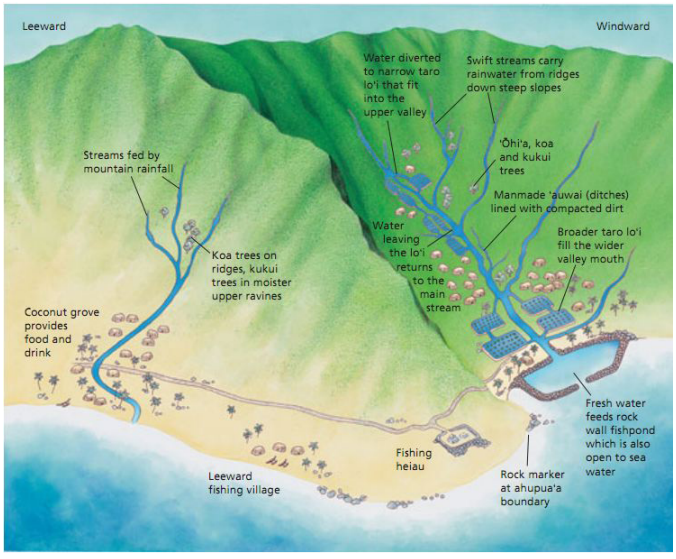


Figure 4.2: Layout of ancient Hawaiian ahupua'a

[63] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 9.
[64] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 9.

the importance of water and its upkeep in society was fundamental. The Hawaiian had great expertise in controlling and redirecting the water to where they needed it in a manner that worked with the natural system. "In the grading and building of terraces for growing "water" or "wet taro, kalo wai, and the construction of a system of aqueducts, flumes, and ditches, ha wai and 'auwai, to bring water from the dammed steams or springs to these terrace areas, the Hawaiians showed greater engineering and building skill, ingenuity, industry, and planning and organizing ability than any other Polynesian people."[65]

While these infrastructural manifestations of human built intervention did affect the natural systems, it was to a degree that the environment could easily handle. This was in part due to the fact that the Hawaiians were conscious of how these redirections of water affected the natural systems, and made great efforts in supplementing areas made deficient by their restructuring of the natural system. Through careful design and maintenance, the aqueducts and trenches were as minimally invasive as possible, and worked with the existing natural system. There was an understanding of how resources and subsystems were broken up from watershed to watershed, and the Hawaiians reinforced containment and separation of these ecosystems from one another. Resource from one ecosystem was not directed to another ecosystem in order to maintain balance. As each watershed had evolved according to its specific degree of resource, the Hawaiians were aware that changing this would throw off the delicate balance within the ecosystem.[66]

Possessing the understanding of how the natural ecosystems work, their value, and their boundaries, is essential in building successful urban subsystems. The native Hawaiian peoples respected the natural subsystems and understood how to work with them. Post-contact, agriculturally driven colonizers sought to derive full potential from the natural systems for irrigation.[67] While they were able to derive more immediate success from a production basis, the water systems within each ecosystem were disrupted. Tunnels were drilled through the mountains to transport water from the windward side to the leeward side. This broke the tightly knit ecosystems and disrupted their interior efficiency.[68] Because modern urban subsystems did not work with natural ecosystems, they can no longer function as they once did pre-contact.

[65] Beatrice H. Krauss, *Plants in Hawaiian culture* . (Honolulu: University of Hawaii Press, 1993), 3.
[66] Beatrice H. Krauss, *Plants in Hawaiian culture* . (Honolulu: University of Hawaii Press, 1993), 7.
[67] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 13.
[68] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 13.

Environment and Resource:

The agricultural strategy employed by Native Hawaiians was a strong example of non-natural subsystems working in collaborative conjunction with a natural ecosystem. Hawaiian diet was based upon what they could farm, and resources within the natural environment were not harvested or gathered unless there were times of famine. This is another example of the Hawaiian people harboring an understanding that their needs cannot be fulfilled in a parasitic manner through the natural environment. While their agricultural processes worked in conjunction with the natural subsystems, they produced their own resource without the need to deplete resources that are part of the natural ecosystem.

For agriculture, as well as fishing, this idea of existing in a manner secondary to the natural environment stays consistent. To gather a bulk majority of fish, fishponds were constructed to feed the masses, without over depletion of the natural reef system. The ahupua'a was seen as an extension of the watershed systems not only across the valley, but into the respective ocean zones and reef areas. While traditional fishing was an important and vital part of the food source, as many of the Leeward communities were fishing villages instead of agricultural due to the lack of water, fish ponds allowed for mass quantities of resource not found in a natural instance to be harvested without depletion of resources within the natural ecosystem.

Summary: Extractable Subsystems Elements

Social:

Culturally connected with natural environment. Common knowledge frequently shared concerning qualities of natural environment and how coexistence is most efficiently achieved. Sharing of knowledge and culture is oral, which allows for greatly ingrained concepts to be implanted into the societies memory.

Policy:

Laws implemented called for strict punishment, often death. While impractical in modern societies, environmental law reflected importance of natural ecosystems health. Policy set was rigid, while the society governed was flexible. In contrast to today's society, where both policy and social realms are inflexible. As a result, the natural environment takes on the role of adjusting to our societies, while efficiency and productivity is sacrificed.

Infrastructure:

Infrastructure is planned in a method that will have the lightest effect on the natural subsystems structure. Natural subsystems are sources of design basis for society, as urban function is arranged according to paralleled functions within the natural system.

Resource:

Resource is only solicited from the natural ecosystem during times of hardship. Agricultural establishments work with the natural environment but are a separate system.

4.1.2 PRESENT DAY MAPPING: MODERN CULTURE AND SOCIETY

Case Study 2: Honolulu and the Watershed Ecosystem

Ecosystem Background Information (includes modern dependencies):

The watershed ecosystems found on the Hawaiian Islands are like no other found elsewhere on earth. Because the guidelines formulated for this dissertations case studies are founded with the inclusion of human society, the subsystems will require slight translation, to detach them from human culture and society. These natural watersheds ecosystems are the result of three million years of development, from the time that the Hawaiian islands emerged from the Pacific Ocean floor.[69] While many subsystems exist within the ecosystem, the main subsystem that has a large element of control over the other subsystems is the hydrological system that feeds the entire ecosystem. "Hydrological cycles in oceanic islands are in constant motion and transformation. As water changes form through evaporation, condensation, melting and freezing; energy is released and absorbed, linking water to the environment's larger energy cycle."[70]

Figure 4.3: Manoa Watershed

These ecosystems are in constant slow evolution, with small changes occurring at a constancy, due

[69] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 3.
[70] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 2.

to external forces. These forces include climate change, human intervention, and erosion of the mountains, which is the force which most controls the ecosystemic processes in a holistic manner. As erosion occurs, a Pacific Islands ability to catch rain filled clouds lessens. The difference is dramatic, from island to island, as mountain range types vary in form. This difference in water supply equates to the difference in ecosystem type. While younger higher mountains such as those found on the Big Island catch a majority of precipitation, lower regions on the mountain receive great amounts of rain, and the peaks of the mountains are left dry. In contrast, older and more eroded islands, such as Oahu and Kauai can only catch windward clouds, resulting in dry leeward areas.[71] The Manoa watershed system, depicted in Figure 4.3, is a result of the more eroded mountain ranges on Oahu. The water delivery system thus becomes the primary shaper of the ecosystem, with all subsystems adapting their form and functioning appropriately.

Social System (panarchial relativism):

Because this case study is an example of a system absent of human interaction, the panarchial subsystem will instead be outlined. Similar to human social systems, panarchial systems are complex and intangible, based upon individual connections made between subjects existing within a perspective ecosystem. As explained earlier, panarchy is an ecosystemic theory involving the interconnections of processes and structures found within a larger realm. It is one of the founding theories which attempts an explanation of the ways symbiotic relationships are fostered.[72] Found in the Hawaiian watershed systems, is a tangible projection of an instance of panarchial subsystems. The evolution of tree types according to water distribution in the Hawaiian Island has resulted in a tightly regionally specific process with which endemic species are interconnected. "Hawaii's native forests have evolved over millions of years to become highly effective watershed covers. Vegetation in the forest fills every level. It soaks up rainfall like a giant sponge, allowing water to drip slowly underground and into streams."[73] The species included in this subsystem of water collection which include Koa, 'Ohia, 'Olapa, and hundreds of other unique plant types, are specifically geared for the climatic and regional conditions of their immediate surroundings.

[71] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 3.
[72] Hartmut Bossel,. *Earth at a crossroads: paths to a sustainable future.* (Cambridge, UK: Cambridge University Press, 1998), 99.
[73] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.

This regional specificity in native endemic species equates physically through highly specialized leaf shape, root porosity, bark typology, etc. Therefore, only a native species that has taken millions of years to adapt to its perspective watershed system, can carry out the absorption of rain at the highest efficiency rate. "When a native forest is eroded and damaged, opportunistic foreign species invade. While these new plants can stabilize bare ground, the watershed cover they create is not as effective as that of the native forest."[74] In the same way, all species, both flora and fauna, that have evolved together, are the only species that can fulfill their roles within the ecosystem. Replacement or substitution of species, to fulfill a particular ecosystemic need, for example, the keeping of a particular plant species population in check, will not result in the upkeep of an efficient ecosystem. The panarchial establishment of interdependent subsystem elements results in the most efficient type of ecosystem. Hawaiian watershed ecosystems prior to human settlement, was one of the most efficient systems due to its isolation from possible intrusion.[75] Intrusion can be seen in the feral boars introduction to the native ecosystem, which resulted in destruction of several subsystems. The feral boar over consumes native plant species, uproots and erodes soil, as well as spreads disease to native fauna.[76]

Environment and Resource:

While the panarchial systems within the Hawaiian Watershed act as a functional translation of what can be explained as a social system, the resource subsystem can be translated in a functional realm, where certain overriding rules are formed from our dependency on the ecosystem. This can be analyzed by extracting the human relationship from within the ecosystem, something found in the Native Hawaiian Ahupua'a system, and viewing natural ecosystems acting as a single entity in partnership with the human species as another entity. When generalized, the relationship between human and ecosystem is not panarchial or symbiotic, and is instead highly parasitic. There is a strong and unrecognized dependency on ecosystems services that is not clearly delineated within our society.[77] As a separate entity not integrated within the natural ecosystem, humans depend on systemic processes for four main services. These include provisioning, regulating, cultural, and supporting services.[78]

[74] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.
[75] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.
[76] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 5.
[77] Kanchan Chopra. *Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group*. (Washington: Island Press, 2005), 2.
[78] Kanchan Chopra. *Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group.* (Washington: Island Press, 2005), 7.

The watershed ecosystem found in the Hawaiian Islands effectively supplies all four of these resources within a very small land area. This is can be attributed to the unique topography found in these islands. The rapid rate in which the elevation increases results in a tightly knit concentration of different land types. This allows our modern societies to gather a high amount of resource from a small land area. Consequently, as our modern urban environments have not been developed in accordance with the natural ecosystems that have evolved here, we are not able to work efficiently with the resources provided naturally. Our current urban landscapes are not in complete symbiosis with the natural watershed ecosystems, which results in our inability to gather efficiently. Below is an outlined analysis of the resources available to our modern societies, and the ways in which they are or aren't supplied.

Provisioning:

Within food subsystems resource, there are five sub-categories of food gathering typology. Crops, livestock, capture fisheries, aquaculture, and wild plant and animal products. While the small acreage of Hawaiian watershed ecosystems does not provide crops, or livestock supplements naturally, our modern societies have adapted these areas to provide for these types of food generation. Farms and ranches, though successful in the short term, do not work in symbiosis with the watershed system, and instead damage and disrupt the natural flow of water. On the other hand, because of the strong connectivity watershed ecosystems have with the ocean, capture fisheries and aqua culture are still readily available.[79] Under the provisioning aspect of resource gathering, fiber, genetic resource, biochemical, and fresh water. Our modern urban frameworks are structured in a somewhat efficient way to work with the natural water supply and filtration system. While a realization has been established of the fact that our fresh water consumption exceeds the natural rate of production, new technologies have been implemented to work alongside the natural watershed ecosystem. The Honouliuli Water Recycling Facility works to help supplement the water that the natural ecosystem filters. This removes the usage burden as well as efficiency rate of the water system. "Before the facility was built, wastewater was treated and then discharged offshore. Now, water arrives at the Honouliuli plant for further treatment and eventual reuse."[80]

[79] Kanchan Chopra. Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group. (Washington: Island Press, 2005), 7.
[80] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 21.

Regulating Services:

These include air, climate, water, erosion, water purification, disease, pest, pollination, a natural hazard regulation. The watershed ecosystems in the Hawaiian islands provide all of these resources, but are overloaded by human presence. Water, air, climate, and disease regulation have declined in efficiency due to the loss of biodiversity.[81] Biodiversity in an ecosystem translates to system efficiency. It "provides not only a wide range of possible pathways for the future development of life, but the library of learned repertoires for responding to environmental change and disturbance."[82] Hawaiian watersheds pre-contact fulfilled these regulatory services with a high level of efficiency. "Biodiversity loss and habitat destruction on islands can have more immediate and serious repercussions than on continental systems, as a consequence of relatively restricted genetic diversity, small population sizes and narrow distribution ranges of plants and animals on islands."[83] While island watershed ecosystems are highly efficient and rapid as regulating systems, they are highly susceptible to destruction from external forces.

Cultural Services:

because of the presence of an indigenous people, the cultural resource systems are strongly connected to the natural ecosystem. Knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, and cultural heritage are all integrally tied to the natural watershed system, and are based off of the human connection with the natural subsystems which allow the ecosystem to function.[84] The relationship between human and nature is addressed in terms of formal knowledge, and traditional knowledge. Traditional knowledge is the result of cultural resource in terms of medicine and agriculture, and the mapping of tangible benefits drawn from traditional ecological knowledge.[85]

[81] Kanchan Chopra. Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group. (Washington: Island Press, 2005), 8-9.
[82] J Isabella Jennings, and Peter Newman. *Cities as Sustainable Ecosystems: Principles and Practices*. (Washington, DC: Island Press, 2007), 102.
[83] Kanchan Chopra. *Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group.* (Washington: Island Press, 2005), 18.
[84] Kanchan Chopra. *Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group.* (Washington: Island Press, 2005), 10-11.
[85] Kanchan Chopra. *Ecosystems and human well-being: Policy responses, : findings of the Responses Working Group.* (Washington: Island Press, 2005), 14.

Supporting Services:

Supporting services, such as soil formation, photosynthesis, primary production, nutrient cycling, and water cycling, are all present in Hawaiian watersheds. The urban environments that coexist don't necessarily take full advantage of the supporting resource services, both because of the small land size, and because of the high density of people living on the islands.[86] These supporting systems usually express functionality to urban systems in an indirect manner, as they form the basis, through productivity and efficiency, for the above systems listed. For example, the success in an ecosystems ability to regenerate soil will eventually translate to the nutritional value of the food resources pulled from a particular ecosystem. An ecosystems success in supporting systems equates to the eventual success in all other systems.

Infrastructure (resultant from resource dependency):

In each of these ecosystem resources, human societies create tangible connections through the active shaping of our build systems to react and effectively utilize these sources. Our urban systems efficiency ratings often correspond directly in respect to their interconnectivity with the surrounding natural ecosystems. In the instance of Hawaiian watershed systems, urban infrastructures are minimally synchronized at a subsystems level. For example, the food resource supply offered by the watershed system is underutilized in modern urban societies because of the priority we have placed on fresh water. The watershed system in Hawaii provides its inhabitants with some of the purest drinking water in the nation, without the need for heavy filtration and processing.

Throughout the watershed systems found within the islands, an average of 150 million gallons of water are produced daily, all of which is sourced naturally, without the needed for secondary treatment.[87] Our physical water infrastructure system is the only system within the current urban fabric which exists in a dependent relationship with the natural ecosystem. Even so, the infrastructural systems implemented have caused a loss in efficiency and damage to the natural watershed system. "When the first artesian well was sun on Oahu, it hit a pristine aquifer that had never been disturbed and water came gushing forth. But as more and more wells were sunk on Oahu, the aquifer began to recede. As a result, brackish water intruded on the fresh

[86] Kanchan Chopra. E*cosystems and human well-being: Policy responses, : findings of the Responses Working Group.* (Washington: Island Press, 2005), 12.
[87] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 16.

water lens, causing wells to "salt up."[88]

Summary:

Subsystems within the watershed system of Hawaii are all highly synchronized and regionally specific. This results in a high instance of vulnerability pertaining to exterior forces, as well as high levels of interior efficiency and productivity. The isolation and small size of the island ecosystems has resulted in high levels of specialization within specific species, and tightly interconnected symbiotic relationships. Because the natural ecosystem is delicate and highly specialized, the urban built systems that coincide with the watershed system must be applied in a manner of expanded sensitivity and "lightness." Higher dependency on technology to supplement the areas where human societies could potentially exhaust the natural ecosystem should be a priority. In implementing successful coexistence of natural and urban systems, delicate phasing must be employed. Natural systems of such high sensitivity and containment like the watershed system in Hawaii, must be allotted time to adjust to and exterior force if high levels of biodiversity are to be maintained.

Summary: Extractable Subsystems Elements

Social (Panarchial):

The panarchial relationships in the native Hawaiian watershed system are very strong due to the islands isolation. This isolation has resulted in interdependence within subsystem elements to one another. Interior subsystem dependence equates to higher levels of efficiency, as each element does not need to fulfill all functional requirements in a solitary manner.

Infrastructure: Subsystem typology derived from topographical quality. The unique watershed system in these islands is a result of landform, the most basic regional element. Landform and soil typology have thus led to the resulting ecosystem and subsystems formation.

Resource:

Watershed systems exist in a somewhat isolated manner from one another. Each has a defined territorial zone, with which subsystem elements, such as flora and fauna, can pass, but main infrastructural elements, such as the river and stream systems, maintain isolation within the ecosystem territory.

[88] Honolulu Board of Water Supply. "Water for Life." (Honolulu, US: Info Grafik, Inc./EMA, Inc., 2009), 13.

4.1.3 FUTURE MAPPING: BIOREGIONAL SOCIETIES

Case Study 3: Beddington Zero Energy Development (BedZED)

Project Background Information:

The Beddington Zero Energy Development in London is currently the largest bioregional development existing today. It was designed in partnership between the BioRegional Development Group, the Peabody Trust, Bill Dunster Architects, Arup, and Gardiner and Theobald. Constructed between 2000 and 2002, BedZED, as it is more commonly called, is the longest standing bioregional development today, and employs the latest sustainable development in achieving high efficiency ratings. The project, consists of 82 houses, 17 apartments, and 1405 square meters or workspace. Shown in Figure 4.4, BedZED is distinctly identifiable. Through the incorporation of roof gardens, solar energy, natural lighting, high reduction of energy consumption, and waste water recycling, BedZED is able to maintain very high environmentalist standards.[89]

Figure 4.4: Bird's eye view of BedZED

BedZED goals were to develop a way to reinvent perception of sustainable lifestyles, attractive, affordable, and convenient. Conventional housing approaches are challenged through holistic sustainable design strategies. Reduction in heating and water demands, are drastic, through elimination of space heating and water consumption, as well as education their residents in how to reduce usage. High density living is achieved while at the same time providing healthy interior environments with strong connections to open green space and natural lighting. Not only is continual sustainable living a priority, but construction and maintenance are also kept to tight sustainable methods. Materials chosen and construction processes used were all carefully

[89] Kate Andrews. "BEDZED: Beddington Zero Energy Development in London | Inhabitat - Green Design Will Save the World." Green design will save the world | Inhabitat. http://www.inhabitat.com/2008/01/17/bedzed-beddington-zero-energy-development-london/ (accessed November 8, 2010).

considered, and used because of their pertinence to local sourcing and low environmental impact.[90]

Subsystem Mapping Analysis:

Social System: The BedZED culture has been altered and exists in a different manner from other housing development groups in that the residents have been somewhat reincorporated with one another and a greater sense of community has been developed. This is due to the developments transportation, density, and amenities. BedZED has minimalistic tendencies pertaining to vehicular transportation, and encouragement of its residents to walk resulted in increased levels of interaction. A report titled BedZED Seven Years On conducted in 2009 concluded after surveying residents that on average, each individual was well acquainted with an average of 20 other residents in the development. This is vastly improved from the UKs national average of 8 residents.[91] As well as the reduced solitary vehicular transportation, higher density forced more interaction of individuals, and the developments amenities allowed for more interaction with inhabitants outside the home. The village square is used as a free for all type of activity area, where residents socialize and hold congregational activities. As well as purely social, a bioregionalist culture had begun to form, as the village square provided a space for people to sell and exchange home grown vegetables, and to repair bicycles.[92]

While a stronger community is established through increased opportunity for interaction, there is also a general awareness that exists, inherent to all inhabitants who decide to live at BedZED. Because the development makes very clear its ideals for the way its inhabitants should live, there is heightened awareness of the impact all activities have on the surrounding environment. In a social sense, this "belonging to a cause" is an element that ties these individuals together. The residents of BedZED come from a variety of different backgrounds, educational levels, and employment. The community is held together not through similarities in individual occupation or interest, but in the understanding that their way of life is similar because of a goal set by the development, not just the individual.

[90] Nicole Lazarus. *BEDZED Toolkit Part 1: A guide to construction materials for carbon neutral footprints.* (Surrey, UK. BioRegional Development Group, 2002.), 3.
[91] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 34.
[92] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 34.

Because the development makes very clear its ideals for the way its inhabitants should live, there is heightened awareness of the impact all activities have on the surrounding environment. The BedZED pavilion is used by a majority of the residents, and includes a recreational area for exercise, as well as a café and a food market.[93] The overall lifestyles of residents are encouraged in a very specific direction, one of increased physical activity, and increased relationship with the outdoors. The natural environment surrounding the development is not ideal in the sense that it is close to sewage works and a landfill site.[94] This does not allow for very direct interaction with the surrounding immediate natural environment. In this sense, the social subsystem is not well connected to a regional natural ecology. Instead, the social system is connected to the natural environment through development-fabricated nature, and the implementation of environmental impact in the lifestyle of residents.

Policy:

The institutional aspect of BedZED keeps the environmental impact in high priority. Strict measuring of ecological footprint and monitoring of residential use is employed to instill a sense of awareness in the developments residents. Every residence is equipped with energy and water monitoring devices, which provide the residents with an awareness of their consumption levels.[95] This informational system connects the development to its users in a collaborative means, where both are working towards a common goal of reduced ecological impact.

Above informational analysis policies, there are two main areas where strict governance of policy is enforced. These include the construction materiality of the development as a whole, and the transportation used within the development. BedZED employs a Green Transport Plan which "incorporates three strands; to reduce the need to travel, to promote public transport and to offer alternatives in private car travel."[96] BedZED encouraged the reduction in car usage by eliminating the need to commute through work-live housing types, and by initiating a City Car Club, where members share the use of locally based vehicles. While not all residents could keep from living without a car, the bicycle and pedestrian friendly development made it easy for bicycles to be used instead of cars. Homes had integrated bicycle storage, and it was indicated by residents that more secure bike storage would be useful, as it is in high demand.[97]

[93] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 34.
[94] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 36.
[95] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 23.
[96] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 26.
[97] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 28.

This holistically design transportation system isn't completely efficient yet, as cars are still needed, but the ultimate goal is to completely eliminate the need for residents to rely on cars. While the transportation policies are strict in monitoring their residents, and through constant encouragement of car clubs and bicycle utilization, there is not a strong relationship between the way in which the residents travel and their interaction with the natural environment. This is largely due to the context in which BedZED is set. Interaction, or travel outside of the development is difficult because of its removed placement.

The second policy driven element of the BedZED development was the materials usage. Policy instilled by the formation of the BedZED toolkit, a mass of information dedicated to outlining methods needed to establish a low-impact bioregional development, required local usage of all materials built. This subsystem connects in a strong manner with the surrounding natural environment, as all materials were locally sourced. If the design called for a material outside the delineated region, the design was altered, rather than the policy bending to include regionally exterior materials.[98] This policy also controls the maintenance of the residences, which will require continual use of regional materials, and the employment of local specialists to conduct repairs and upkeep. Regionalization of construction and maintenance is forced restriction, and forced dependency that correlates indirectly with the natural environment. Instead of drawing raw materials, local companies who sustainably manufacture materials locally are relied upon, which allow for the conservation of the natural environment. This ecological connection is not physical, but dependencies are established from the need to preserve local natural resource, and avoid using outsourced materials.

Infrastructure:

The physical infrastructure of BedZED is naturally, the easiest subsystem to trace due to its material locality, and on site production of electricity, and water conservation. Beddington Zero (Fossil) Energy Development was a subdivision of the whole organization, focused on the generation of the highest percentage of renewable energy as possible. Interior dwelling demands are reduced through employment of standardized low energy fixtures, etc. while a high percentage of energy is produced using an onsite CHP plant, fed by locally-produced waste wood.[99] The

[98] Nicole Lazarus. *BEDZED Toolkit Part 1: A guide to construction materials for carbon neutral footprints.* (Surrey, UK. BioRegional Development Group, 2002.), 37.
[99] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 14.

infrastructural systems implemented in BedZED allow for a tightly integrated development that exists in a self supporting manner. All physical infrastructural systems are designed with maximum efficiency.

Beyond upholding maximum efficiency within its electrical systems, the ventilation systems at BedZED are the most interconnected and dependent on the developments immediate natural surroundings. Electric heating needs are minimized through an intelligent south facing wall design. With a combined high percentage of class inclusion in the façade (a rare occurrence for structures in England due to the heating loss), and a high insulation value, natural heat from the sun is captured, and eliminates the need to use the high energy using heating systems common of typical dwelling units. Along with the minimization of heating demands, air throughout the units is circulated naturally. A distinctive characteristic to BedZEDs appearance are the brightly colored masts which are an inclusive part of the air conditioning system. Shown in Figure 4.5, these masts are "Powered by the breeze, the fins rotate to let stale warm air out and fresh air in without the need for electric pumps or fans."[100] These natural ventilating fans are physically connected and dependent on the natural conditions and wind direction that exists in the region. This small element of mechanical infrastructure provides a necessary comfort to the developments inhabitants, and also acts as a method of connectivity because of its reliance on external input.


Figure 4.5 - Natural ventilation system

Environment and Resource:

BedZED maintains connectivity to its surrounding through observing strict conservative rules pertaining to the use of natural materials. While the construction process was a prime example of minimalistic environmental resource use, for example, the regionally specific gathering of materials, two other subsystems within the BedZED development show significant connection in terms of dependency on the immediate surrounding environment. The food and waste subsystems implemented by the BedZED development aim towards both a zero carbon

[100] Iain Aitch. "From A to (Bed)ZED," Dwell (2003): 44

footprint, as well as the maintenance of regionally supplied resource and regionally disposed of waste. BedZED wanted to "address the impacts of food by encouraging residents to grow their own food and promoting organic fruit and vegetable box delivery schemes."[101] Residents were also encouraged to grow their own food, as BedZED was strategically placed out of walking distance from large chain grocery stores. This placement, while comes at some cost, when residents choose to drive to the grocery store, also provides another form of instituted dependency. While convenience in growing food at home is realized, ownership and concern for the well being of the land and soil are established. The instillation of dependency has equated, in the BedZED to the upholding of the garden spaces as a more cherished commodity. In this resource subsystem attaches another social subsystem of coordinated resource management within the development. Social propagation of resource connects a community. While farming is not appropriate in this era due to the time required and the advances in technology which render individual application the group farming found in BedZED allows for a unified sense of dependency realized by a large group of residents.

The waste in BedZED is another environmental issue dealt with that can be mapped at a subsystematic level. It is made apparent to residents, through monitoring systems, the amount of waste they create, and the impact it has by allowing the volumetric value of waste to be realized. While in typical homes, waste is broken up in small amounts, where its true volume is not realized, the disposal system at BedZED is monitored, and reports are formulated at regular intervals. The majority of the waste in BedZED is recycled. Recycling measures are at a much increased level of specificity in terms of sorting. Wherever applicable, items are composted instead of being sent to landfills. "As kitchen and garden waste is bulky and comprised 42% of the waste stream by weight in the UH, it is desirable that it is treated on-site rather than being collected by the local authority."[102]

A large proponent to the success of the dramatic reduction in waste is due to the community-level standard of education concerning waste management, as well as community activity when composting is taken into consideration. This waste system is tied tightly to the food growing resource system. As residents realize the importance of maintaining a high quality of soil to produce high quality food, the want of improvement through composting is established. In this establishment of realized dependency, the subsystems become self-sufficient, through

[101] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 29.
[102] *BEDZED: Seven Years On.* (Surry, UK. BioRegional Development Group, 2009), 31.

connection that occurs between humans and the natural environment. BedZED's food and waste systems begin with strict monitoring, which will eventually lead to the establishment of a communities want to maintain the surrounding environment. It would appear that dependencies are established through an educational process. Policies must be implemented in order to educate and inform residents of their impact, as well as the ways in which impact can be lessened.

4.2 CONCLUSION

Qualities of Ideal Social Spaces: Reconnection Culture with the Immediate Surrounding Environment

Figure 4.6 is a diagram illustrating the parallel structure of the elements extracted from the case studies, which play significant roles within each case in the formation of ecological awareness. Reintegration of knowledge: for successful reconnection, a society wide understanding of subsystems within the built and natural environment must be gained. The measures used to create this environmentally connective social space will adopt many subsystems elements pulled from the case study. Perhaps the most controversial of these elements is the use of strict policy.

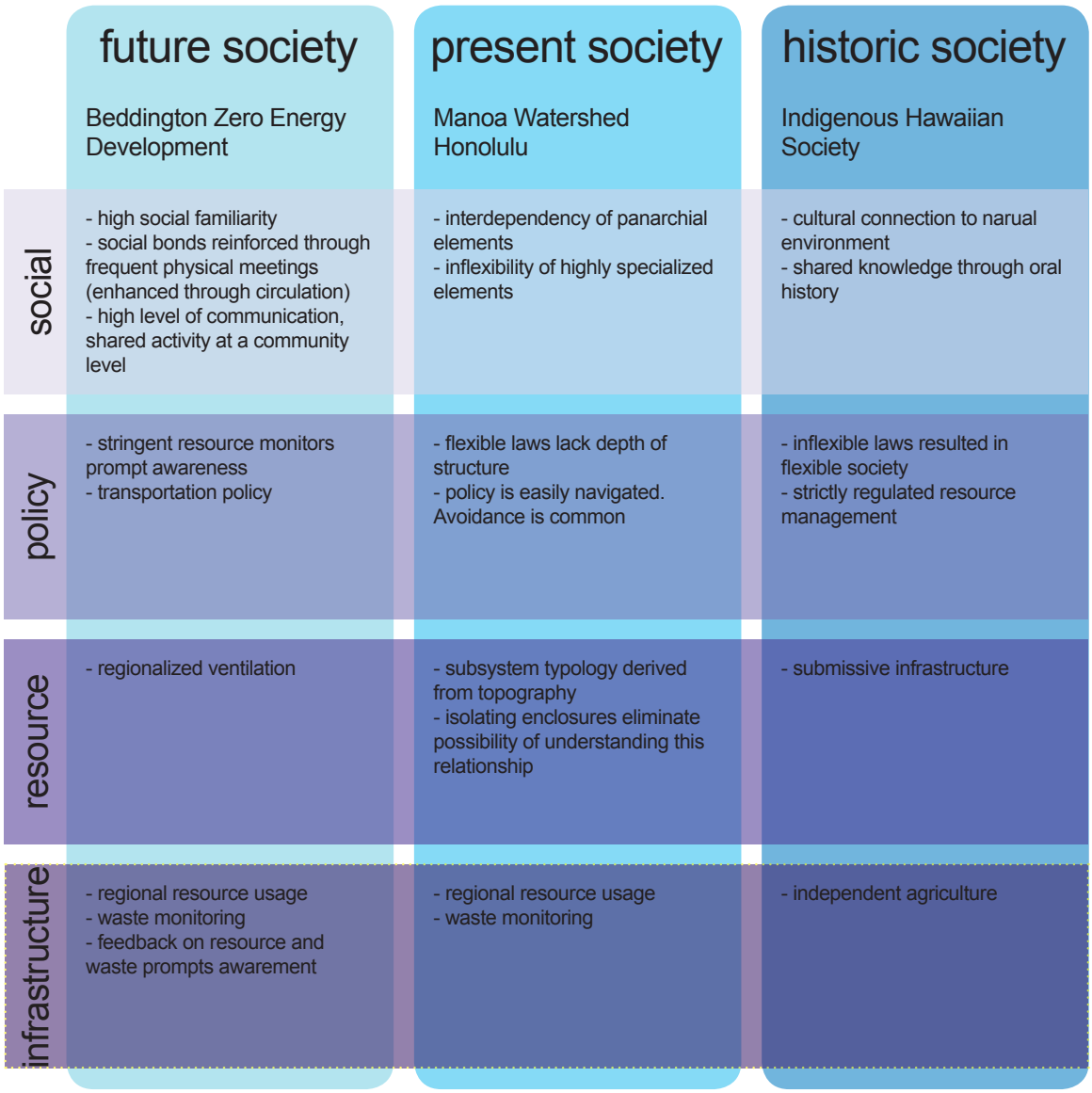


Figure 4.6 - Parallel structure of systems

These social spaces are seen as necessity, and individuals will require their use. However, strict policy will allow for the comfort and quality of social space services of inhabitants to be slightly compromised, in order to reinforce understanding.

Informative Elements

Resource Use: installation of elements within social spaces that allow for understanding of resource use in built environment surrounding the social space. This allows for people participating in social activity to understand simultaneously the human impact on the surrounding environment. The information could be gathered at a daily our hourly instance, where it is then relayed to the inhabitants.

Environmental Stability/Dependency:

The efficiency rate of an element within the social space is affected by the efficiency rate of the surrounding natural environment. These elements are reactive, and effect the social space, for example, water pressure, shade level, etc. This doesn't cause a total loss in comfort, but a physically felt indication of a deficiency in the natural environment that is caused by human existence. This can even occur through a simple visual connection, for example, color saturation of a particular architectural element will change in accordance to the level of water saturation in the surrounding natural environment. Users will understand the low color saturation correlates to a low amount of water in the surrounding natural environment, and in turn, will be prompted to act in a more conservative manner with water use.

Infrastructural/Form Elements:

The materials and form of the social spaces will also be visually representative of the surrounding natural environment. Through the use of immediately existing natural elements a sense of place is derived. Local plant species will be used not only for their aesthetic purposes, but for their spatial quality. This will allow for a recognizable spatial sense that is paralleled to that in the natural environment.

Evolutionary Parallel:

Like the natural environment around it, the social environment will evolve. With a reconnection between the two, symbiotic evolution at an intangible level. Cultural reference and understanding

will change along with the changes in natural environment, which in turn will correlate with the built environment. The design for these social spaces should evolve spatially and systematically with the evolving social and environmental changes. This will allow for continued evolution, without a stagnant urban form affecting the changing human behavior. Thus efficiency and success of the human built and social environment, as well as the natural environment, can increase throughout time. This in turn will result in better resource production, biodiversity, cultural diversity, and quality of life.

V. MAINSTREAM CONNECTIVE METHODOLOGIES

5.1 SINGAPORE SKY GARDENS

Sky gardens are an architectural typology that is rapidly gaining popularity, especially in cities pushing their urban density limits. They are currently being looked at as a hopeful alternative to the common spaces that are being lost at the ground level to high levels of development, in particular, that of Singapore, a small South-East Asian city-state. As an a supplementary spatial type added to an existing architectural language, a sky gardens can be defined as planted areas that do not exist at the ground level of a building. While they do not always qualify because of the incorporation of greenery into the space, quite often high amounts of planting, whether potted or roof garden installations, are seen as defining attributes.[103] Sky gardens, vary widely in accessibility as

Figure 5.1, The Shard London Bridge [left] and Figure 5.2, Commerzbank Tower [above] are examples of iconic buildings being developed with the incorporation of skygardens.

well, and while one of the main reason they are incorporated into a specific building's design vocabulary is to act in replacement of social areas lost at the ground level, sky gardens can also represent a certain amount of exclusivity.

In Jason Pomeroy's Room at the Top-the roof as an alternative habitable/social space in the Singapore context, the incorporation of this new typology into current building languages is thoroughly explored. From the standard view on a socially

[103] Theodore Osmundson. *Roof gardens: history, design, and construction.* (New York: W.W Norton, 2009).

integrative spatial typology, sky gardens are becoming elements that exist on every social spectrum, ranging from public to private.[104] The current understanding of roof top social spaces in general has become somewhat diluted in crossing typologies. Pomeroy uses the forgotten rooftop shanties of Hong Kong in contrast with the pent house spaces highly celebrated in New York. "In some instances they have been forgotten spaces of refuge for the under privileged where, in cities such as Hong Kong, they have been the reserve of complete shanty communities forgotten by society and planning processes.[105] Yet they have also been celebrated spaces for the privileged, as expressed in the art deco penthouses of 1930's Manhattan – skyscrapers being the legible icons that were symbolic advertisements for the buildings, their clients, architects, and indeed, the entire city."[106] In this sense, the public understanding of sky gardens and spaces above the ground level are still somewhat diluted in how people feel they should interact in these spaces. In time, greater employment of these spaces will hopefully lend to the public incorporating their spatial typology into the common realm, and confusion of spatial boundary will be eliminated.

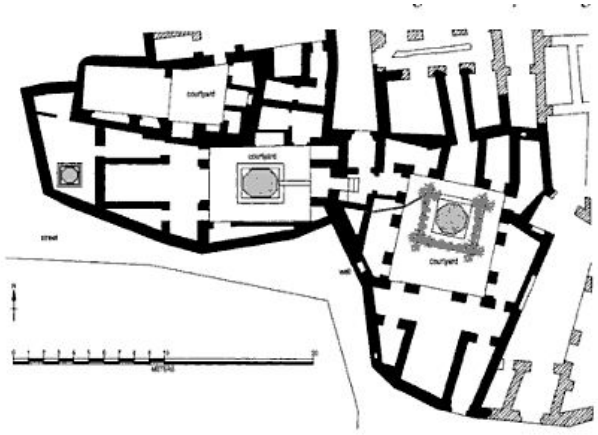


Figure 5.3 [left]: Depiction of the Babylonian Hanging Gardens
Figure 5.4 [above]: Al-Fustat city layout

[104] Jason Pomeroy. "Room at the top-the roof as an alternative habitable/social space in the Singapore Context," *CTBUH*, accessed April 20, 2011. http://www.ctbuh.org/LinkClick.aspx?fileticket=C8T61HnArWE%3D&tabid=1452&language=en-US
[105] Wing Hong Chui and T. Wing Lo, *Understanding Criminal Justice in Hong Kong* (UK: Willan, 2008), 69-70.
[106] Johann Eisele and Ellen Kloft, *High-rise manual: typology and design, construction, and technology. (*Basel: Birkhäuser-Publishers for Architecture, 2003), 12-13.

Historic Precedents

Throughout ancient times, the notion of sky gardens and elevated garden spaces was not foreign. The Hanging Gardens of Babylon are considered one of the seven ancient wonders of the world, because of their strong incorporation of garden spaces at different levels throughout architectural structures. Built by King Nebuchadnezzar for his wife, the gardens displayed a wide variety of plant species on several levels of the ziggurats atop which they were built. An ancient example of sky garden typology, the Hanging Babylonian gardens combined elevated privatized garden spaces with typical dwelling spaces.[107]

The Egyptian city of Al-Fustat (now part of Cairo) was similar to the Babylonian gardens in that high amounts of planting were incorporated into areas that were at levels of the built environment other than the public ground space. This was possible because of the advanced irrigation systems employed to transport water throughout the city. The amount of vegetation found within the urban city center was at a much higher concentration of that found in surrounding towns, and residents took to customizing their properties heavily with planting additions. These low-level sky gardens found at the tops of multi-storey residential developments where highly customized and privatized and served as the main social space for individual family units. Within the highly dense Al-Fustat development, thirty-nine families re-adapted their roof spaces to re-accommodate social activity pushed from the dense ground level.[108]

Later on in history, Le Corbusier would develop his five pillars, the fifth being addition of rooftop gardens. His reasoning behind the addition of rooftop gardens to spaces was a combination of both building performance and socially accommodating spaces. Le Corbusier's notion of the sky garden was based on its application at solitary dwelling or apartment complex, but is re-scalable in an urban context. The sky garden spaces Le Corbusier specified worked in congruence with the building to raise its physical performance level, as well as provide a space that would "become the most favored place in the building."[109] He explained the closely knit relationship between the reinforced concrete

[107] "Hanging Gardens of Babylon." *Hanging Gardens of Babylon.* N.p., n.d. http://hanginggardensofbabylon.org/ (accessed April 25, 2011).
[108] D. Fairchild Ruggles. *Islamic gardens and landscapes.* (Philedelphia: University of Pennsylvania Pres, 2008), 170.
[109] Le Corbusier, *Towards a New Architecture* (United States: CreateSpace,2011), 13-16.

structure and its symbiosis with the applied garden space. "The flat roof demands in the first place systematic utilization for domestic purposes: roof terrace, roof garden. On the other hand, the reinforced concrete demands protection against changing temperatures. Over activity on the part of the reinforced concrete is prevented by the maintenance of a constant humidity on the roof concrete. The roof terrace satisfies both demands (a rain- dampened layer of sand covered with concrete slabs with lawns in the interstices; the earth of the flower beds in direct contact with the layer of sand). In this way the rain water will flow off extremely slowly. Waste pipes in the interior of the building. Thus a latent humidity will remain continually on the roof skin.[110] As a functional application, this manner of working to better the living environment and building performance has been carried to our current applications of sky gardens, but at a much larger scale.

The modern notion of sky gardens in standard urban spaces has also reached somewhat of a standardization. Many of the sky garden spaces found in high density areas have slowly shifted into typological categories from which they can be further classified. This is the current existence of sky gardens, and how a majority of the public perceives them in the urban landscape.[111] Sky gardens in office buildings have been designed for a wide range of users in a many different types of space. The access levels of these sky gardens is also varied, as they can range from fully restricted access, reserved solely for the private used of executives, open to all employees no matter their positions, and some are open to the public at large. For the publicly available spaces, there are two varieties of access, ranging from "guest" access, where a pass or permit is required, yet the sky garden spaces are open to all, and there is full public access, where all members of the public are free to enter and exit as they please.[112] The change in privacy level from sky garden to sky garden is currently a source of confusion, as the physical attributes of sky garden design are not standardized, yet their access allotments are. This leads to neglect of sky garden spaces, as the general public would rather not risk exploring into sky gardens for fear of rejection.

[110] Le Corbusier, *Towards a New Architecture* (United States: CreateSpace,2011), 13-16.
[111] Theodore Osmundson. *Roof gardens: history, design, and construction.* (New York: W.W Norton, 2009).
[112] Theodore Osmundson. *Roof gardens: history, design, and construction.* (New York: W.W Norton, 2009).

5.2 FUNCTIONAL PERFORMANCE ASPECTS

In conducting a thorough analysis of all performance enhancing features sky gardens attribute to the buildings upon which they are installed, many elements that are commonly overlooked were uncovered, more specifically in the impact sky gardens could have on the environment at a global scale.

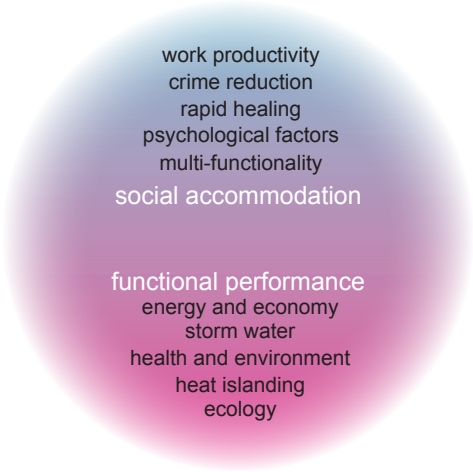


Figure 5.5: Roles fulfilled by skygardens

Energy and Economy: The presence of soil, plant matter, and increased moisture in sky parks at higher levels of a building have positive effects on the building environment as well as building components. The soil layer often found in sky garden installations protects the waterproofing membranes placed within the cladding systems of a building. The soils and plant matter also insulated, and reduce wind chill in colder climates, which in turn provides a lowering of the heating cost in the building. The soil and plant coverage provides shading and increases insulation values for both heating and cooling climates. Planted roof systems are part of the vernacular language in Northern European countries because of their ability to shield dwellings from the cold. The roofing membrane installed in typical cladding systems has a life expectancy of roughly 25 years. With additional soil insulation and buffer created by the plantings, the membrane is not subjected to as much concentrated heat and lasts longer saving maintenance and replacement costs. One

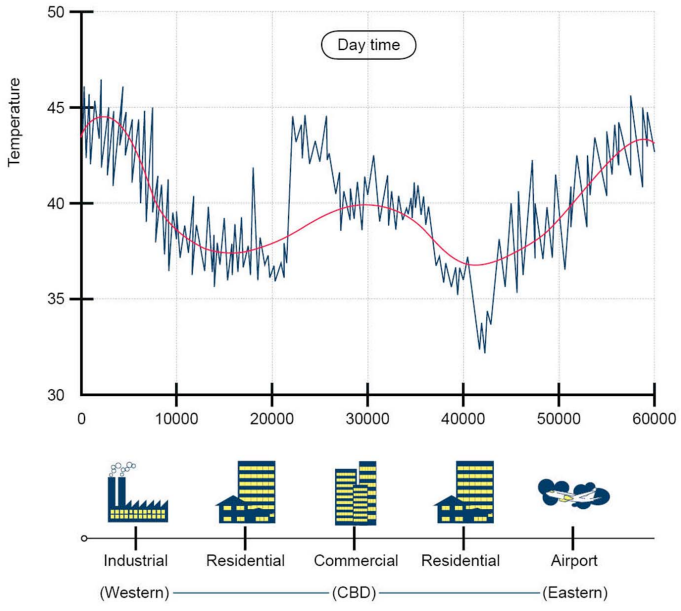


Figure 5.6: Temperature correlation with zoning

of the more interesting dynamic relationships recently understood was the collaboration that can occur when solar electric photovoltaic panels are place within a sky garden setting. Conventionally, developers had to choose between the two sustainable design methodologies, but more recently, it has actually proven more beneficial to place PV panels within a sky garden, especially in areas densely planted, that don't necessarily receive heavy foot traffic. As PV panels heat from sun exposure, their efficiency levels decrease, and less electricity is produced during peak hours of the day. Placed in highly planted areas, the PV panels benefit from the sky gardens ability to maintain a more ambient temperature, maintaining standard efficiency ratings.

Storm Water: In terms of storm water management, having an ample amount of planting in a sky garden helps in lessening the pressure on drainage systems during times of heavy rain. Sky garden planting delays the water that falls in their area from reaching the drainage system as it takes time for the plants to process the moisture they take in. When drainage systems overflow, storm water runoff will run across paved surfaces picking up chemicals, loose soil, and debris and bring it straight to the ocean. This problem has led to pollution of coastal waters and coral bleaching on an international scale.

Health and Environment: The planting found within sky garden applications also helps to mitigate noise, and electromagnetic radiation. Plant applications to building roof and façade surfaces have shown surprising acoustic value, as well as protection against radiation sources. For instance, the noise heard by an airplane passing over head is significantly lessened when one is in a room shielded by a sky court or sky garden. Dust, pollution and the increased greenhouse effect are also mitigated, because of plantings ability to process pollutants in our unnatural environments. The nitrogen compounds generated in dense urban environments can be somewhat sequestered by the addition of sky gardens. Sky gardens play a two part role in this sense, as its role in storm water runoff prevention leads to prevention of a much larger green house effect cause. In cities without large amounts of green areas, nitrogen is not absorbed, and is eventually washed to the sea, where algae suffer from over rapid growth with the excess of nitrogen. Algae, which is responsible for the sequestration of 30% of the carbon in the atmosphere, dies from this over rapidity, and begins to decompose, a process which requires oxygen. This

depletes the oxygen levels in the ocean, and leads to a further cycle of leaving green house gas levels unaltered.[113]

The Heat Island Effect: Heat islanding is an effect that causes dense urban environments to reach higher temperatures than the countryside surrounding them. This is due mainly to the high percentage of paved area that absorbs and retains heat throughout the day. An air current is created from the increased volume of hot air in the urban vicinity, and the heated air volume pushes any cool air over the areas inhabited by people, effectively blocking any cooling ventilation. This blocked ventilation also causes a buildup of pollution to occur within the city center, where air is kept stagnant. At night, the heat stored in the hard paved surfaces is released back into the city, and causes sleeplessness, higher air conditioning costs, and heat waves. Sky gardens work to mitigate this issue, in that their placement in open rooftop areas prevents the absorption of heat. In Jason Pomeroy's paper Green the Urban Habitat: Green Plot Ratio, a correlation between land use and heat island susceptibility is identified. "Singapore's urban morphology is made up of an array of object driven configurations ranging from tall, to medium to low rise developments. Commercial, industrial and residential land uses characterize the Island, with a predominance of residential blocks at the peripheries set within verdant landscape; a nature reserve to the north, industrial warehouses and business parks to the west and a centrally located business district."[114]

Ecology: In some cases, sky gardens offer ecological benefits in that they supply habitat to species acclimated to urban environments. Much of the modern city planning techniques center around the installation of urban corridors, where sky gardens are a primary vocabulary in the greening language of these planning strategies. Bird and insect species have been known to take residence in sky gardens, which offer food and shelter in the midst of an otherwise vapid landscape.

5.3 SOCIAL ACCOMMODATION ASPECTS

[113] P. Kaladharan. "Carbon sequestration by a few marine algae: observation and projection." Journal of the Marine Biological Association of India. Version 51. eprints.cmfri.org.in/2212/1/Kaladharan_107-110.pdf (accessed April 24, 2011).
[114] Jason Pomeroy. "Greening the Urban Habitat: Green Plot Ratio," *CTBUH*, February 2, 2011, http://www.ctbuh2011.org/speakers/speakers_03_s2_82.asp

Multifunctionality: in a social aspect, these exterior green spaces are designed to hold a variety of gathering typologies, and can house several different types of social groups. The formality levels of these spaces is also flexible, and many occasions can be held in exterior sky garden spaces. In high density urban spaces, green areas can be seen as places of retreat, often frequented on a regular basis by the same individuals. Green spaces that serve social function often fall under areas that inherit claims of ownership by its frequenters. As people begin to familiarize themselves with a social space, this sense of ownership grows, which then translates to territoriality. Ownership will often translate to the identification of a "sense of place," which from a cultural context, is a unifying element in urban social realms.

Psychological Factors: Exposure to green spaces such as parks, tree lined streets, landscaped traffic islands, and sky gardens effectively reduce the stress through the invocation of tranquility. Studies have proven that intermediary exposure to natural scenes leaves individuals feeling better. In terms of overall general health, exposure to green areas has also proven to increase success of human lifestyles. "Cities with high numbers of parks battle obesity and diabetes. Recent studies in the Netherlands and Japan show that people with easy access to green space boasted better health and lower mortality rates. Even relatively passive contact with nature—such as viewing it from a window—lowers

Figure 5.7 and 5.8 [far left]: D'leedon by Zaha Hadid
Figure 5.9 [above]: School of Art at Nanyang Technological Institute

blood pressure and anxiety levels."[115]

Exposure to plants also has benefits in that rapid healing is made more feasible. In studies conducted by Dr. Roger Ulrich of Texas A& M, "window views from a hospital room effected recovery time in surgical patients. He matched patients with similar demographics and surgical procedures but different window views—one facing a brown brick wall of an adjacent building, and the other looking at a small stand of deciduous trees. Those looking at the trees had fewer negative nurses' evaluations and post-surgical complications, used weaker pain killers, and remained in the hospital a shorter time—by 8.5%—compared to patients looking at a building wall."[116]

Figure 5.10 [above] - Interlace Building by OMA
Figure 5.11 [right] - Reflections at Keppel Bay by Daniel Liebskind

Crime reduction has also been found to occur when planted areas are introduced into the urban fabric. While one would assume that planted areas could further crime because it shields a perpetrator in the public realm, studies have shown otherwise. "A study of 98 vegetated and un-vegetated apartment buildings in Chicago showed that vegetated spaces cut crime by half, in addition to inspiring pride for surroundings that translated into less litter and less graffiti. Besides mitigating psychological precursors to violence by reducing stress and anxiety, green spaces increase a neighborhood's collective

[115] "Human Benefits of Green Spaces." *Sustainable Landscape Series. Version 137.* http://ag.udel.edu/udbg/sl/humanwellness/Human_Benefits.pdf (accessed April 25, 2011)
[116] Roger Ulrich. *Benefits of Gardens in Hospitals.*" International Exhibition Floriade 2002. Center for Health Systems and Design , n.d. http://www.greenplantsforgreenbuildings.org/attachments/content-managers/25/HealthSettingsUlrich.pdf (accessed April 24, 2011)

surveillance: Vegetated landscapes invite more people to use them, ensuring more eyes on the watch to prevent crime in outdoor spaces."[117]

Being subjected to planting and greenery also promotes concentration and workplace productivity. This substantiates the application of sky gardens in an urban landscape, because of their ability to spike productivity where placed, especially in office settings. The manner in which subjection to greenery effects human concentration levels occurs at a primeval level. "Voluntary attention, the exhausting focus required to ignore distractions and remain intensely devoted to work or study must be employed throughout the traditional workday. Involuntary attention is the effortless and enjoyable awareness of sensory stimuli in the environment-a benefit that has been selected for throughout the course of human evolution. In the past, those who found nature effortlessly engaging were more likely to know where the berries were, more likely to find the critters, and more likely to escape predators. Focusing on natural scenes gives voluntary attention a rest and allows involuntary attention to take over and recharge the human psyche."[118]

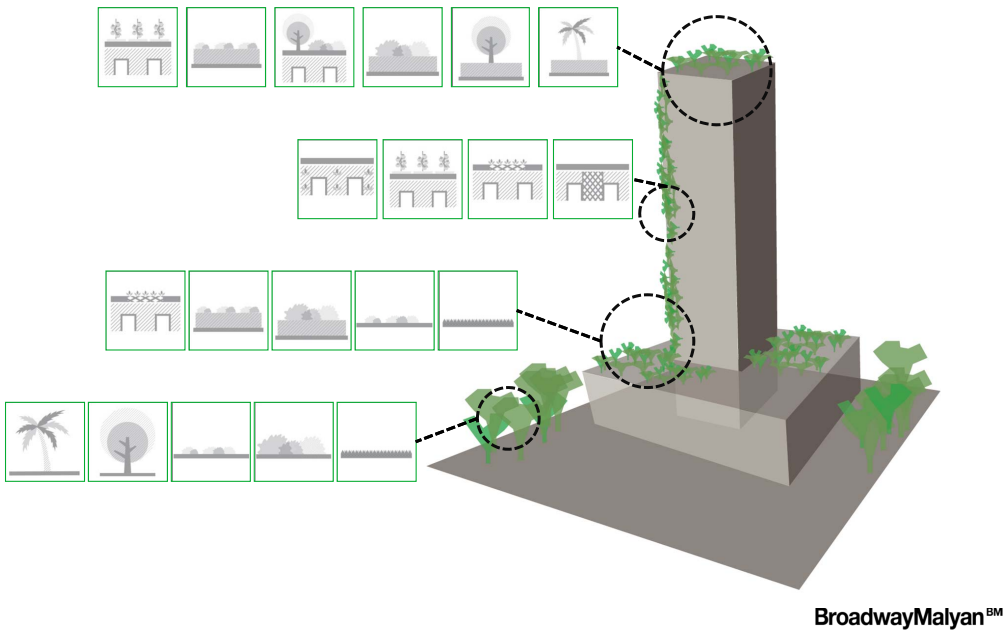


Figure 5.12: Applicable surfaces

[117] "Human Benefits of Green Spaces." *Sustainable Landscape Series. Version 137.* http://ag.udel.edu/udbg/sl/humanwellness/Human_Benefits.pdf (accessed April 25, 2011)
[118] "Human Benefits of Green Spaces." *Sustainable Landscape Series. Version 137.* http://ag.udel.edu/udbg/sl/humanwellness/Human_Benefits.pdf (accessed April 25, 2011)

As well as helping in the workplace setting, exposure to greenery received by children has proven to have several different benefits, especially in areas where educational institutions are placed in highly urban environments. Richard Louv's book, Last Child in the Woods, outlines the benefits children receive from exposure to natural areas. "One national study of 450 children with Attention-Deficit/Hyperactivity Disorder determined that exposure to natural environments alleviated symptoms of the condition. Another study shows that views of trees from the home improves self-discipline among inner city girls, including enhanced concentration, inhibition of impulsive behavior, and delay of gratification. After creative play in verdant settings, children overall demonstrate increased ability to concentrate, complete tasks, and follow directions.[119]

Singapore as a Garden City: Standardizing the Sky Garden Typology

Singapore is seeking to create for itself an image of the garden city, in which greening in this urban habitat is much more concentrated than that of any other high density financial hub. The benefits of this identity could potentially exist at two scales. The social benefits on the micro scale will take form in the small scale social spaces created through the insertion of green spaces and sky gardens within the city. At a macro scale, greening the Singapore urban environment will provide an overriding, cross-cultural identity which has been derived from its tropical climate and local plant species.

In Room at the Top, Pomeroy further analyses the manner in which the sky garden application has worked its way into the Singapore urban architectural typology. "Singapore similarly sought to replicate Le Corbusier's modern city model in its post colonial urban development program that echoed Paris' quest for urbanization and sanitization. His influence can be found not just in Singapore, but in the form of many a global city."[120]

The need for another architectural typology in Singapore came most likely from the rapid population increase, and in turn the increasing transfer of private space to public space. As area is lost at the ground floor of Singapore's dense urban environment, social dwellings such as circulation and communal space require transfer from the conventional

[119] Richard Louv. *Last child in the woods: saving our children from nature-deficit disorder.* (North Carolina: Algonquin Books of Chapel Hill, 2005), 81.
[120] Jason Pomeroy. Room at the top-the roof as an alternative habitable/social space in the Singapore Context. (2010).

level, elsewhere. Pomeroy suggests that the rooftop may continue to play an increasingly important role in shaping the open space network within the city, as demonstrated in Singapore. The displacement of these culturally enriching spaces, such as the low rise colonial shop houses to accommodate modern urban skyscrapers took with it the spatial typologies necessary for strong cultural interaction to occur.[121]

Since the start of urbanization in Singapore, the need for an alternative social gathering space has been clearly identified, most commonly in the form of sky courts and sky gardens. This spatial typology, with its public access attachments, is often seen as unfavorable by development authorities, which has made the greening process more difficult. In response, the Singapore government's Urban Redevelop Authority (URA) has invoked development standards that require the inclusion of green space. "Sky courts as an alternative social space could be a worthy addition to the urban vocabulary. There is, however, still a certain reticence to their incorporation into the tall building typology. This is often due to the perception that the sky court contributes to a loss of lettable or sellable area, thus requiring government agencies, such as Singapore's' Urban Redevelopment Authority, to legislate the incorporation of such sky court spaces and offer planning incentives."[122]

There are currently several government standardizations and incentives present in the construction development process in Singapore that prompt the inclusion of sky gardens in new buildings. The National Parks Singapore (NParks) has introduced a Green Roof Incentive Scheme, which encourages owners of existing buildings to add greenery to their roof tops. This will come with all the environmental benefits, boost skyrise greenery, and enhance the city's identity. The scheme ensures that NParks will fund up to 50% of all installation costs of the green roof applications. As the incentives are still in their infancy, the existing buildings eligible must be in the Downtown Core, Orchard Road, Rochor, Museum, Singapore River and Outram planning areas, but hopefully with success, this scheme can be expanded to other areas throughout Singapore.[123]

As well as NParks, the URA has also placed incentives in greening development.

[121] Jason Pomeroy. *Room at the top-the roof as an alternative habitable/social space in the Singapore Context*. (2010).
[122] Jason Pomeroy. *Room at the top-the roof as an alternative habitable/social space in the Singapore Contex*t. (2010).
[123] "Skyrise Greenery Incentive Scheme | Skyrise Greenery." *Skyrise Greenery*. ihttp://www.skyrisegreenery.com/index.php/home/gris/green_roof_incentive_scheme/ (accessed April 26, 2011)

The Landscaping for Urban Spaces and High Rises (LUSH) initiative is a program that hopes to consolidate a large number of existing incentives, and form them into a well organized movement. "These green initiatives will help strengthen Singapore's distinct identity as a tropical City-in-a-Garden and benefit our environment by mitigating the urban island heat effect and improving air quality. The provision of greenery within developments will also help provide visual relief and improve the quality of life of urban dwellers."[124] The LUSH program hopes to achieve several objectives in the furthering of green spaces in the urban environment. Firstly, the quality of life is to be enhanced through the movement's provision of greening spaces that will relieve and unite users. Secondly, a distinctive architectural identity is to be established, primarily through greenery at the ground, and sky-rise levels. Lastly, and most importantly, the URA hopes that LUSH will jumpstart the transpirative and filtration benefits, as well as all other environmental benefits that come with urban greening.[125]

In hopes to further socially stimulating green spaces off of the ground level, and slowly move circulation and habitation to higher levels in the urban fabric, there have been GFA exemptions introduced into the LUSH program. The GFA guidelines have slowly been relaxed throughout the years of continued development, to provide more design flexibility when incorporating sky gardens into design schemes. "Floors which are predominantly for sky terrace use are allowed higher floor to floor height as well as additional GFA exemption for residual areas. It is intended that with larger and loftier sky terraces, developers would be able to provide more attractive and meaningful communal spaces."[126]

In order to further the greening initiative of Singapore's urban development, the URA, NParks, National University of Singapore (NUS), and Broadway Malyan have undertaken a research project called the Green Plot Ratio (GnPR). Pomeroy, in his essay Greening the Urban Habitat, explains the purpose and the process that this research project undergoes. He mentions the reasoning behind the need to such a study as GnPR to be conducted, as "Singapore's cultural imperative of creating a garden city has seen

[124] "LUSH Programme - Landscaping for Urban Spaces and High Rises." *Welcome to Urban Redevelopment Authority*. http://www.ura.gov.sg/circulars/text/lushprogramme.htm (accessed April 26, 2011).
[125] "LUSH Programme - Landscaping for Urban Spaces and High Rises." *Welcome to Urban Redevelopment Authority*. http://www.ura.gov.sg/circulars/text/lushprogramme.htm (accessed April 26, 2011).
[126] "Revised GFA Exemption Criteria for Sky Terraces."*Welcome to Urban Redevelopment Authority*. N.p., n.d. http://www.ura.gov.sg/circulars/text/dc09-12.htm (accessed April 26, 2011).

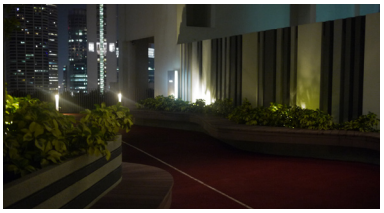
the deployment of far reaching legislative guidelines that promotes the replenishment of greenery as well as the incorporation of sky courts and landscaped terraces in a bid to restore balance in an increasingly high density environment."[127] The GnPR theory was initially developed by Dr. Ong Boon Lay, and it deals with the notion that like a Gross Plot Ratio requirement for a building, a Green Plot Ratio requirement should be added to the development standards in Singapore. The GnPR is calculated using the surface area of greenery found on a particular site. This is known as the Leaf Area Index (LAI) and is estimated through a thorough assessment of a particular sites plant coverage, as well as the species types.[128]

5.5 SKY GARDEN ANALYSIS

The following sky gardens were chosen based on their program typologies, and availability to the public. The analysis conducted sought to gain a better understanding of how well the sky garden services it users in a functional performance sense, as well as in how it accommodates social activity. Rough floor plans, view mappings, visitor frequency and demographics, and well as general aesthetic characteristics were analyzed, in hopes of uncovering how successful the particular sky garden was.

[127] Puay Yok Tan, *A selection of plants for green roofs in Singapore*, (Singapore: National Parks Board, 2008), 23.
[128] Jason Pomeroy. *Room at the top-the roof as an alternative habitable/social space in the Singapore Context*. (2010).

Address
1A Cantonment Road
Singapore 085101



Zoning
Residential (HDB)

Architect
ARC Studio Architecture + Urbanism

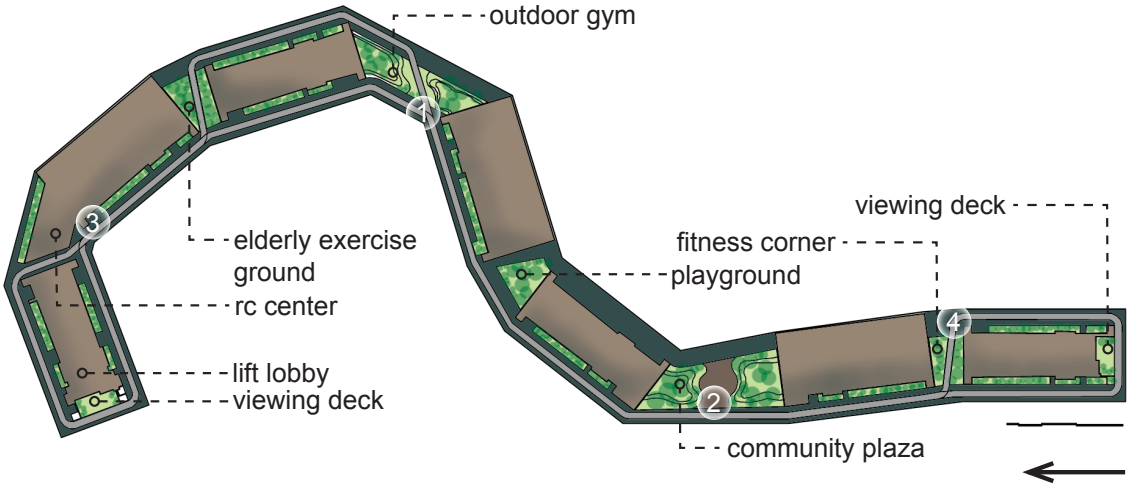
Date of Construction
2009

THE PINNACLE@DUXTON 26TH STOREY

Sky Garden Area
100,000 sq ft

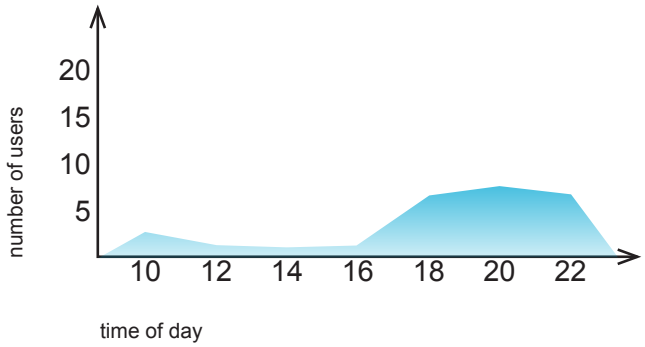
Sky Garden Elevation
26th and 50th storey

SKY GARDEN COMPONENTS



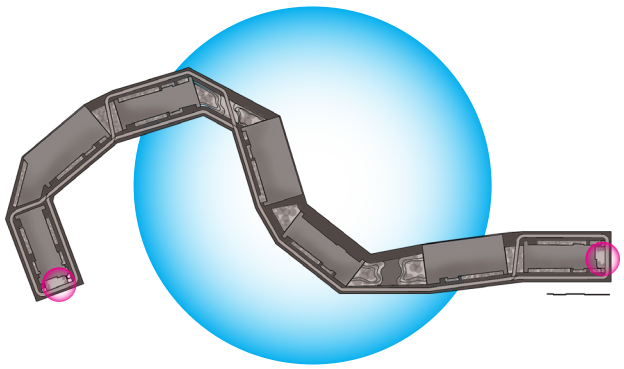
FREQUENCY OF USE

The 26th storey sky garden is frequented most often during the evening, after 7 pm. It is used in the morning, mostly by the elderly, but remains highly under utilized throughout the day. Though it is shaded, temperatures reach unbearable levels during midday.

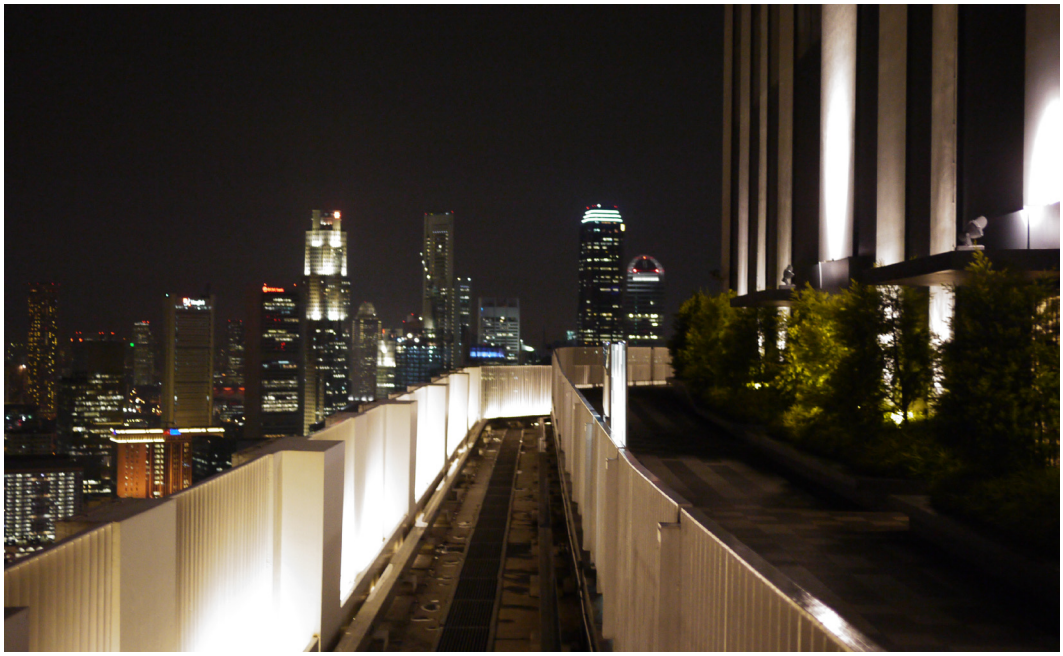


HOT SPOTS/VIEW CORRIDORS

There is a complete 360 degree view from the 26th storey deck, and is high enough where one can still catch much of the skyline. The end viewing decks are shaded, and most popular for stationary activity. The jogging path is the most used component overall.



THE PINNACLE@DUXTON 50TH STOREY



Address
1A Cantonment Road
Singapore 085101

Zoning
Residential (HDB)

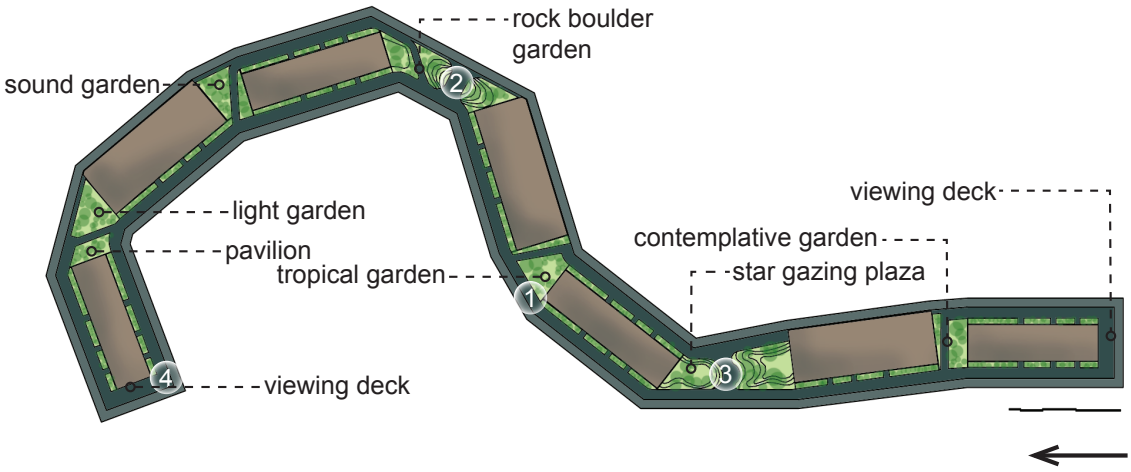
Architect
ARC Studio Architecture + Urbanism

Date of Construction
2009

Sky Garden Area
100,000 sq ft

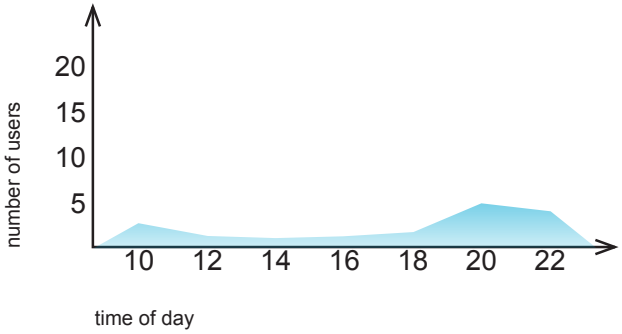
Sky Garden Elevation
26th and 50th storey

SKY GARDEN COMPONENTS



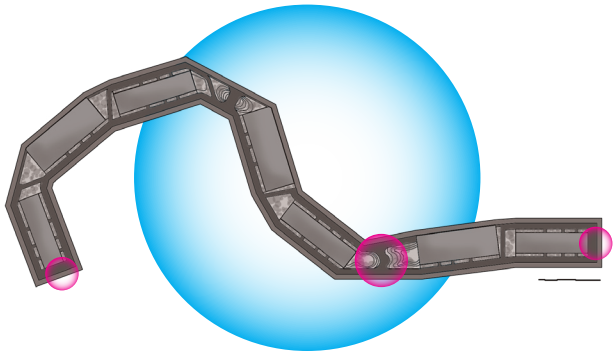
FREQUENCY OF USE

The 50th storey sky garden is highly neglected, mostly because of the heat during the majority of the day. It is also closed during lightning storms. The amount of tourists that pay to visit the site averages 2 a day (discounting holidays with fireworks, when the deck sells out), while locals will use the deck run during the evening hours.



HOT SPOTS/VIEW CORRIDORS

Like the 26th storey, a 360 degree view is also available from this sky garden. The most highly used areas are again, the viewing decks at the end of the building, and the star gazing deck, especially during nights with fireworks.



SINGAPORE NATIONAL LIBRARY


1


2 view towards building

Address
100 Victoria Street
Singapore 188064

Zoning
Civic

Architect
Ken Yeang

Date of Construction
2005

Sky Garden Area
3550 sq ft

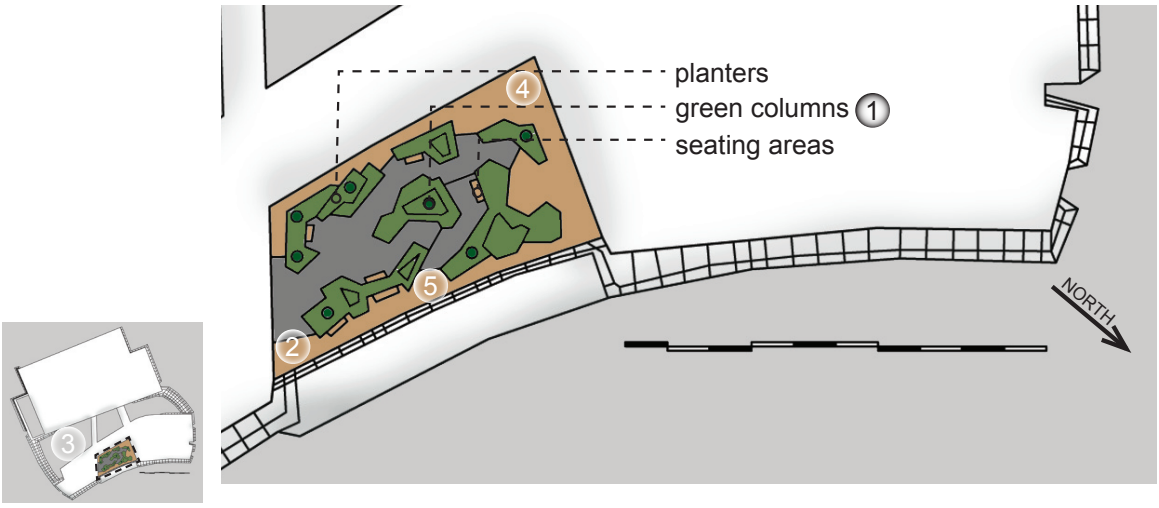
Sky Garden Elevation
10th storey


3 towards ceiling from ground floor


4 view of planers

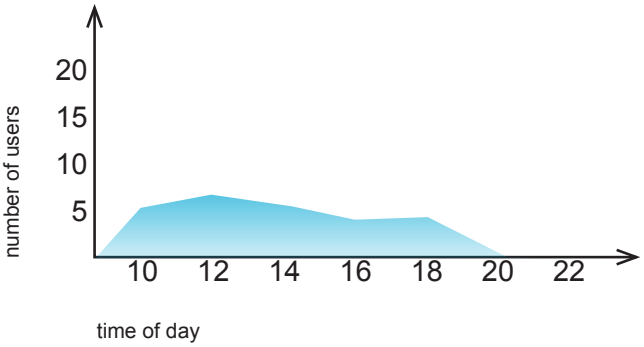

5 view of iluma

SKY GARDEN COMPONENTS



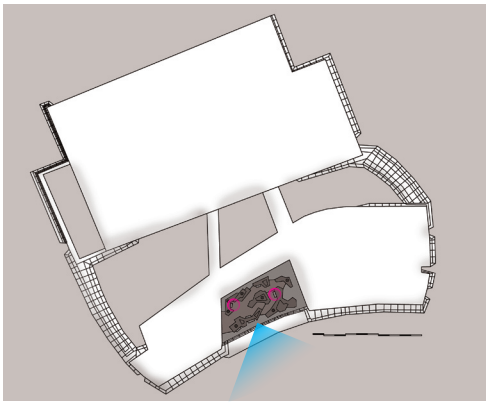
FREQUENCY OF USE

Out of the 14 sky gardens in the building, only two are accessible to the public, and only one truly received any use. The 10th storey sky garden was used by students mainly, but after noon, the number of users dropped drastically due to the heat. There is little to no ventilation in the space, and it becomes unbearable in the afternoon.



HOT SPOTS/VIEW CORRIDORS

There are only views towards the north eastern side, looking mainly at the Iluma building. Locals did not use the sky garden for the view, and a few tourists throughout the day passed through, but none stayed long because of the heat.



FUSIONOPOLIS

Address
1 Fusionopolis Way
Singapore 238896

Zoning
Industrial (JTC)

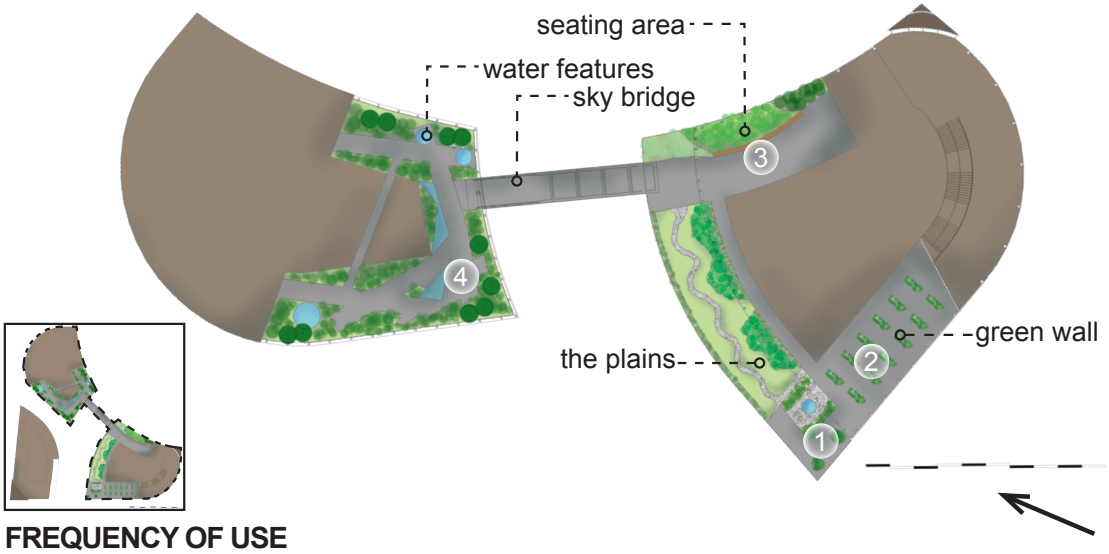
Architect
Dr. Kishio Kurokawa

Date of Construction
2008

Sky Garden Area
14,950 sq ft

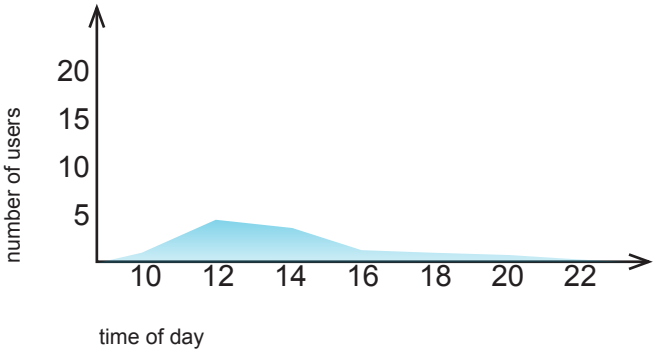
Sky Garden Elevation
21st storey

SKY GARDEN COMPONENTS



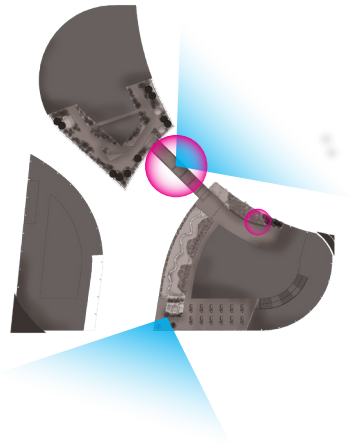
FREQUENCY OF USE

Discounting maintenance workers, there were very few people who use this space throughout the day. The majority of the users work within the office, and use this space for their lunch breaks or smoke breaks. There were very few members of the public who frequented the site. Visitors need passes to see the sky garden.



HOT SPOTS/VIEW CORRIDORS

The views from the sky gardens were stunning, and one can literally see all of Singapore from this building. The most frequently used areas were the sky bridge, with a vast panoramic view, and a shaded benched area where employees ate lunch, smoked, and talked on the phone.



ORCHARD CENTRAL


1 garden aesthetics

Address
181 Orchard Road
Singapore 238896

Zoning
Commercial

Architect
DP Architects

Date of Construction
2009

Sky Garden Area
7,700 sq ft

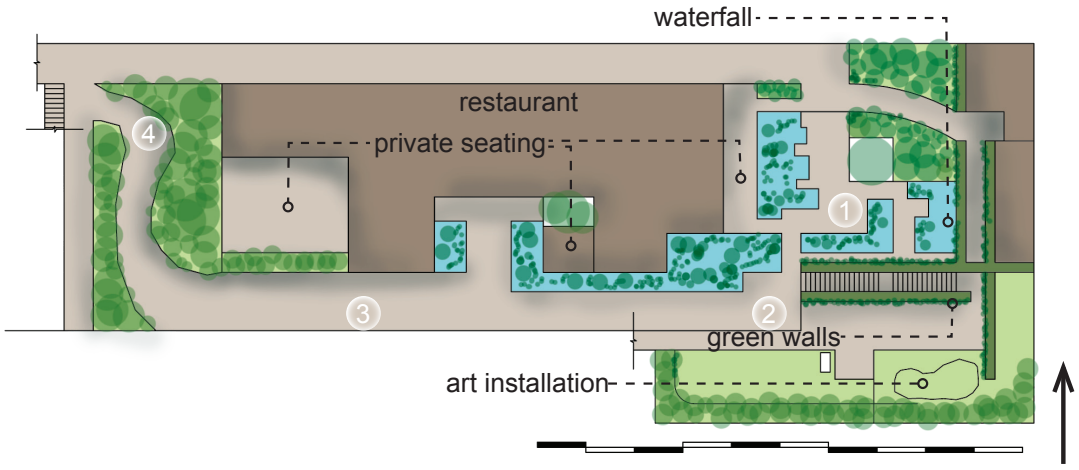
Sky Garden Elevation
12th storey


2 view of city at night


3 view towards orchard

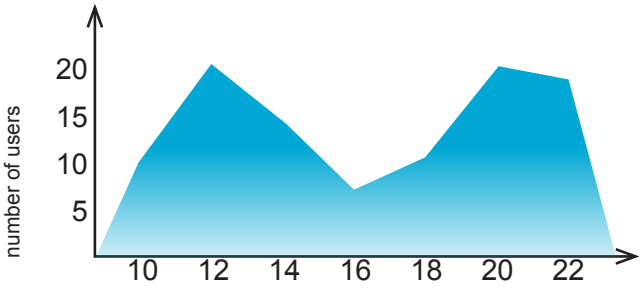

4 back entrance

SKY GARDEN COMPONENTS



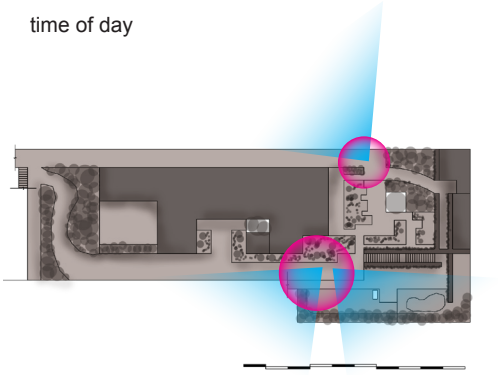
FREQUENCY OF USE

This was the most highly utilized sky garden out of all analyzed in this study. The main drawers were the restaurants, and the night views. The amount of visitors never fell below five, and people of all demographic frequented the site, locals and tourists alike. The evening was filled with couples, and groups of teens



HOT SPOTS/VIEW CORRIDORS

The views from the north and south sides of sky garden were the most attractive, and mainly what brought people to the garden at night. From the northern side, a view of marina sands is available, as well as the central business district



5.6 SKYGARDEN IMPACT

Sky gardens in Singapore are definitely working their way into the regular architectural language. Whether or not they are successful as a social space is highly dependent on their design, and proximity to other drawing mechanisms, such as the restaurants at Orchard Central. Exclusivity seems to often hinder a sky garden's success, as the Pinnacle at Duxton and Fusionopolis observe very few visitors, mainly due to the difficulty of access. Many of the sky gardens are not suitable spaces for even more basic reasons, such as the Pinnacle's issue with heat gain during the noon hours. The government incentives for adding roof top gardens to existing and new buildings is seemingly effective in placing sky gardens at the tops of buildings, yet does not seem to address the social spatial issues that is currently causing the sky gardens spaces to lack success. In time, perhaps we will see new incentives passed focused more on social aspects of sky garden design, thus truly solidifying Singapore's identity as the Garden City.

VI. DESIGN PROJECT STATEMENT

6.1 DESIGN GOAL

In the new age of environmental awareness, the average urban inhabitant is unaware of the affect their daily lives have on the surrounding natural environments, upon which they are directly dependent. Dense urban environments have isolated people and allowed them to function as a society at a level above what the surrounding natural environment can support. While society depends on a properly scaled agricultural industry to provide and deliver food, it is still dependent on the natural environment for many other resources. The scale of modern urban environments causes strain on the ecosystems responsible for carbon sequestration, water purification, and other various resources.

The daily activities of an individual living in a city will rarely involve interaction with the natural environment, thus leaving them unaware of the stresses the environment is under. The more the environment is strained, the less efficient it becomes at delivering the daily needs of society, which in turn disadvantages the human population. Ecosystems work in a way which ultimately seeks equilibrium, but never achieves it. Natural systems are always in a mode of correction, undergoing processes which seek to balance the flow of resource and energy. All subsystems within an ecosystem are affected by this balancing process, and feel pressures, such as food scarcity, as ecosystems readjust. Though dependent on these ecosystems, people living in dense urban cities do not feel these pressures, and do not adjust to accommodate ecosystemic balance. People are the only dependents on the environment which do not participate in balancing its current status, resulting in environmental degradation.

This research attempts to address this urban isolation by providing an environmental communicator within the urban context that will allow inhabitants to understand the pressures felt by the surrounding natural environment. The communicator will act as a connective device, uniting urban inhabitants with the surrounding natural environment, and reincorporating them into affected entities of the ecosystem. It will function as a means of communicating through spatial experience, the status of the natural environment, to the urban inhabitants. This will instill a sense of awareness into the public, and prompt them to act accordingly to the imbalance in the natural habitat. With reconnection and awareness of the natural environment a priority, the communicator will help in maintaining environmental efficiency levels.

For the latter portion of this research, the focus will be primarily in the design of the

environmental communicator. These urban insertions will embody inhabitable social space, within which one receives an update of the current environmental conditions. The design of the space will employ biomimetic design principles that take cues from the surrounding natural environment. Through the use of these principles, a biomimetic vernacular will hopefully be established, in which the overall design language will embody regional specificity, and will differ in each climate. An individual traveling from one urban center to another in a different climate will be able to experience an entirely different space. There are two sides to the design process, being the information that is gathered pertaining to the natural environment, and the design methodology in which it is expressed. The expression of data, or sharing of information will be present in the form of different programmatic components, as parts of the design intervention. These components will fulfill a programmatic purpose, as well as communicate the status of a specific element within the natural environment.

6.2 DESIGN PARAMETERS

To ensure typological consistence between each of the varying sites, a design standard is to be established, from which each of the biomimetic elements will be based. Each site occurs at heavy urban intersections, where sets of crosswalks are the only means of crossing these intersections. The design intervention will take the form of overpasses, each designed to alter the crossing experience in relation to the current status of the immediate surrounding natural environment. Within each of the overpasses, five main environmental factors will be communicated, all of which directly affect the users' quality of life. Air quality, water quality, soil quality, climate change, and efficiency rate of the natural environment are all elements in which inhabitants of dense urban environments require to exist, yet lack a connection to.

Footbridges of recent construct have been taken to more innovative levels, in that they are becoming opportunities for interesting spatial compositions. Many famous footbridges are top destinations for tourists, many of which traverse short distances over water, highly congested traffic intersections, or placed strategically to provide users with a more adequate view. Calatrava's Campo Volantin Footbridge in Bilbao, Spain is known for its dynamic structure and dramatic pathways[129], while Heatherwick Studio's Rolling Bridge in London is an example of an interactivebridge that changes to accommodate exterior constraints.[130] Footbridges are

[129] Maria Shollenbarger, "The Future of Bridges | Calatrava in Venice," *Travel + Leisure*, accessed September 10, 2011 http://www.travelandleisure.com/articles/future-of-bridges.
[130] Andrew Michler, "Rolling Bridge/Thomas Heatherwick," *eVolo*, accessed September 10, 2011, http://

experienced daily, when placed along busy urban routes, and utilizing the transporting of people as an engaging spatial communication method will provide the opportunity to affect many individuals efficiently.

The footbridge will constantly receive input from various Environmental Indication Systems that sense information on each of the following categories. The input will control components within the footbridge that will actively change the user experience, at a scale human, that will relate to the fluctuation in the natural environment between what will be considered either a positive or negative status. Within the site, the footbridges are placed to influence the greatest amount of people, as they depart from major transit stations to their destinations within the dense urban context. The five environmental factors will receive their inputs from specific Environmental Indication Systems, which will then, through biomimetic translation, be embodied in a specific footbridge component, and will affect a certain pedestrian experience, as further illustrated in the diagram below. Each of the environmental factors is eventually translated into a spatial device, each slightly different per site, based off of specific natural elements found in their corresponding environments.

6.3 BIOMIMETIC DESIGN EXPRESSION OF ENVIRONMENTAL INDICATION SYSTEMS

The sensed information will be gathered through the use of Environmental Indication Systems (EIS), which is a system for delivering "a numerical value that helps provide insight into the state of the environment or human health."[131] An "environmental indicator represents the state of certain environmental conditions over a given area and a specified period of time." The United States Environmental Protection Agency further describes EIS as being developed based on quantitative measurements or statistics of environmental condition that are tracked over time. EIS are developed and employed over a large variety of geographic scales, and are used at the governmental level to ensure that beneficial environmental policies are put into legislation.[132] Through developing an understanding of how the different EIS calculate environmental information, the design that will relay this information to the public will be more specifically geared towards a particular data set. The following definitions go further into the measurement processes used in each specific EIS that will be translated to a spatial experience. Internationally,

www.heatherwick.com/rolling-bridge/

[131] "Environmental Indicators Gateway," *Environmental Protection Agency*, accessed September 2, 2011 http://www.epa.gov/igateway/whatIndicator.html

[132] "Environmental Indicators Gateway," *Environmental Protection Agency*, accessed September 2, 2011 http://www.epa.gov/igateway/whatIndicator.html

the goal has been to further clarify policy through condensing the amount of indicators used to analyze a specific environmental element. Climate change, for example, has many EIS with which conclusions are drawn, the multitude of which makes reaching a single measurement difficult.[133] In the diagram below, the translation process is illustrated. The design process will produce fifteen bridge components, each with a positive and negative input stance. This translative method was employed in attempt to produce somewhat parallel results in terms of spatial experience and communicative function, in terms of how the user interacts with both the positive and negative data.

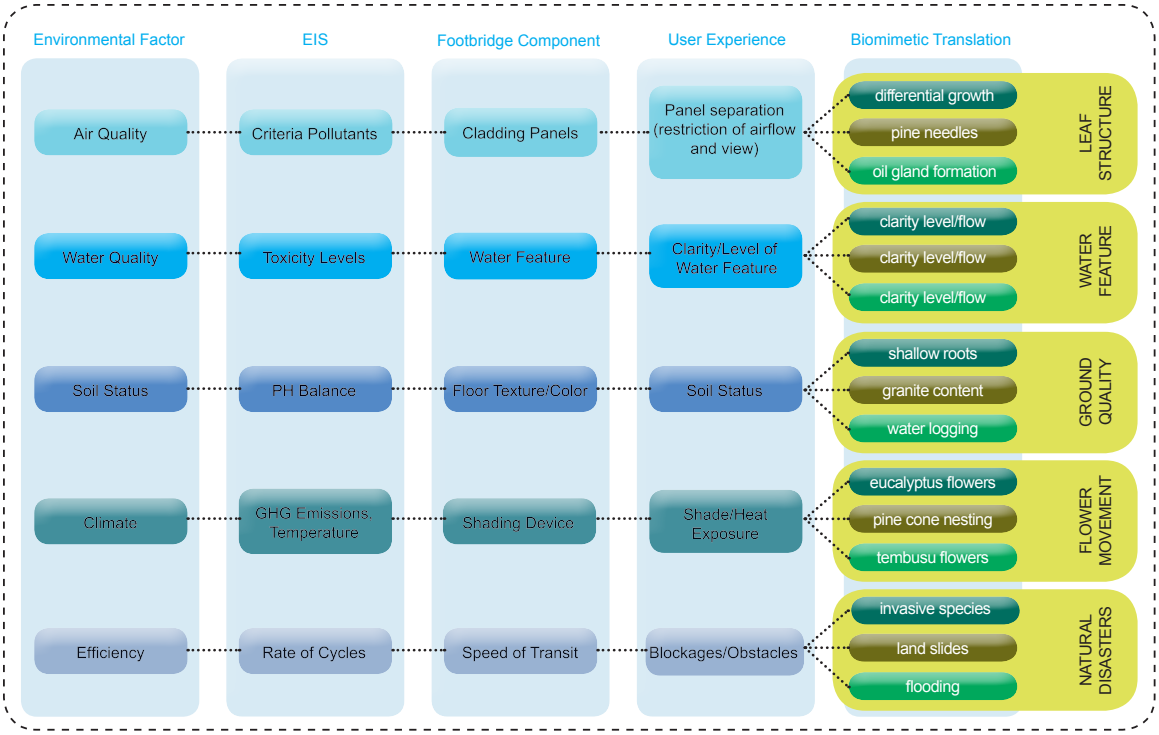


Figure 6.1: Design Process

[133] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.

Air Quality

The levels of SO_x (sulfur oxide) and NO_x (nitrous oxide) emission intensities are only part of how air quality levels are mapped. The effects of poor air quality on human health are detrimental, and not fully understood. "Human exposure is particularly high in urban areas where economic activies and road traffic are concentrated. Causes of growing concern are concentrations of fine particulates, NO_2 toxic air pollutants, and acute ground-level ozone pollution episodes."[134] Sulfur and Nitrous oxides contribute to acidified precipitation, which harms all ecosystems, especially those found in tropical regions, which require high levels of hydration. When looking towards a future where a larger percentage of the human population does exist in dense urban areas, air quality becomes an ever growing concern. The US EPA lists several criteria pollutants from which the EIS concludes overall air quality. These criteria pollutants include CO (carbon monoxide), SO_x (sulfur oxides), NO_x (nitrogen oxides), O3 (ozone), Pb (lead), and particulate matter. Criteria pollutants originate from fuel combustion, metal processing, industrial processes, and waste disposal, among other man-driven processes.[135]

The measurement that the EIS performs allows society to gain a better understand of the effects that poor air quality has on living conditions. Acid rain, the greenhouse effect, stratospheric ozone depletion (higher ultra violet index), smog, and visibility impairment are among the disadvantages of living in dense urban areas that generate high levels of pollution. While people are severely disadvantaged by the effects of poor air quality, the natural environment suffers to balance the pollution levels. The urban activity of people is a major source of poor air quality, but even more so is the process of deforestation. Forests hold very high amounts of carbon, in both the trees, and in the soil. While half a tree's dry weight is composed of carbon, the disturbance of forest soil releases the highest amounts of carbon into the atmosphere. Twice the amount of carbon is held in the forest than what is held in the trees, and depending on the size of the forest, the amounts of carbon released are very high. Disturbed soils continue to release carbon into the atmosphere for up to twenty years post disturbance, and release

[134] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.
[135] "Environmental Indicators Gateway," *Environmental Protection Agency*, accessed September 2, 2011 http://www.epa.gov/igateway/whatIndicator.html

this carbon at a rate faster than trees can sequester.[136] The measurement of carbon release into the atmosphere is an important EIS that requires translation into design. An individual living in a dense urban environment such as Sao Paulo for example, should understand the levels of carbon that are being released from the nearby deforestation of the surrounding natural environment.

This environmental factor has an indication system that consists of monitoring criteria pollutants (mainly sulfur and nitrous oxides, carbon monoxide, ozone, lead, and particulate matter). Positive input will equate to a low amount of criteria pollutants in the air, while a negative reading will equate to a high amount. To communicate this, the user experience will be affected through constraints on views out of the footbridge, as well as ventilation. This can be accomplished architecturally through louvers or fins which restrict wind flow and visibility, or surfaces with perforation with expand and contract. As users walk through the space, they will experience varied levels of visual inconvenience, as their view of the urban landscape will be obstructed. With lowered levels of ventilation, slight discomfort may also be experienced, especially in the humid Singapore climate. Along with the blocking of ventilation, a positive data reading could equate to the creation of further ventilation, built within mechanical systems of the footbridge. This will add a level of comfort in response to positive environmental factor indication.

Water Quality

This EIS is measured by evaluating the emissions of N and P in water and soil, as well as the nutrient balance found in freshwater. Also measured are the pollution levels in secondary and tertiary water treatment facilities. One of the main issues in freshwater quality is the toxic contaminants that originate from large urban centers. Organic compounds, heavy metals and pesticides are among the top contributors to lowered vitality levels in forest and freshwater ecosystems.[137] Two main measures are taken within the freshwater EIS to determine water purity. Both living organisms, in particular Esherichia coli are tested for, as this bacterium is known to indicate intestinal waste

[136] "Trees: The Carbon Storage Experts," *Department of Environmental Conservation*, accessed September 2, 2011, http://www.dec.ny.gov/lands/47481.html.
[137] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.

within the water. Other indicators involved measuring the diversity of microorganisms living in the water. The more diversity between the microorganisms living in the water supply indicate a higher level of water quality.[138] Poor water quality is worrisome not only because a vital resource is compromised, but because it indicates an issue within the natural environment. As dense forests act as filtering watersheds from which many societies get their clean water, recent EIS results have shown a decline in not only water quality, but the amount of water available to our growing population.

Having enough freshwater supply, along with energy resource, are the two environmental aspects which most greatly affect the average person. Studies have shown that while our natural environment has been able to supply water at a very stable rate, our population growth is pressuring freshwater needs. Freshwater EIS test the intensity of the use of water resources, the frequency and duration of water shortages, as well as legislative responses, such as prices for water and sewage treatment.[139] Currently, one third of the world population lives in conditions with moderate to high water stress, mostly affecting the impoverished. This resource is going to require an accelerated rate of proper stewardship, as our global population is slowly succeeding its carrying capacity. The current carrying capacity is roughly 7 billion people, with our current population at 6.78 billion.[140] The carrying capacity reflects the population that the natural environment can support with its current systems efficiency and area. In order to accommodate the projected rise in population, living styles must change in both developed and developing countries.

Through the monitoring of streams and ponds for nitrogen and phosphorous, as well as the diversity of microorganisms, positive input will equate to a healthy diversity of microorganisms, and nitrogen and phosphorous will translate in the footbridge environment to a water feature that is flowing freely with clear water. Negative input, for example a high phosphorous level, will result in clouded water, with slow or little flow, appearing stagnant in nature. High phosphorous levels in nature result in dangerous algae blooms which negatively impact oxygenation and toxicity levels in the water. The

[138] "Watershed Quality," *Water Encyclopedia*, accessed September 3, 2011, http://www.waterencyclopedia.com/Tw-Z/Watershed-Water-Quality-in-a.html.
[139] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.
[140] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed.* (San Fransisco: Benjamin Cummings, 2011), 26.

water incorporated into the foot bridge design will communicate through varying levels of aesthetics, from pleasant to unpleasant.

Waste Generation/Soil Quality

Inappropriate waste management has had very poor effects on the natural environment. The great pacific garbage patch is the result of excessive waste generation, and poor waste management. Waste generation EIS involve the monitoring of municipal waste, industrial waste, hazardous waste, as well as nuclear waste, all of which have detrimental effects upon water, air quality, land use, and soil quality.[141] The amount and composition of waste varies from nation to nation and is widely dependent on national waste management practices. For the general public to understand the amount of waste the society body is creating, the level at which it can be processed, and the means in which the waste is processed is important.

Knowing the percentage of waste that is burned or put into a landfill, and the effects that these waste management methods have on the natural environment will hopefully prompt societal change. [the goal is to slowly change the behavior of an unaware society. Perhaps only EIS that change drastically from a day to day basis should be considered, as waste generation levels remain very constant. How can a waste-related element be incorporated into the urban insertion, and how can it provide people with an understanding of how it is damaging to the environment. the public has little control over how municipal and industrial waste is handled. EIS considered should be changeable in terms of individual activity]

The environmental indication systems monitored through the identification of toxicity levels in the soil, as well as the eutrophication rates in surrounding bodies of water. The higher the rate at which the bodies of water experience eutrophication, the higher the nutrient value in the soil. These nutrients are beneficial to a certain extent, but can also reach harmful rates and result in oversaturation of the soil. Within the footbridge context, the positive and negative data sets will be communicated through changes in the floor plane. These changes could potentially affect the texture of the floor, color saturation, or patterning. For example, if the data set were positive, reflecting a

[141] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.

healthy level of nutrients in the soil, the flooring would respond by converting to a rich tone and a smooth texture. Negative data sets could result in dull color saturation, and a change in texture that makes the footbridge less comfortable to walk on. The floor could also experience changes in firmness, by changing the pressure of a fluid-filled walking surface. Changing the way the ground feels beneath the users has one of the most immediate impacts to the user experience.

Climate Change

To successfully track climate change, several environmental indication systems need to be employed. Various sets of data are required, some sets which monitor the causal elements of climate change, as well as sets which monitor the level of change through effected environmental elements. The monitoring of temperature change and humidity levels is vital in that they have a high impact on the overall climatic change levels. According to the Organization for Economic Development and Cooperation (OECD), climate change can be more accurately mapped through EIS which measure CO_2 emissions intensities as well as the index of greenhouse gas emissions. The main concerns in monitoring climate change deal with tracking increasing atmospheric greenhouse gas (GHG) and concentrations on global temperatures. GHG emissions are tracked through monitoring their intensity levels per unit of GDP, including CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrogen dioxide), PFC (perfluorocompound), HFC (hydroflurocarbon), and SF_6 (sulfur hexafluoride) emissions.[142] Including GHG emissions, several other EIS have been noted as important in quantifying the total extent to which the climate's status is calculated.

Other EIS which contribute to an overall measurement of climate change include measurement methods for drought levels, as well as algae levels.[143] While algae is known as a valuable carbon sequestering plant, heightened temperatures have caused more rampant algae bloom, much of which release toxicity into the surrounding environment. Monitoring the bloom levels could potentially help to document the rate at which climate

[142] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.
[143] Paul English, "Environmental Health Indicators of Climate Change for the United States: Findings from the State Environmental Health Indicator Collaborative," *Environmental Health Perspectives*, accessed September 2, 2011, http://ehp03.niehs.nih.gov/article/info:doi/10.1289/ehp.0900708#Materials and Methods

change levels are quickening or slowing down.[144] Climate change needs to be represented, as has one of the greatest overall impacts on the natural environment. It affects all other EIS categories, therefore is the most prevalent contributing factor when change is mapped in other systems.[145]

Using indications systems that detect GHG (Green House Gas) emissions, climate change can be communicated most effectively through changes in shade. Higher rates of GHG emissions result in higher temperatures and lower air quality. Each footbridge will have shading devices that communicate the positive data results through full shading of the pathways, lowering the ambient temperature and glare levels, allowing for a more pleasant user experience. Negative data results will be communicated through a retraction of the shading devices, exposing users to sunlight and precipitation. The change in the shading devices, from positive expansion to negative withdrawal of the shading devices will also have a major aesthetic impact on the footbridge, and results in a noticeable difference in the overall experience.

Efficiency Rate

Similar to freshwater resources, but less detrimental, are the needs for changing how energy resources are handled. While technological innovation has allowed the population to somewhat supplement energy production, freshwater resource rests almost entirely on the natural environment. Energy resource EIS measure the rate of energy efficiency, intensity, as well as analyze the structure of energy supply. Currently, fossil fuels remain the main source of energy for the human population, as well as the greatest contributor to environmental degradation and loss of ecosystemic efficiency.[146] While changes in legislation are the most definitive way to manage energy resource, a change of perspective could potentially help the conservation of this resource.

One of the main challenges of this resource is developing a method to make users aware of energy usage, most importantly the times at which energy use is highest.

[144] Paul English, "Environmental Health Indicators of Climate Change for the United States: Findings from the State Environmental Health Indicator Collaborative," *Environmental Health Perspectives*, accessed September 2, 2011, http://ehp03.niehs.nih.gov/article/info:doi/10.1289/ehp.0900708#Materials and Methods
[145] "Earth Trends: Environmental Information," *World Resources Institute*, accessed September 2, 2011, http://earthtrends.wri.org/.
[146] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.

This correlates to the highest output of industrial pollution, and the time at which conservation is most important. Every single available energy resource technology today has at least moderately negative effects on the natural environment. Biofuels, coal, geothermal, hydropower, petroleum, solar, nuclear, and wind energy all have specific detriments, whether it be air, water, or soil pollution, or the high use of natural resource.[147] Understanding the amount of energy used, as well as the effect that used amount has on the surrounding natural environment can aid in lifestyle change.

Biodiversity

Biodiversity is perhaps the most difficult in terms of developing an accurate EIS. Biodiversity is crucial in overall ecosystemic efficiency and well-being. The higher the biodiversity level within an ecosystem, the faster it can recover from a particular deficiency. The purifying of water, recycling of nutrients in soil, and pollination of flowers is all more successfully carried out within ecosystems that are more biologically diverse.[148] Pressures upon biodiversity exist in many different forms, whether they are "physical, dealing in habitat alteration and fragmentation through changes in land use and cover, chemical, resulting from toxic contamination, acidification, oil spills, or pollution, or biological, which can result from population dynamics and species structure disruption due to the release of invasive species."[149] Currently, high percentages of species are threatened, which impact unthreatened species indirectly. Biodiversity is measured through simple counting and species population monitoring, as well as land area of protected territories. The current status of all animals and plants are carefully monitored, but as there is no method of measurement, such as chemical analysis, the EIS for biodiversity is most extrapolated and difficult to assess.[150] Rough estimates of biodiversity, however, will still allow for a way to communicate efficiency rates in the natural ecosystems.

Measured through bioindicators, and is most likely the most complex and labor intensive of all EIS. Bioindicators are specific species that provide quantitative information

[147] "Environmental Impact By Energy Source," *Energy4me*, accessed September 2, 201,1 http://www.energy4me.org/energy-facts/environmental-protection/environmental-impact-by-source/.
[148] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed*. (San Fransisco: Benjamin Cummings, 2011), 30-32.
[149] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.
[150] Lorents G. Lorentsen, "Organization for Economic Development and Cooperation," *Key Environmental Indicators*, accessed September 2, 2011, www.oecd.org/dataoecd/20/40/37551205.pdf.

on the current status of the environment which surrounds it.[151] These species are monitored for their "content of specific elements or compounds, morphological or cellular structure, metabolic-biochemical processes, behavior, and population structure."[152] The labor involved is intensive, as researchers will need to closely monitor these species in the wild, and will not be as rapidly updatable, in comparison with indication systems that use sensors placed in the natural environment. Though more difficult to establish, the efficiency rate of ecosystems is perhaps the most important aspect that urban populations depend on, as it reflects the rate at which all other environmental factors are processed.

When environmental efficiency rates are low, and the natural environment struggles because of various pressures to cycle nutrients, all other environmental factors are processed poorly, or at slower rates. This translates to a lower supply of clean air and water, as well as a less amicable climate. The efficiency rate of the surrounding natural environment will correlate with the pace in which people will move through the footbridge. Through spatial constriction of the pathways on the footbridge, the width of pathways will be expanded and contracted, allowing more or less people through, respectively. The spatial constriction will be carried out differently in each of the footbridges, but all will actively affect the rate at which people can commute. When environmental efficiency rates are low, the bridge will experience higher levels on pedestrian congestion.

[151] "Bioindicators," *BioBasics*, accessed September 4, 2011, http://www.biobasics.gc.ca/english/View.asp?x=740.
[152] James Karr, "Assessment of Biotic Integrity Using Fish Communities," accessed September 3, 2011, http://www.epa.gov/bioindicators/pdf/AssessmentofBioticIntegrityUsingFishCommunities.pdf

VII. RECONNECTION THROUGH COMMUNICATIVE SPACE

7.1 SITE REQUIREMENTS

For a site to be considered as suitable for the footbridge insertion, it needs to fulfill several requirements. As the footbridge will primarily serve as an outdoor pedestrian circulatory causeway, they will need to be currently occupied. It is vital that circulatory paths, both pedestrian and vehicular, cross the site, as the urban insertion should occupy a portion of the normal path individuals take on a daily basis. If possible, mass transit should be incorporated as well, to ensure high pedestrian traffic through and around the area.

7.1 TROPICAL SITE: SINGAPORE

Singapore is a city-state located on a small island at the Southern end of the Malay Archipelago. Founded in 1819, Singapore gained independence from Anglo-Dutch colonization and separated completely from Malaysia, and today has become the world's fourth leading financial center, with the fifth most active trading port, which supports its highly successful market based economy.[153] Singapore has a diverse demography with 64% of the population as citizens, and the remaining 36% being foreign workers, primarily from the United Kingdom, Australia, Japan, Malaysia, and the Philippines. The four national languages spoken are Mandarin, English, Tamil, and Malay, representing large percentages of each demographic group. Singapore, though totaling a land area of 268 square miles, successfully supports a population of roughly 5.1 million people, through a highly developed Mass Rapid Transit system, which occupies both above ground and underground railways.[154]

Figure 7.1.1: Singapore site specifics

[153] Barbara Leitch LePoer, *Singapore: a country study. 2nd ed.* (New York: Government Printing Office, 1991), 12.
[154] Barbara Leitch LePoer, *Singapore: a country study. 2nd ed.* (New York: Government Printing Office, 1991), 13-14.

7.1.1 NATURAL CONTEXT: BUKIT TIMAH NATURE RESERVE

Biome Typology: Tropical Rainforest

Nutrient Cycle: The nutrient cycle in rainforest ecosystems is one of the shortest due to the poor soil conditions. Unless soils are near fissures or volcanic, they are usually devoid of nutrients from which producers within the first trophic level can feed. The nutrient cycle is completed in nearly twice the rate that it functions in temperate forests, due to the extremely high biomass of tropical rainforests, biomass being "the total combined (net dry) weight," of all elements within an ecosystem. [155] Tropical rainforests, despite their poor soil productivity, are among the most productive of all biomes, second only to algal beds and reefs, with a 2000 g/m2/yr in net primary productivity. This in turn accounts for nearly 20 percent of the entire global net productivity.[156]

Ecosystem Components:

Temperature: 82 degrees on average

Precipitation: 92 inches per year

Sunlight

Because tree canopies in rainforest ecosystems are dense in nature, very little sunlight actually penetrates to the ground level. The dense vegetation also prohibits any air movement, making the humidity levels very high. The forest floor is a shaded humid warm habitat, under which fallen vegetation is very rapidly decomposed.

Water or Moisture

"Rainforests are distinct in that they are constantly rich with moisture due to their location in intertropical convergence zones, where intense solar energy produces a convection zone of rising air that loses its moisture through frequent

[155] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed*. (San Fransisco: Benjamin Cummings, 2011), 22.
[156] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed*. (San Fransisco: Benjamin Cummings, 2011), 18.

rainstorms."[157] Between the moisture created through rainfall, the cloud cover, and transpiration of trees, the local humidity of rainforests is high.[158] Trees transpire at a rate of 200 gallons per tree annually, equating to 20,000 gallons per acre of canopy. At this transpiration rate, rainforests essentially create their own rain.[159]

Soil Chemistry

Rainforest soils are very low in nutrients, as most of the nutrients exist on the top layer, and are reabsorbed back into the ecosystem before they can reach the soil. Known as an oxisol, this soil type is the result of high precipitation and temperature, exhibiting quartz, clay, aluminum and iron oxides.[160] There is a very high concentration of decomposers within this ecosystem, including bacteria, fungi, and termites. These detrivores process nutrients, which are from there taken directly back up into the ecosystem by the plants. Trees within the rainforest ecosystem have adapted to the poor soils through the development of a symbiotic relationship with a fungi, mycorrhizae, which attach to plant roots and allow for more efficient gathering of nutrients. The fungi use the tree roots to gather sugar, as well as a source of shelter. Tree roots in rainforests are shallow, and creep outwards for better stabilization, in the form of buttress roots and tangled lianas.[161]

Biodiversity

There are at most three trophic levels within the Singapore rainforest ecosystems, because of the small scale of these forests. While they were once large enough to support up to four trophic levels, supporting large predators such as the Malayan Tiger, they now support only small mammals and reptiles.

[157] "Structure and Character," *Tropical Rainforests*, accessed October 2, 2011, http://rainforests.mongabay.com/0201.htm
[158] "Structure and Character," *Tropical Rainforests*, accessed October 2, 2011, http://rainforests.mongabay.com/0201.htm
[159] "Structure and Character," *Tropical Rainforests*, accessed October 2, 2011, http://rainforests.mongabay.com/0201.htm
[160] Michael Pidwirny, "Soil Classification," *Fundamentals of Physical Geography*, accessed October 3, 2011 http://www.physicalgeography.net/fundamentals/10v.html.
[161] "Structure and Character," *Tropical Rainforests*, accessed October 2, 2011, http://rainforests.mongabay.com/0201.htm

Flora

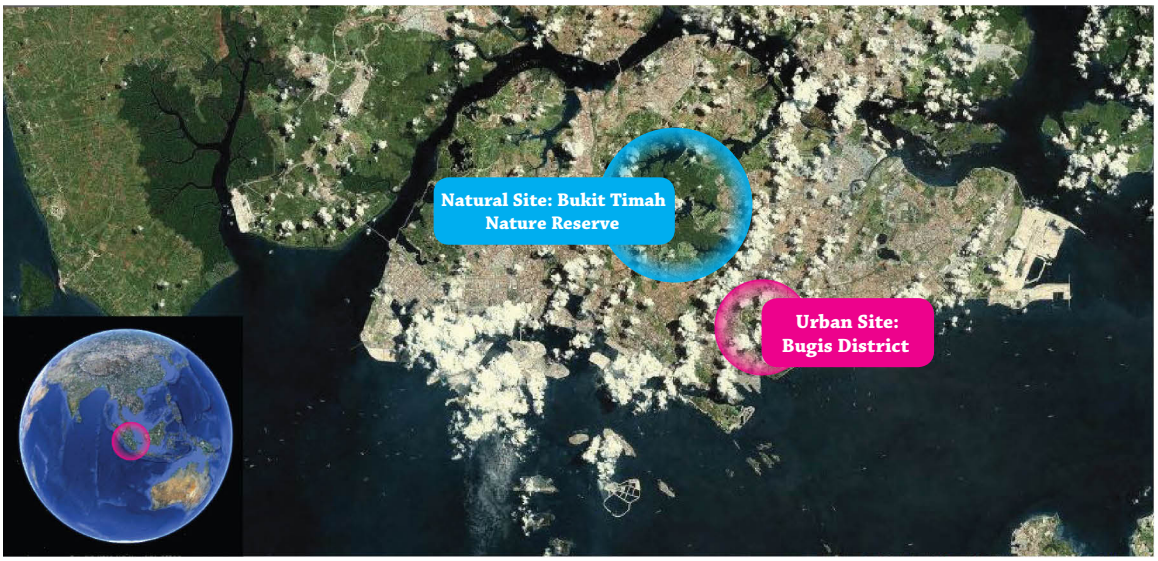
Several plant species important to the Bukit Timah rainforest ecosystem are the rain tree, Angsana, Yellow Flame, Senegal mahogany, the Tembusu, Trumpet tree, and the Sea Almond. All of these species grow to heights of 25 meters and above, with broad canopy coverage and shallow roots, often with buttressing.[162] Besides large canopy trees, Singapore is extremely biodiverse, supporting hundreds of orchid species, heliconias, palms, and ginger species.

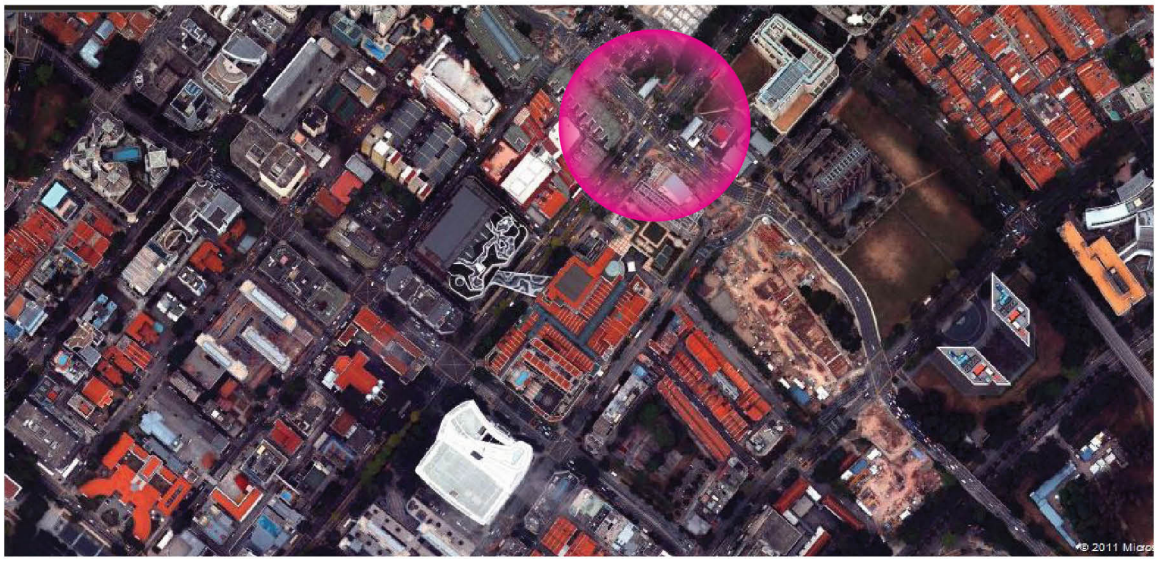
Fauna

While all animals living within the rainforests of Singapore are small, there is still a high level of biodiversity among the different species. There are hundreds of bird species, many endemic to the Singapore/Malaysia areas, as well as bat species found only on the Singapore island. Several small mammals and monkeys, such as the long-tailed macaque, are supported within the rainforest as well, feeding off of insects and smaller reptiles and amphibians.[163] The rarest of these mammals are the sunda pangolin and the lesser mousedeer, which are rarely seen in the wild. Very few of these species are hardy, and rely on the rich environment with constant access to food and water in order to survive.[164]

Current Environmental Status: While the Singaporean government has implemented many different legislative laws which help to insure the upkeep of the natural environment in Singapore, the commercial side to the country has had somewhat of an effect. While Singapore itself maintains low pollution levels, haze from slash and burn farming in Indonesia has a great effect on the local air quality. Unfortunately, the Singapore coastline suffers from high levels of environmental degradation, due to the Port of Singapore being the busiest port, with high levels of ship traffic.[165]

[162] "Know Ten Trees In Singapore." National Parks Singapore. http://www.nparks.gov.sg/cms/index.php?option=com_content&view=article&id=173&Itemid=161 (accessed October 2, 2011).
[163] "Environment in Singapore," *Focus Singapore*, accessed October 2, 2011, http://www.focussingapore.com/information-singapore/singapore-environment.html.
[164] "Environment in Singapore," *Focus Singapore*, accessed October 2, 2011, http://www.focussingapore.com/information-singapore/singapore-environment.html.
[165] AFP. Singapore Pollution Levels 'Unhealthy' Due to Indonesia Haze," *AsiaOne News*, accessed October 2, 2011 http://www.asiaone.com/News/AsiaOne+News/Singapore/Story/A1Story20101021-243576.html.





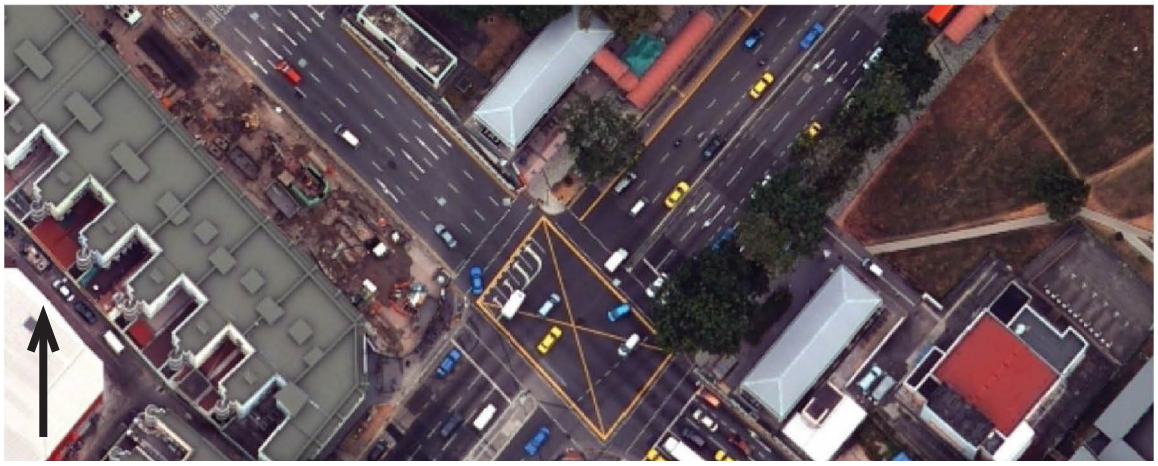


Figure 7.1.2: Map of Bugis

URBAN CONTEXT LOCATION MAP

7.1.2 URBAN CONTEXT: BUGIS STATION

Specific Site Information: The Bugis Station sits on the North East Line of the Singapore Mass Rapid Transit system. This particular line on the Mass Rapid Transit system carries individuals from residential areas to the central business district, and experiences rush hours of dense human traffic. Alighting at Bugis Station forces passengers to cross at least two intersections to reach the business district, which causes delays in both human and vehicular traffic.

Figure 7.1.3 **EXISTING SITE**

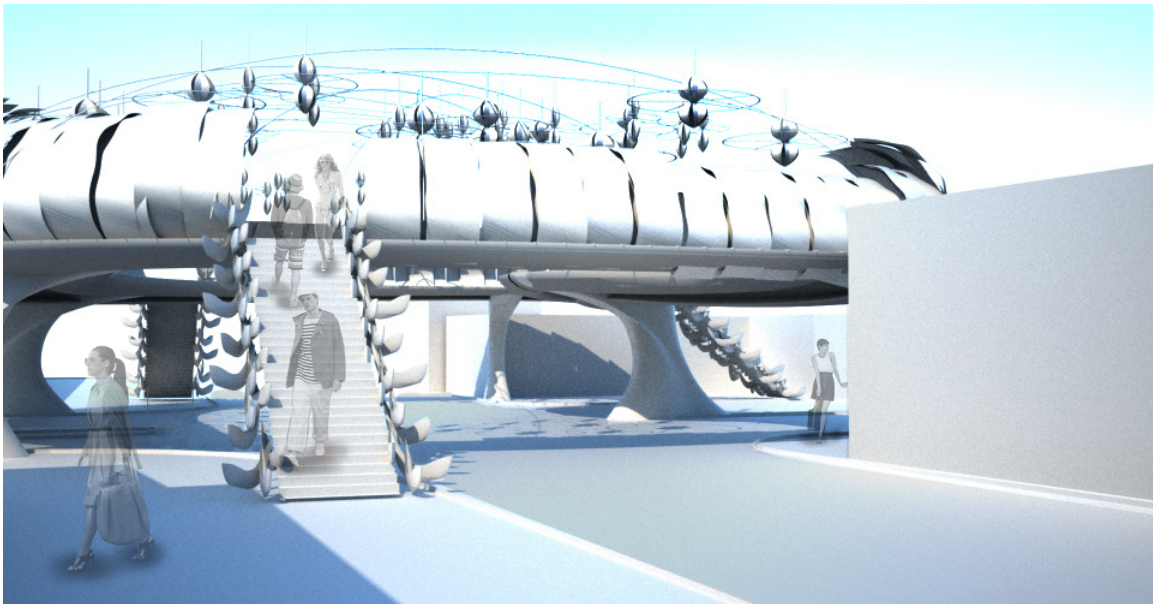


Figure 7.1.4 **SITE WITH OVERPASS**

7.1.3 DESIGN SOLUTION

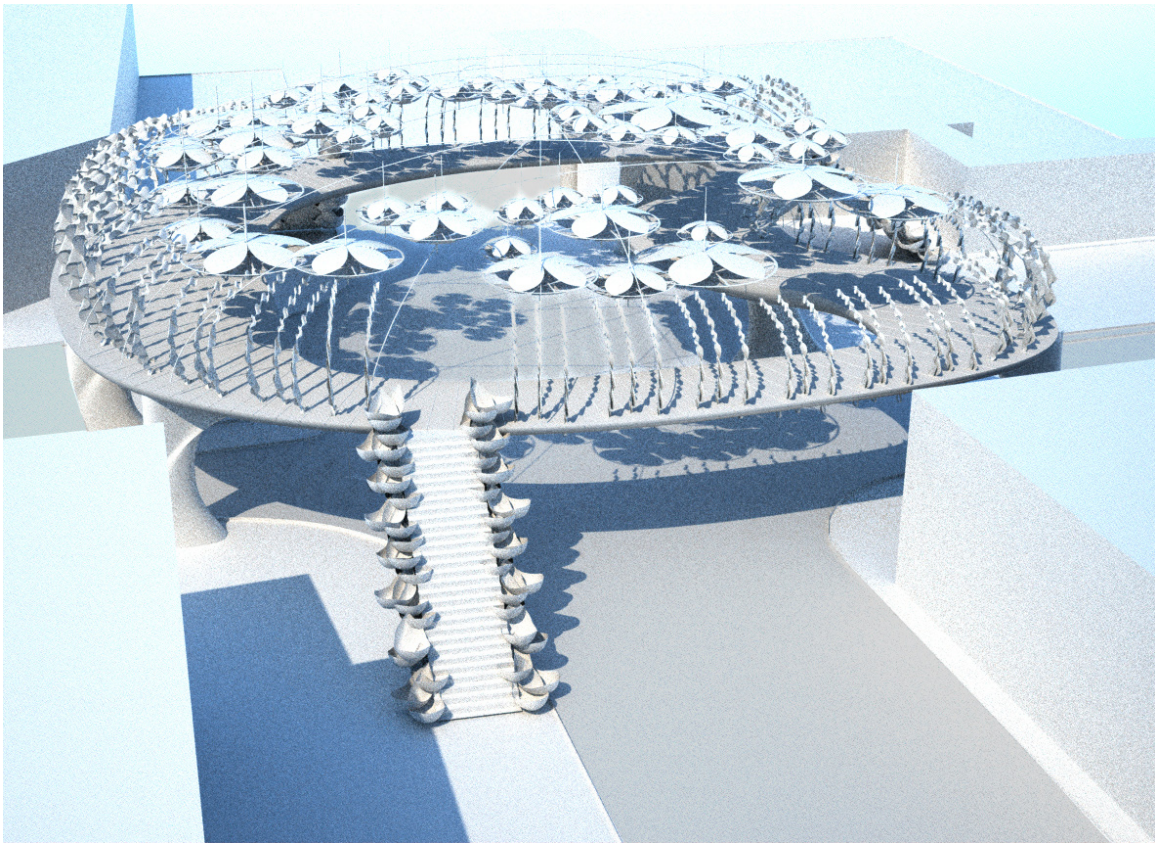


Figure 7.1.5 **SOUTHWESTERN AERIAL VIEW**

STRUCTURAL BASIS: FRAGREA FRAGRANS

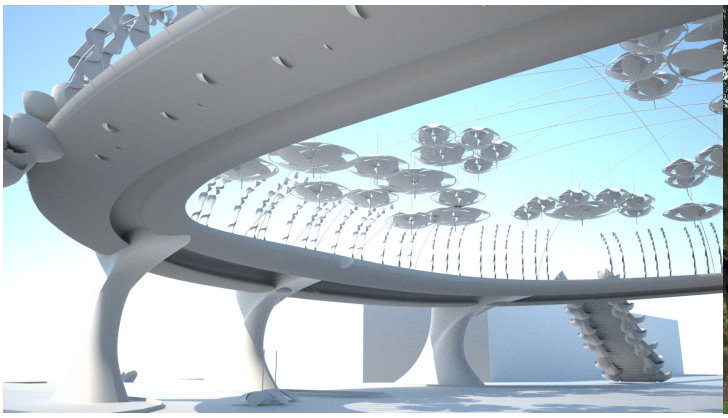


Figure 7.1.7

Figure 7.1.8

The *Fragrea fragrans*, more commonly known as the Tembusu, is a large tree of the Gentianaceae family, native to South-East Asia. Greatly significant in the Singaporean culture, the *Fragrea fragrans* plays a role in local folklore, and is present on the Singaporean five dollar bill. In the tropical rainforest, where plants strive to inhabit the largest area, resulting in a greater leaf area with which to photosynthesize, the *Fragrea fragrans* has evolved with a unique growth pattern, in which the plant spends energy extending its branches at right angles away from the trunk, before extending upwards to the canopy. This is an aggressive growth strategy, with many individual trees sending out large branches often only one foot off the ground, growing completely perpendicular to the trunk. The result is a very distinct silhouette, with a branch profile resembling a sphere.

To support these massive overhangs, the *Fragrea fragrans* has evolved with a buttress root system, which is common in many rainforest tree species. The buttress root system is often very shallow, at times reaching a depth of no more than five feet, and spreads out at a circumference greater than that of the branch system. In translating this physical elements from the *Fragrea fragrans* tree to the structural members on the overpass, buttressing column bases and sprawling supporting members were used, to represent the physical presence of the *Fragrea fragrans*. In profile, the structural grid on which the shading devices are placed is formed in a spherical manner, which emulates the *Fragrea fragrans* profile both up close as encountered by pedestrian users, and from a distance, as seen from a vehicular perspective.

CLADDING PANELS/AIR QUALITY: TEMBUSU LEAF DIFFERENTIAL GROWTH RATES

Tropical rainforest leaves have evolved forms which seek to funnel off of leaves quickly, in order to prevent them from having to hold the weight of the water, as well as leave them susceptible to fungal infestation from residual moisture. In an ecological setting as dense as a rainforest, leaves have adapted forms which allow them to quickly shed water. Two adaptive features are unique to rainforest trees, both of which are exhibited by the *Fragrea fragrans* tree. Leaves have evolved drip tips, which resemble thin stems, growing from the ends of the leaf. These modified tips work with the capillary quality of water, directing water downwards and off the leaf quickly.

The second adaptation seen in many tropical rainforest leaves is differential growth rates in leaf fibers. The fibers in the outer edges of the leaves grow at a quicker rate than the inner fibers, resulting in an edge which aids in funneling water towards the tip of the leaf. Differential growth rates also result in a slimming of the leaf shape, as it is no longer flattened at the edges. In the cladding system, a rigid membrane panel is fixed to a linear structural member, and the edges of the membrane react to the positive and negative inputs of environmental indication systems that sense air quality. The membrane has fibers running lengthwise within them, and upon a positive reading of low air pollutants, the fibers towards the interior of the membrane panel constrict, warping the outer edges of the panel, creating perforation which allows both light and air ventilation through. In response to a negative environmental systems reading, the inner fibers will remain relaxed, and the edges of the panel will remain flat, allowing very little light and ventilation through the breaks in between each individual panel. Figure 7.1.9 illustrates the design process employed to translate the communication of air quality data, into an overpass component that effects natural lighting and ventilation.

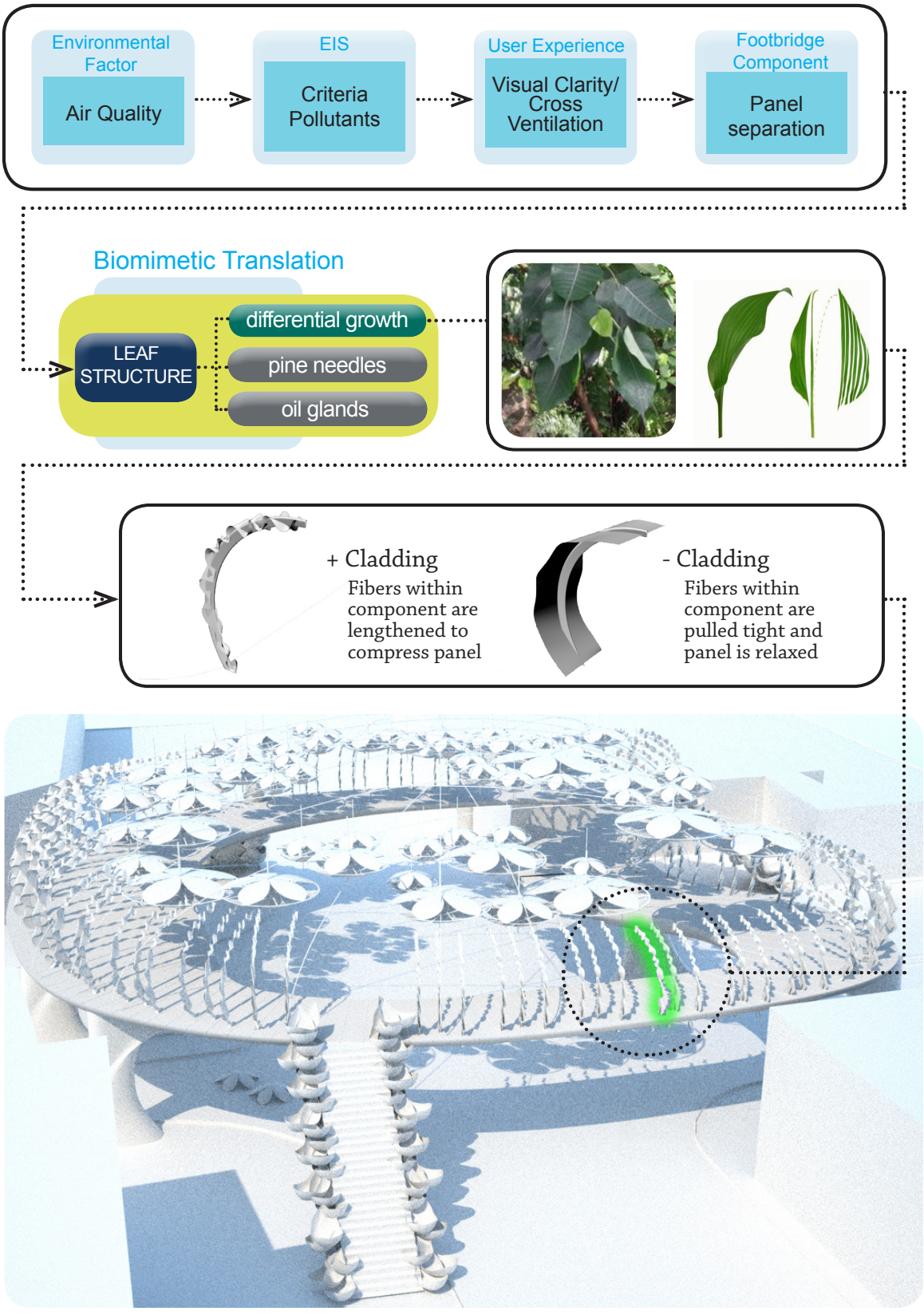


Figure 7.1.9: Singapore shading device design process

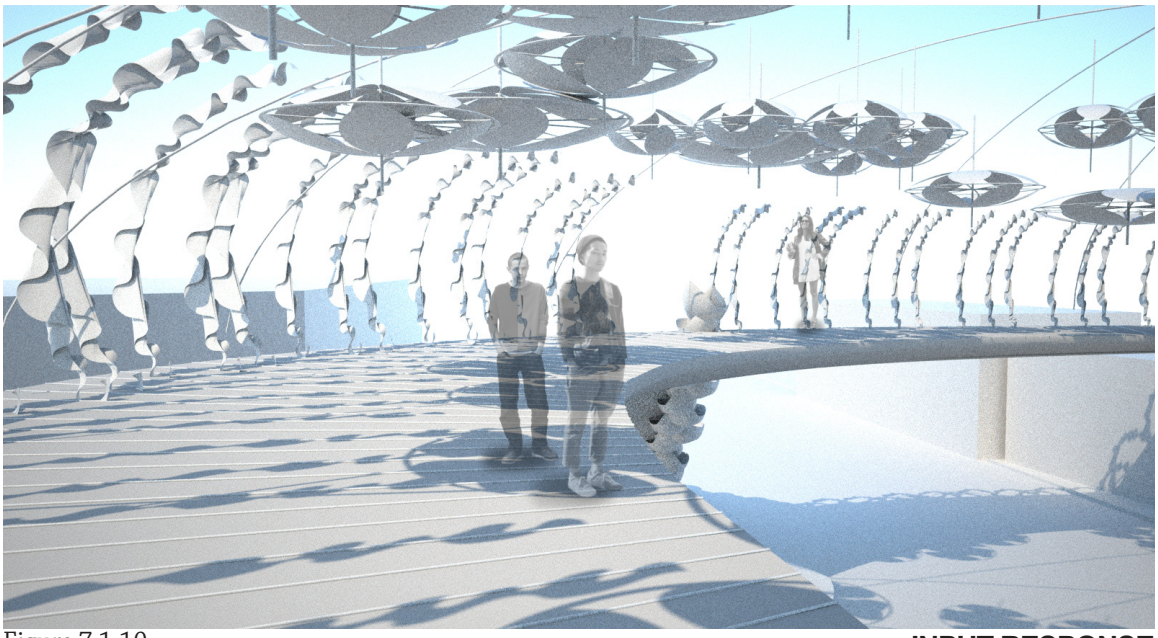


Figure 7.1.10

- INPUT RESPONSE

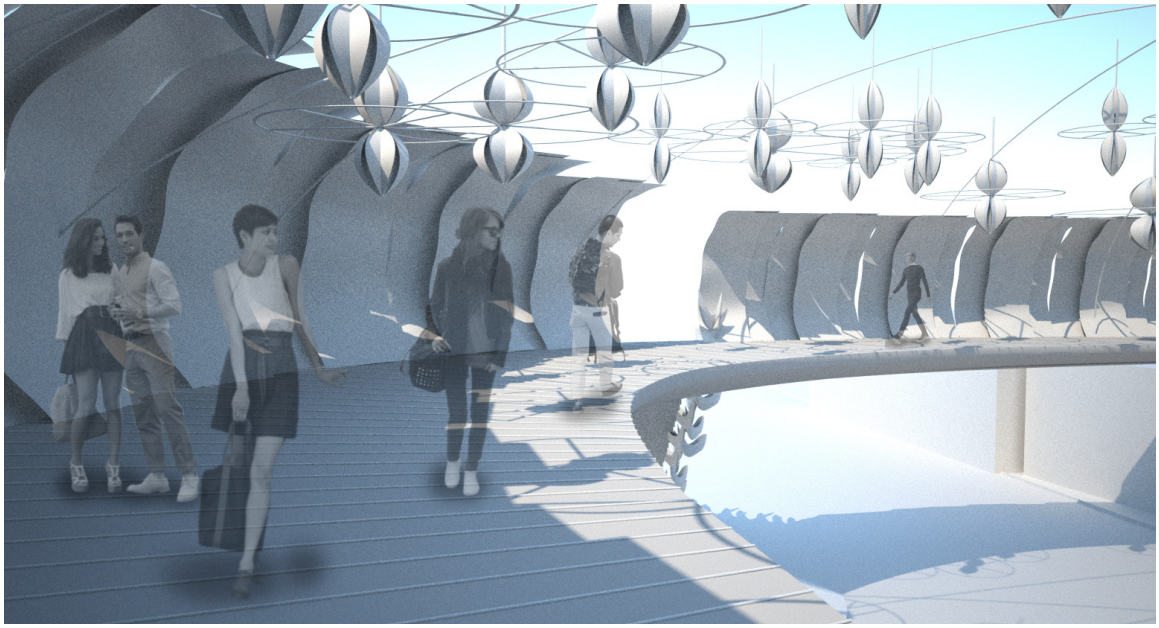


Figure 7.1.11

+ INPUT RESPONSE

WATER FEATURE/WATER QUALITY: BUTTRESS ROOT PUDDLES

Buttress roots are tensioning systems which anchor the large trees with asymmetrical canopies to the ground. Because of the density of tropical forests, often times buttress root systems entwine with one another, forming massive entanglements of roots, which start to form enclosed areas within which water collects. Visually, the saturated root entanglements resemble small terraced rice fields. This temporary set of small puddles becomes a micro-habitat, which amphibians and insects use as nurseries for their young.

The overpass component that communicates water quality will hold water in a similar matter, along the handrails of the vertical circulation. Stacked membrane structures with built in fibers that expand and compress will control the water pressure into the individual "buttress" elements. In response to positive data, the membrane encompassing each component will "relax" filling in the component with water, and allowing for users to visually connect with the water quality. Negative data results in the constriction of the membrane, hiding the water feature from users. Figure 7.1.12 illustrates how the need for a water feature was fulfilled within the biomimetic design constraints.

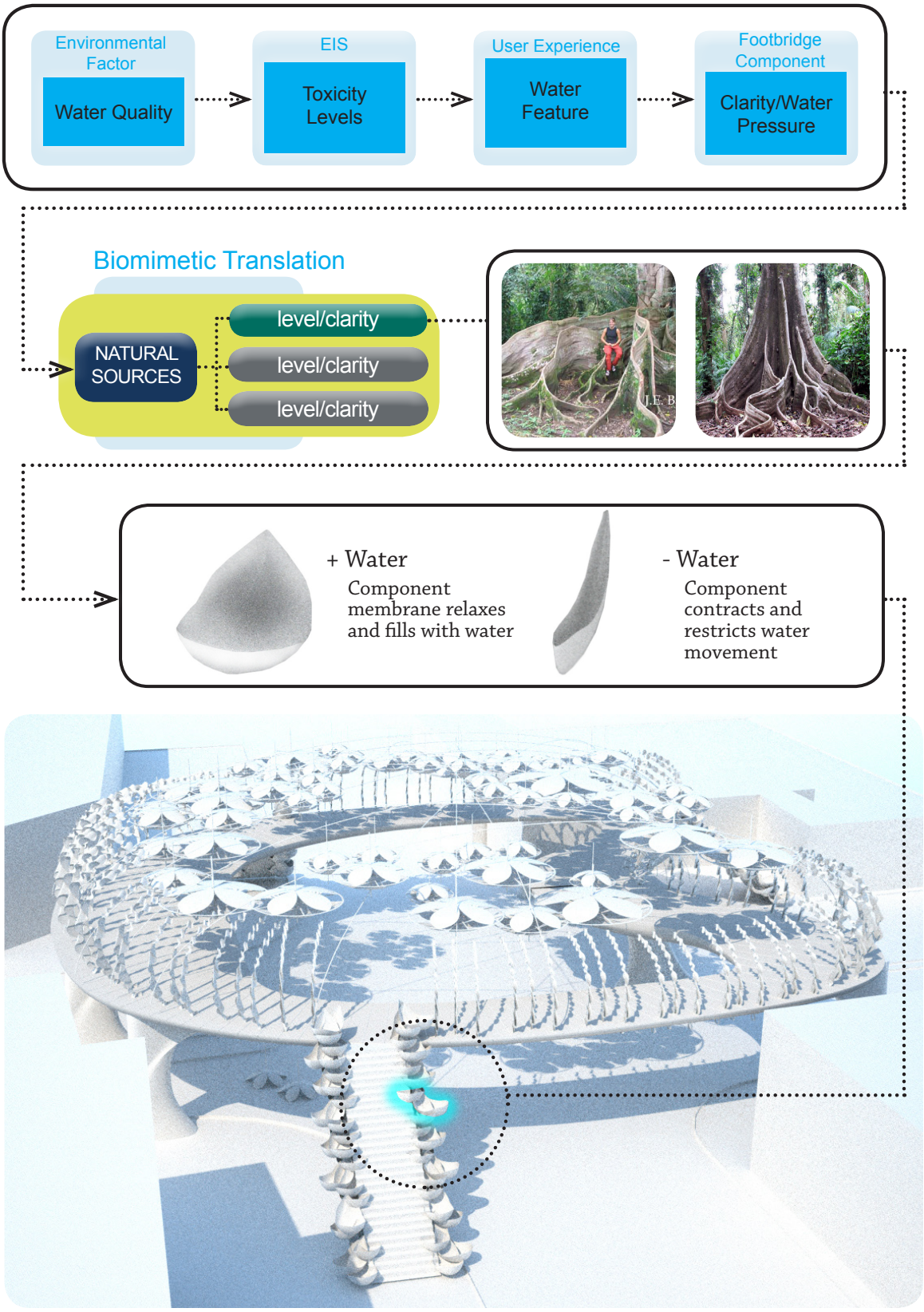


Figure 7.1.12: Singapore water feature design process

Figure 7.1.13

- INPUT RESPONSE

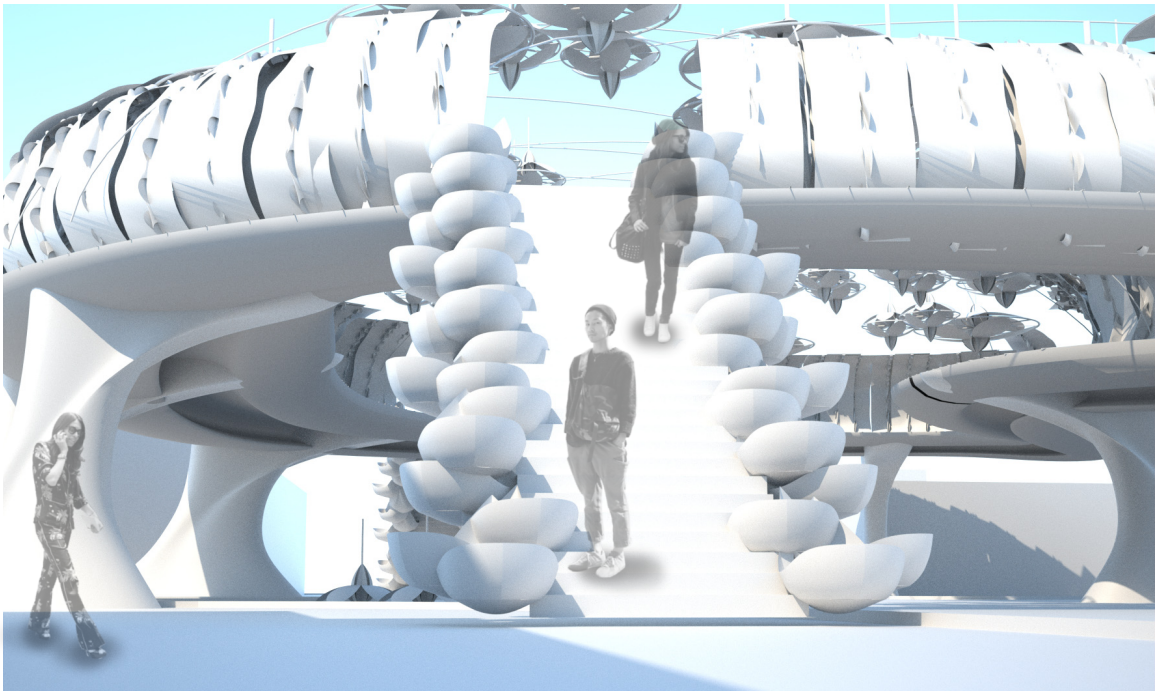


Figure 7.1.14

+ INPUT RESPONSE

SHADING DEVICE/CLIMATE: TEMBUSU FLOWER

The flower of the *Fragrea fragrans* tree grows in clusters that bloom twice annually, in the months of May and October. The flowers are white, with roughly six stamens each, with which pollen is distributed. The shading device is based off of the clustering effect of the flowers, as well as the movement that occurs in the blooming of the flower. The Tembusu flower has five flowers consistently, and blooms in dense clusters near the end of the branches that reach the canopy. The flowers open at night, to avoid competition with other species which bloom at day, and are pollinated by moths and bats, which are very common in the tropical forests of Singapore. These flowers open in the basic way that most angiosperms function, and fan outwards from its budding form. The petal structure is similar to that of the leaf, as flower petals are modified leaves, and of actinomorphic form, with identical petals in a ray-formation. The petals have a rigid stem like structure, similar to the stem found in leaves, which flexes open, allowing the flower to bloom and enable plant reproduction.

The shading device opens and closes in the same manner, responding to positive and negative inputs in climate change relayed from its particular environmental indication systems. The petal stem is translated through to the shading device in the form of a rigid central piece attracted to a track system at both ends. The ends of the tracks move to expand the four rigid central pieces, which are enclosed by a flexible tensile fabric. There are five tracks from which the central piece slides upon, on both the top and bottom of the central shading device structure, which holds the tracks together in the form of a ring. The top and bottom tracks are offset from one another in a rotary manner, allowing for the expanding shading structure to better cover the users, as well as function as a water collection system.

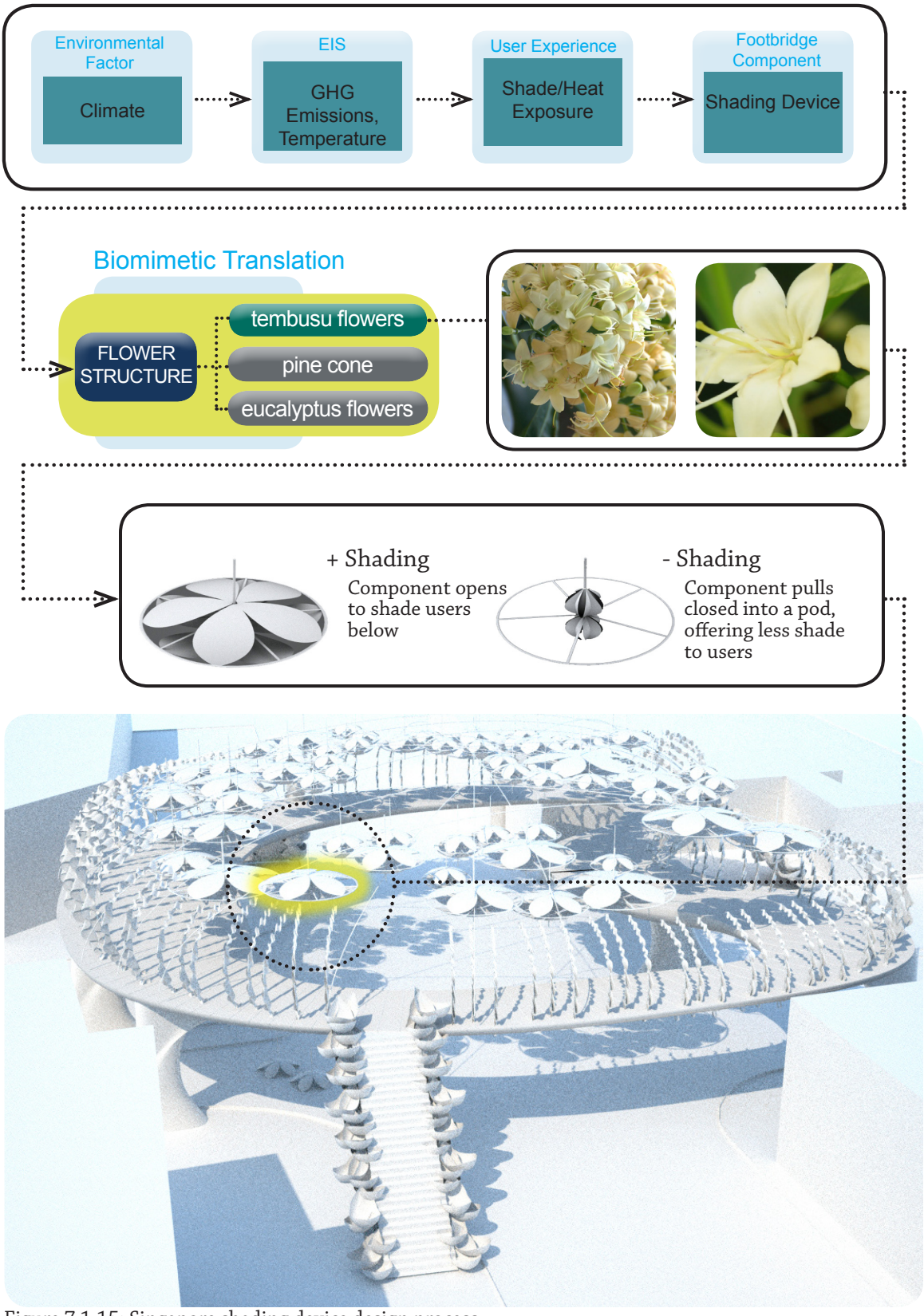


Figure 7.1.15: Singapore shading device design process

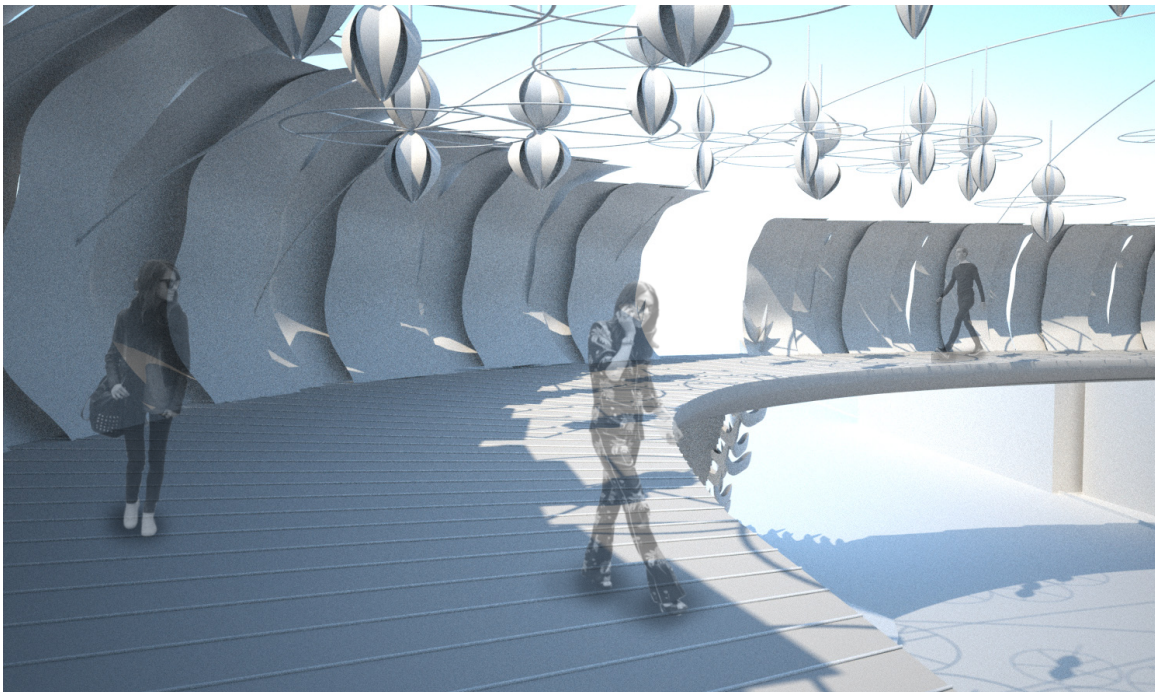


Figure 7.1.16

- INPUT RESPONSE

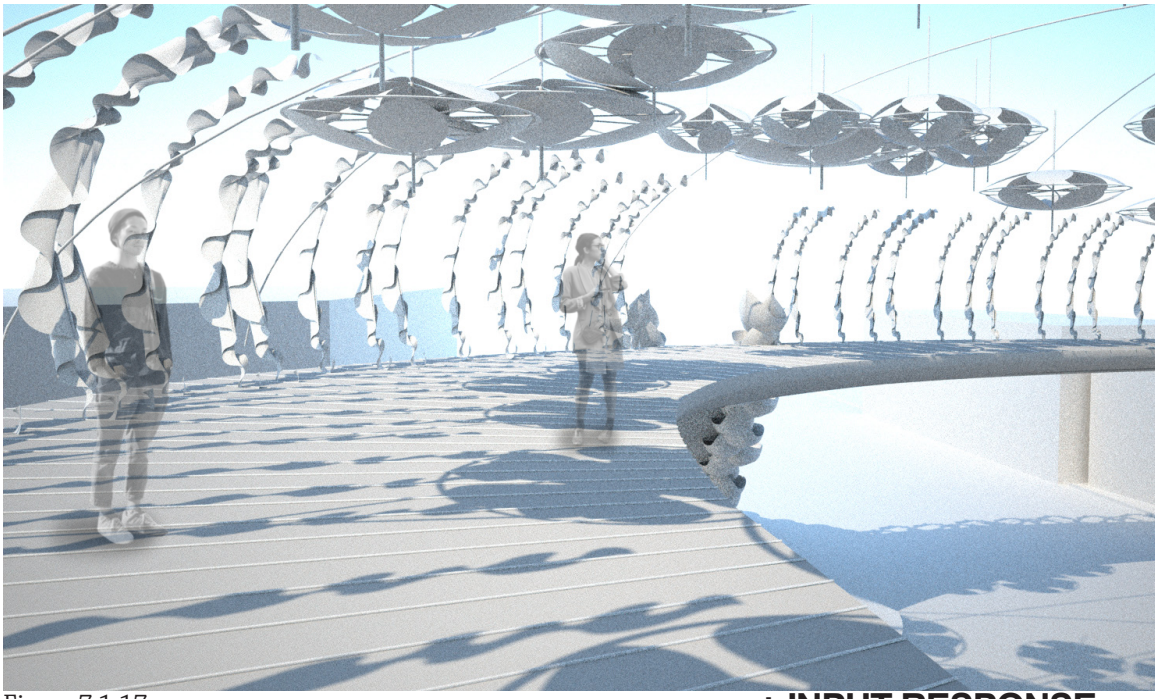


Figure 7.1.17

+ INPUT RESPONSE

GROUND COMPONENT/SOIL STATUS: SHALLOW ROOTS

In tropical ecosystems, the poor soil quality has resulted in the evolution of shallow roots systems within the inhabiting trees. Many trees employ different structural tactics to support themselves, as the absence of a deep tap root has denied the tree the ability for a deep grasp within the soil structure. Buttressed roots, as well as prop root systems are common, all which occur above ground, or close to the surface, where the majority of rainforest nutrients reside. Because rainforests are very dense in nature, the root systems of different trees start to abut one another, and combined trees will entangle their root systems, which allow them to benefit from an even wider structural base. This entanglement of the root system gives the floor a very distinct textural quality, which was transferred into the overpass as a varying floor texture.

The floor will be constructed in two layers, which work to change the prominence of floor texture, and quality of the walking experience. The first layer of the floor will be the actual texture, based off of the randomized root systems, which are somewhat irregular and unpleasant to walk upon. The second layer will be a thick membrane placed atop the roots system, which will hold a liquid of high viscosity between the root texture and the membrane. The variation between prominences of root texture will be dependent on the volume of liquid pumped under the membrane. As more liquid is added, the texture becomes less prominent, and the tactile walking experience is more comfortable, which will correspond to a positive environmental indication systems reading of the actual soil quality in Bukit Timah Natural Reserve. When the soil quality is poor, with higher levels of acidity and pollutants, the liquid underneath the membrane will be reduced, allowing more prominent protrusion, resulting in a less comfortable walk. The feeling of the floor texture underfoot will be similar to the sensation of walking on cobblestone, in that the foot will experience higher intensity levels of pressure in different parts of the foot, with each step.

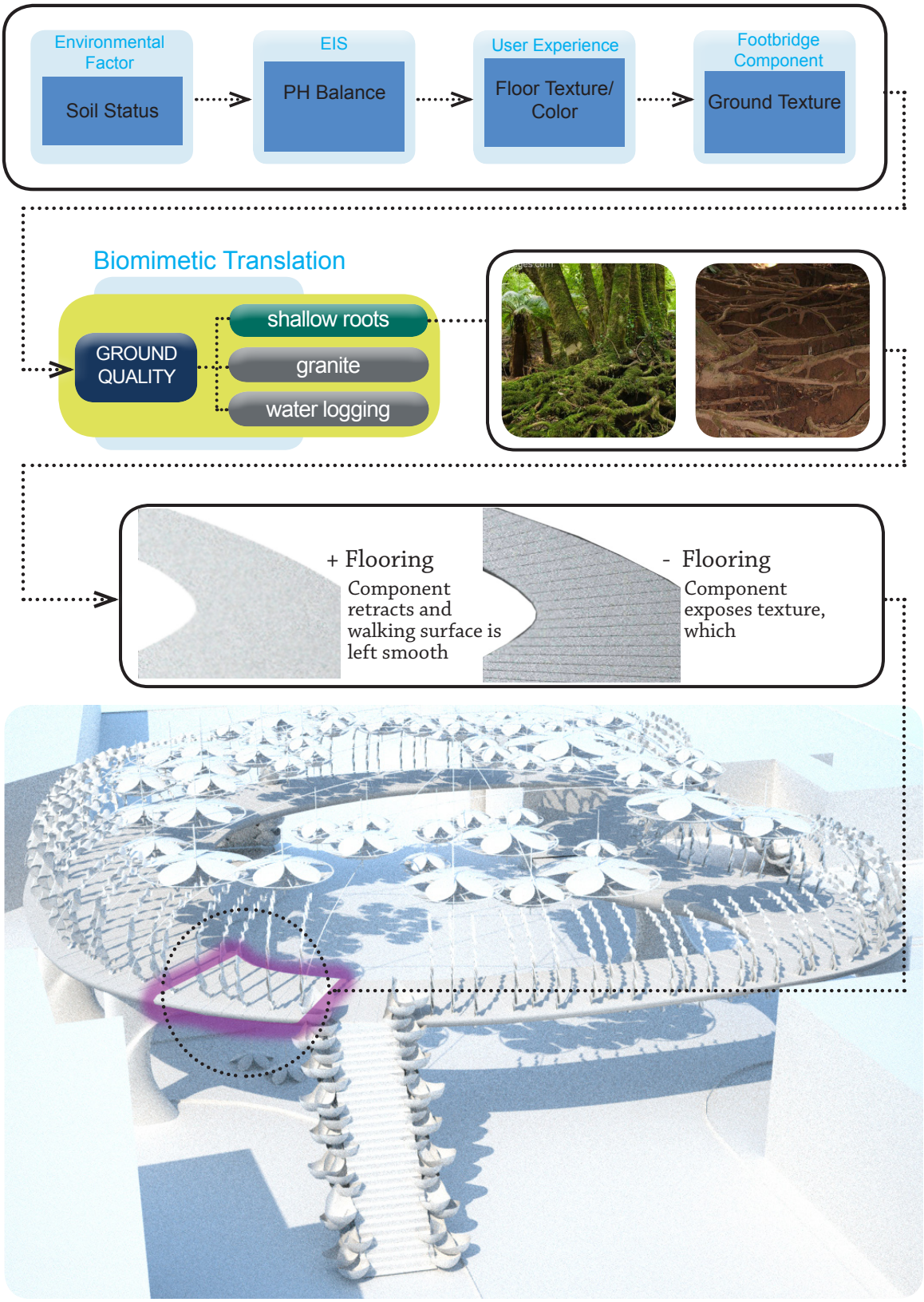


Figure 7.1.18: Singapore flooring design process

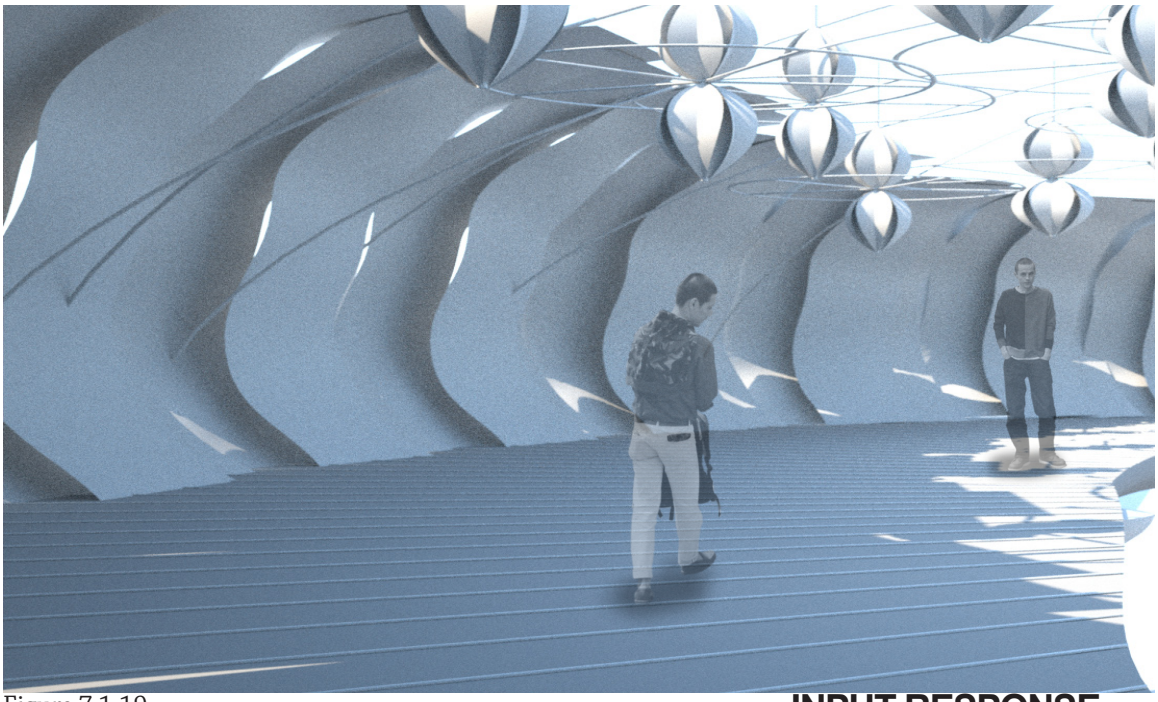


Figure 7.1.19

- INPUT RESPONSE

Figure 7.1.20

+ INPUT RESPONSE

PATHWAY CONSTRICTION/ECOLOGICAL EFFICIENCY RATES: LYGODIUM

The *Lygodium articulatum* is infamous worldwide for its ability to destroy entire ecological systems. The invasive fern is parasitic in nature, and uses the height of existing trees to inhabit canopy areas with high amounts of sunlight to conduct photosynthesis. The fern can grow at rates up to a foot daily, and can easily cover any leaves a tree might send upwards to expose to the sun. This causes the eventual death of the tree, after a long period of malnutrition. This invasive species is also greatly detrimental to forests in that they spread forest fires. While many species of trees can cope with forest fires affecting their root and trunk structures, the invasive fern gives a direct path for fires to spread to the canopy level, completely destroying the forests. Recent studies have shown that forests with high levels of biodiversity, such as the Bukit Timah Nature Reserve, are more successful at combating this invasive species. The greater the diversity of herbivores that feed on the plant, the more difficult it is for the plant to develop defenses to specific species, primarily the larvae phase of many flying insects. If the biodiversity levels decrease in the tropical rainforest however, due to an invasive animal over hunting caterpillar species, or a disease wiping out significant populations, the fern will be able to dominate, and potentially destroy the forests, as they are on the mainland United States. This invasive element is translated into a pathway constriction method as peripheral elements that branch out and obstruct areas of the pathway, lessening the width of the circulation path. The overpass obstruction will be constructed along the handrails of the pathway, of a series of flexible fibers that are based off of the curling tendrils of the invasive fern. The fibers will be fixed at the top, to the hand railing, and tensioned at the bottom, to the floor plate. The level of tension will correlate to the magnitude of protrusion into the circulation space. At the bottom connection of the fiber, at the floor plate, a feeding mechanism will reside, which will push and pull a hidden extra length of fiber, which will change the exposed length. This fiber will be repeated in a randomized pattern and will appear in a language similar to that of the root-based floor system.

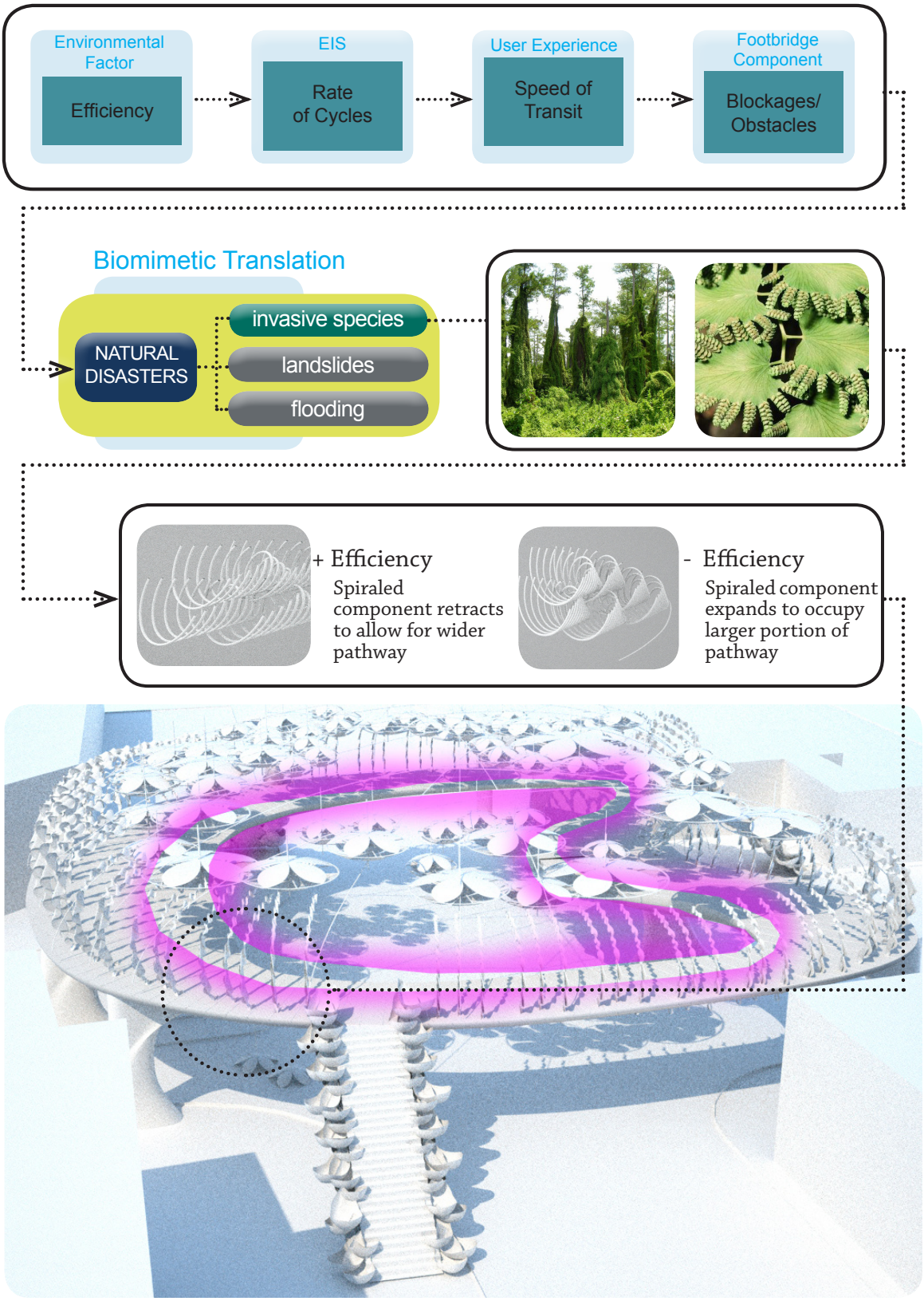


Figure 7.1.21: Singapore pathway obstruction design process

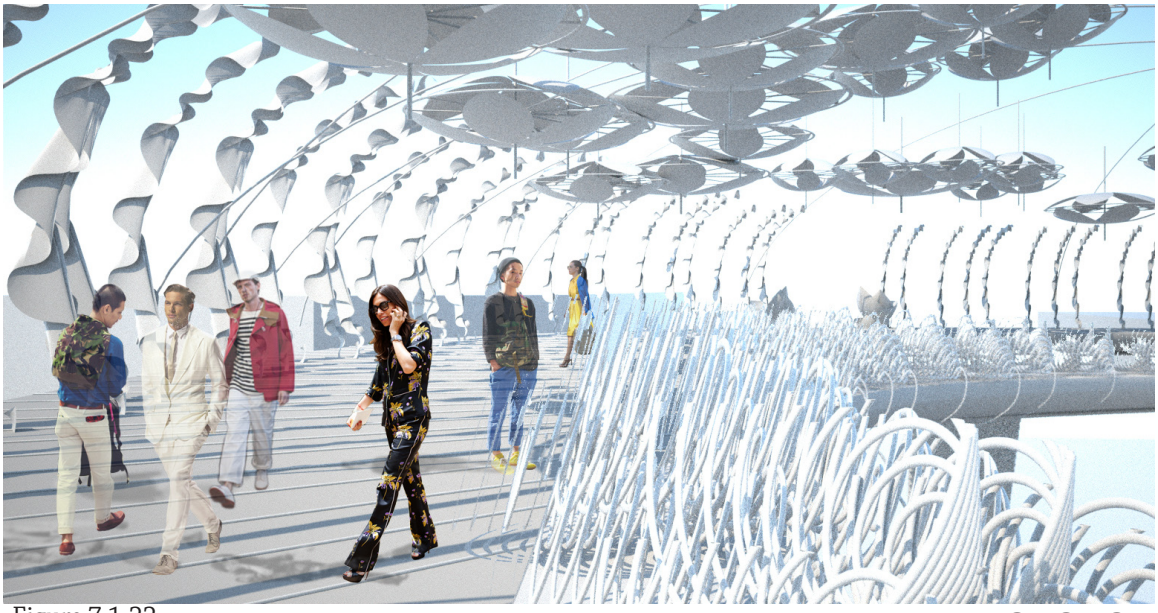


Figure 7.1.22

+ INPUT RESPONSE

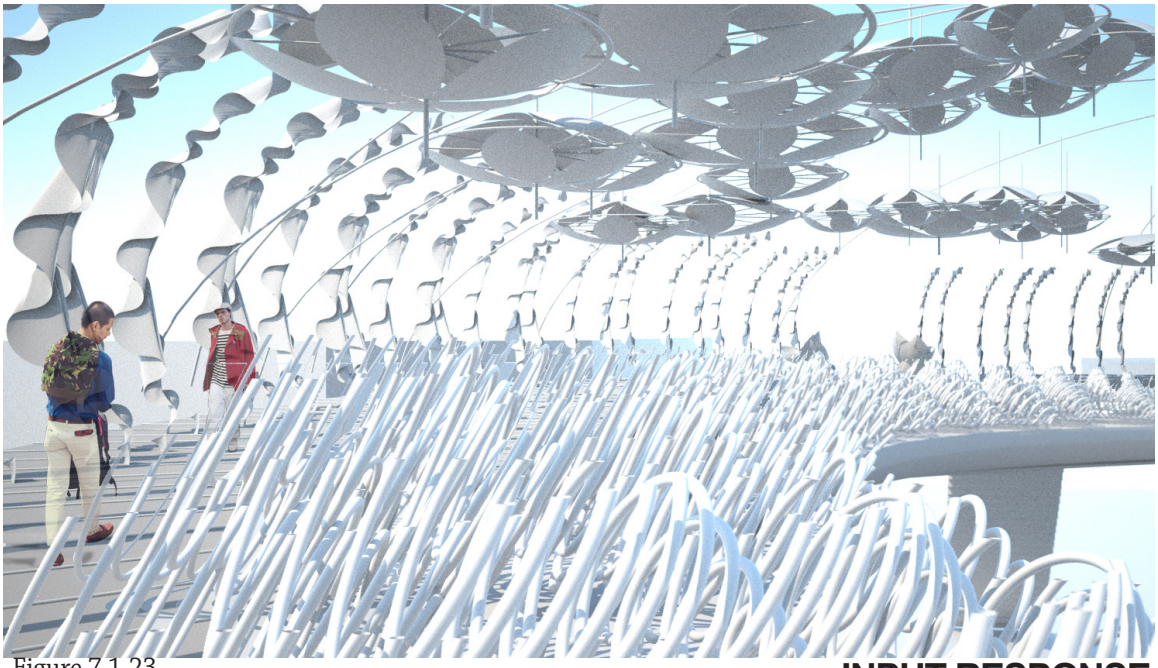


Figure 7.1.23

- INPUT RESPONSE

7.2 CHAPPARAL SITE: PERTH, AUSTRALIA

Founded in 1829 by Captain James Stirling, Perth is the capital of the Australian state of Western Australia, and is among one of the fastest growing cities in the country. It is the fourth most populous city in Australia, and the eighth best in *The Economists 2011 Most Livable Cities*.[166] With a population of only 1.7 million, Perth has almost one tenth the density of Singapore, but is rapidly developing. Perth is dominated demographically by immigrants from the United Kingdom and New Zealand, but also increasingly by foreign workers from Malaysia, Singapore, and Indonesia. The Transperth train and bus services help to transport much of the foreign workers to the Central Business District. The railway stations are underground, and consist of five lines, which are radial in organization, centered around the major business district of Perth.

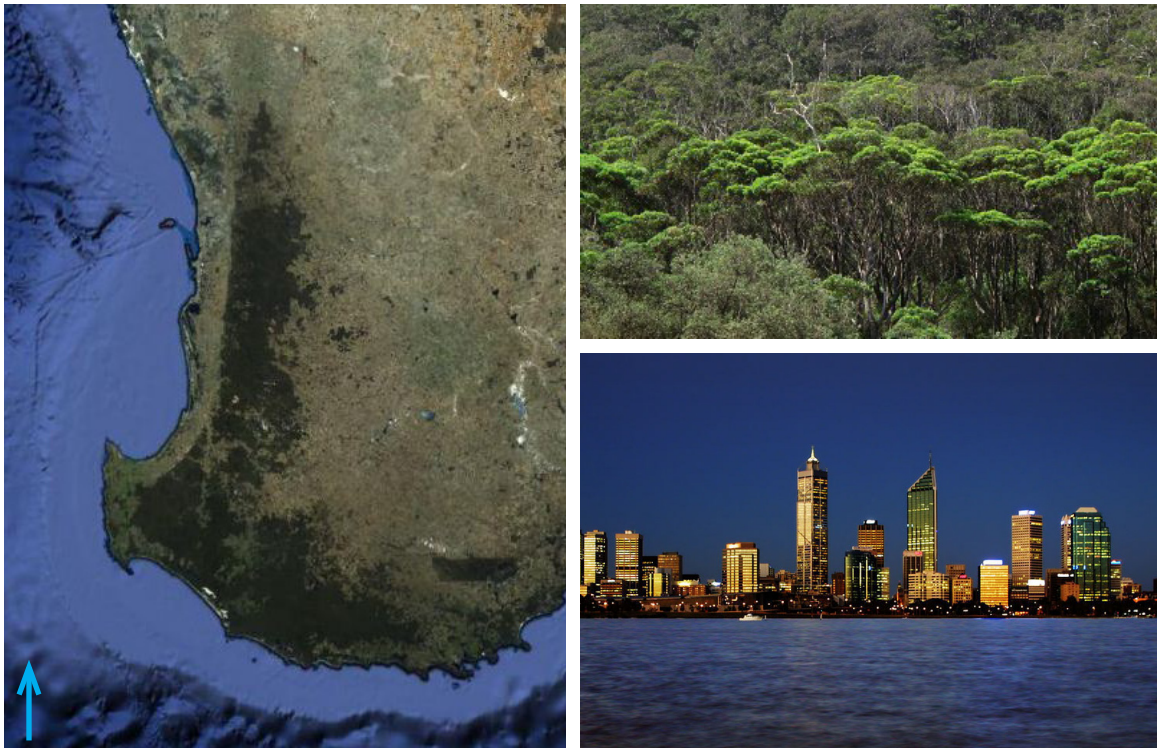


Figure 7.2.1

[166] Lucy Rickard, "Perth the World's 8th Most Liveable City," *WA News*, accessed October 4, 2011, http://www.watoday.com.au/wa-news/perth-the-worlds-8th-most-liveable-city-20110830-1jje2.html

7.2.1 NATURAL CONTEXT: JARRAH-KARRI FOREST AND SHRUBLANDS

Biome Typology: Chaparral Forest

Nutrient Cycle: Unlike tropical rainforests, where nutrient cycling occurs at a rapid rate, Mediterranean eucalypt forests cycle their nutrients at a much slower rate. This is due to the chemical composition of the trees themselves, which contain oils which act as preservatives. Once the leaves drop to the forest floor, the oils within the leaves create a sterile environment because they take long amounts of time to decompose.[167] Many detrivores, organisms such as fungi responsible for decomposition, have difficulty breaking down the leaves because of these oils. Eucalypt forests are unique in their reliance of fire for regeneration. The oils within the trees are highly combustible, often exploding during forest fires, which run aggressively, fueled by the un-decomposed leaves on the floors. These fires transform litter into nutrients which the surviving trees then use to recover. The Tingle species are renowned for their hollowed bases created from decades of surviving fires. The "caves" created serve as shelter for the various fauna found in the forest.[168]

Ecosystem Components:

Temperature: 59 degrees [avg.]

Precipitation: 47 inches per year

Sunlight

Because eucalypts are tall and sparse in nature, a higher percentage of sun makes it to the forest floor. The sun evaporates much of the moisture, further preserving the fallen leaves. As eucalypts are thinner in build, air circulation is also prevalent, lowering humidity levels and allowing for aeration.

[167] D. J. Boland, and M. W. McDonald, *Forest trees of Australia. 5th ed.* (Collingwood, Victoria: CSIRO Publishing, 2006), 31.
[168] D. J. Boland, and M. W. McDonald, *Forest trees of Australia. 5th ed.* (Collingwood, Victoria: CSIRO Publishing, 2006), 198.

Water or Moisture

The evapotranspiration within eucalypt forests occurs at a rapid rate, as eucalyptus are very efficient in their conversion of water and nutrients into biomass, and a larger area of the forest is open to the sun. It is often thought that they are wasteful in water use. The species need, on average, 785 liters of water to produce 1 kg of dry biomass, opposed to agricultural crops or other tree species, which will require 1000-3000 liters of water.[169] While the moisture levels within the Jarrah Karri are moderate, but the ground and undergrowth are usually dry, in comparison to the constant moisture found in rainforests.

Soil Chemistry

Historically, the eucalyptus was viewed as a wasteful plant which, because of its rapid growth, stripped the soils of all nutrients. This species is efficient in the consumption of nutrients within the soil, requiring 192 kg/ha/year of macronutrients to generate the same biomass that other species or crops produce, which use up to 470 kg of macronutrients.[170] Eucalypt forests are shown to have moderate soil nutrition, soils being the most fertile after a fire. The resulting soil type petroferric tensol, which are closely linked to podosol soils found in boreal biomes. These soils have sandy clay particulate, with low water repellence, and are subject to flooding.[171] While the forest floor is thick with underbrush, it is slow to decay because of the inherent preservatives within the eucalyptus oils. The Jarrah Karri forests have rich soil quality, with available nutrients that take a long time to be decomposed, but are quickly re-circulated into the ecosystem after decomposition.

Biodiversity

The Jarrah Karri forests are listed with in the Warren bioecoregion in the pri-

[169] Yitebitu Moges, "Eucalyptus Trees and the Environment: A new perspective in times of climate change," *Forestry Research Center*, accessed October 4, 2011, http://www2.montes.upm.es/Dptos/Dpto-Silvopascicultura/Etiopia/chap2_2.pdf, 106.
[170] Yitebitu Moges, "Eucalyptus Trees and the Environment: A new perspective in times of climate change," *Forestry Research Center*, accessed October 4, 2011, http://www2.montes.upm.es/Dptos/Dpto-Silvopascicultura/Etiopia/chap2_2.pdf, 107.
[171] Noel Schoknecht, "Resource Management Technical Report 246," (Soil groups of Western Australia 3: 2002), 31.

mary Australasian Region, which boasts a highly diverse set of species, many of which are endemic to the region. Eucalypt forests are capable of supporting high levels of biodiversity because of the variation in landscape that they offer. Within the ecosystems trophic levels, there are many species that fulfill the same ecological niche, allowing for a rich level of biodiversity.[172] As the forests themselves are very old and isolated, the species within the forests have all evolved to fulfill their trophic roles efficiently, each fulfilling the role in a slightly different manner. This has allowed for the forests to exhibit fast recovery rates after fires eliminate large areas.[173]

Flora

Within the Jarrah Karri forests are the Jarrah and Karri eucalyptus plants, among the tallest and fastest growing species. Different species of Tingle are found as well, including the Red and Yellow Tingle trees, another type of eucalypt.[174] The undergrowth of the Jarrah Karri is thick, and exhibits similar plant species found in rainforests, including ferns and mosses, that have adapted to existing with lower moisture levels. Most iconic are the eucalypts, several reaching to heights of 300 feet. All posses the shared characteristics of fast growth, and reliance on fire for regeneration, made apparent by their flammable sap.[175]

Fauna

The Jarrah Karri supports a rich variety of mammal species, including the Western Ringtail Possum, Chuditch, Pashcogale, and Quokka are among the smaller mammalian species, most of which are marsupials and endemic to the region. Lower in diversity are the bird and amphibian species, including the Red-eared Firetale, Western Bristlebird, the Purple-crowned Lorikeet, Orange-bellied Frog,

[172] Yitebitu Moges, "Eucalyptus Trees and the Environment: A new perspective in times of climate change," *Forestry Research Center*, accessed October 4, 2011, http://www2.montes.upm.es/Dptos/Dpto-Silvopascicultura/Etiopia/chap2_2.pdf, 108.
[173] Yitebitu Moges, "Eucalyptus Trees and the Environment: A new perspective in times of climate change," *Forestry Research Center*, accessed October 4, 2011, http://www2.montes.upm.es/Dptos/Dpto-Silvopascicultura/Etiopia/chap2_2.pdf, 108.
[174] J. S. Beard, and B. S. Sprenger, *Geographical Data from the Vegetation Survey of Western Australia*, Occasional Paper No. 2, 1984, 12.
[175] Miranda Mockrin, February 15, 2007, accessed September 25, 2011, "Jarrah-Karri forest and shrublands". World Wide Fund for Nature.

White-Bellied Frog, and Sunset Frog, most of which are endemic.[176]

Current Environmental Status

The current environmental status of the Jarrah Karri forest is improving, but still under threat. It is classified within the Australia's Department of Agriculture and Food as an Intensive Land-use Zone. The forest has been cleared significantly for agriculture use and livestock production, despite its relatively poor soils. The forest is also logged for the valuable eucalyptus wood, as well as mined for bauxite. In 2002, the proportion of land that had been cleared was listed at 13.2%. As well as mining, logging, and use for agricultural lands, dams have been erected around fast flowing rivers, which have further reduced the efficiency levels within the forest. Aside from the environmental pressures caused by mans intervention, the main threat to biodiversity within the Jarrah Karri forest is an epidemic of root rot or dieback, a soil born water mould. Perhaps the most detrimental threat to the Jarrah Karri forest is the continued bauxite mining. Bauxite is an aluminum ore, and the main source of aluminum, with Australia being the top producer, mining 44.5 million tons annually.[177] To attain the ore, strip mining is used, which is less evasive in terms of actual disruption of topography, but extremely harmful to the environment because of the removal of the top layer of soil for the ore. Strip mining is conducted by taking a pathways width of forest down, and harvesting the ore found within those soil. This leads to numerous ecological issues, including deforestation, pollution, eutrophication of streams and ponds, and home range defragmentation.[178]

[176] Miranda Mockrin, February 15, 2007, accessed September 25, 2011, "Jarrah-Karri forest and shrublands". World Wide Fund for Nature.
[177] 'Bauxite Mining and the Environment," *Azom*, accessed october 4, 2011, http://www.azom.com/article.aspx?ArticleID=1529

[178] Judith Willson, "The Environmental Impact of Bauxite Mining," *Helium*, accessed October 4, 2011, http://www.helium.com/items/1878788-effect-of-bauxite-mining-on-the-environment?page=2


Natural Site: Jarrah Karri Nature Reserve
Urban Site: Perth CBD
URBAN CONTEXT LOCATION MAP

Figure 7.2.2

7.2.2 URBAN CONTEXT: ESPLANADE RAILWAY STATION

Specific Site Information: Perth's Esplanade Railway Station is situated on the north-south Mandurah line, which carries people to and from residential districts to the CBD. This rail station is also situated close to the Esplanade bus port, making it a major transfer point for travelers. Esplanade Railway Station is also the stop for travelers visiting the Perth Convention and Exhibition Centre.

Figure 7.2.2 **EXISTING SITE**

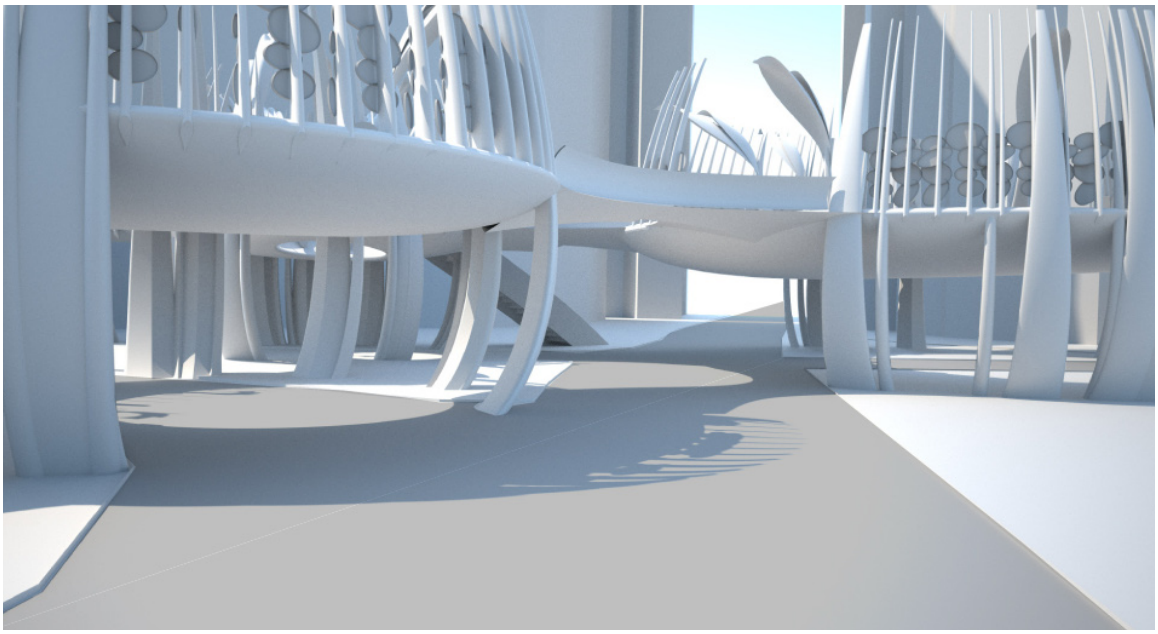


Figure 7.2.3 **SITE WITH OVERPASS**

7.2.3 DESIGN SOLUTION

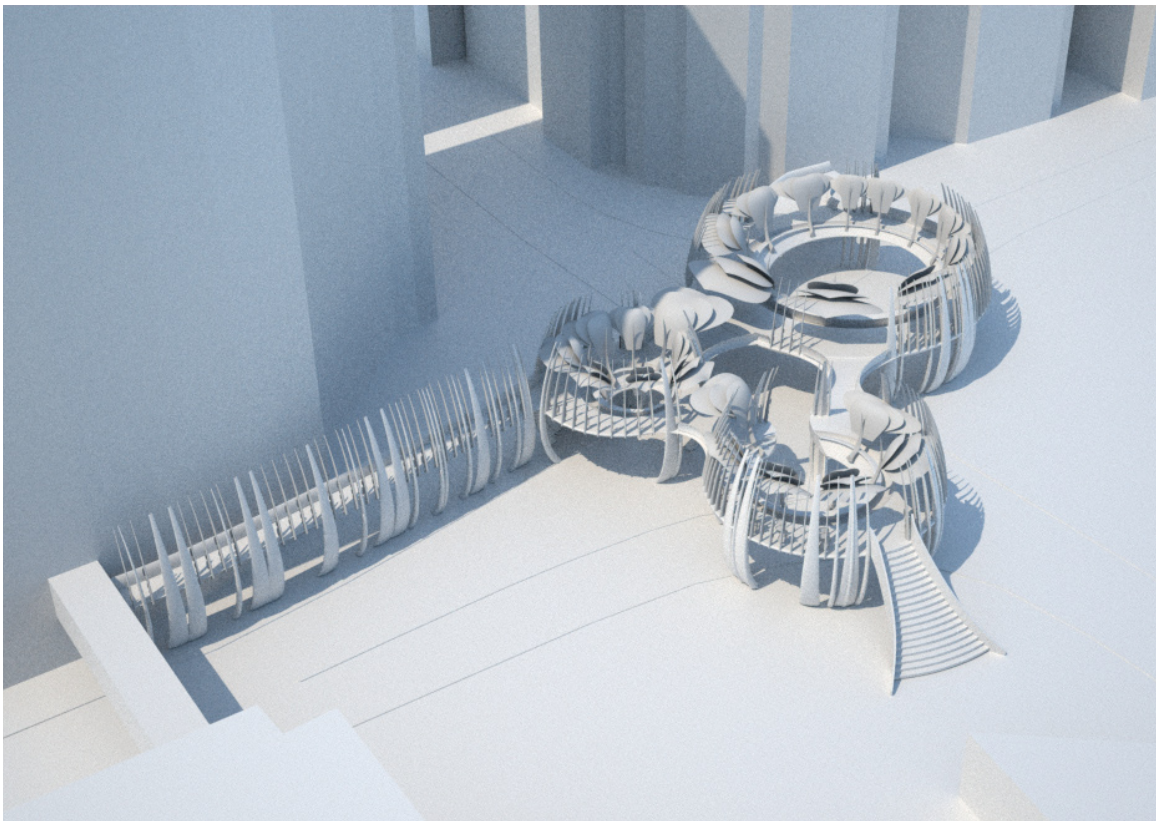


Figure 7.2.4 **SOUTHWESTERN AERIAL VIEW**

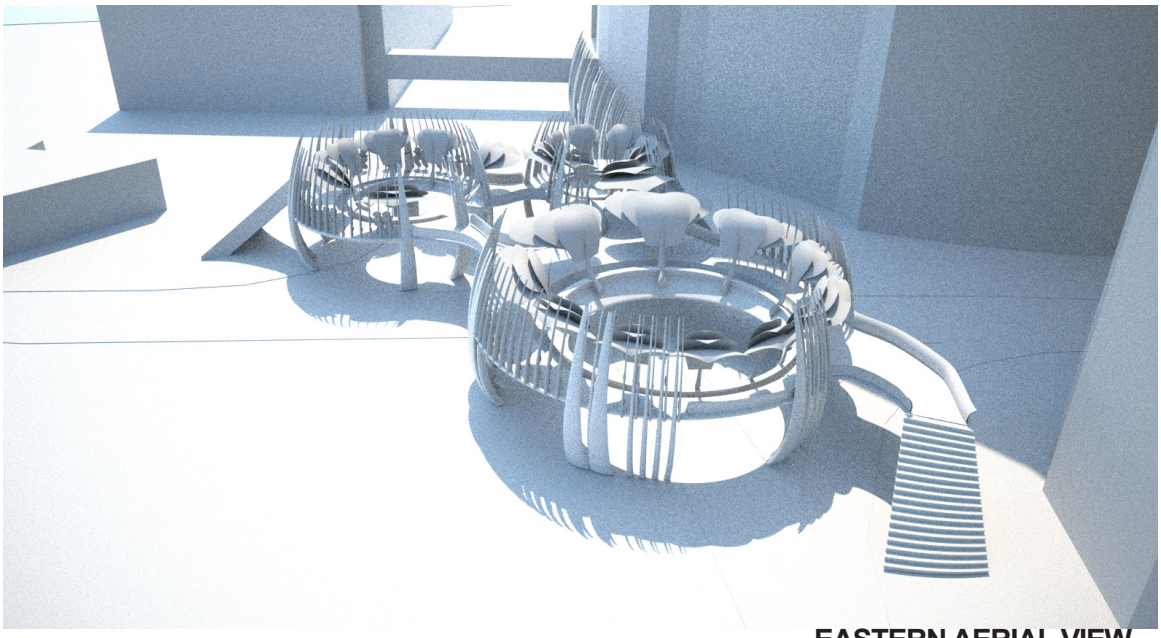


Figure 7.2.5 **EASTERN AERIAL VIEW**

STRUCTURAL BASIS: EUCALYPTUS

The eucalyptus tree resides in the Myrtaceae family, in terms of scientific classification, which includes other trees which are saturated with essential oils. These oils have played a major role in the plants development, as well as its ability to remain the dominant species in the Jarrah Kari forest ecosystems. The Myrtaceae family is one of the tallest growing tree families, with some species reaching up to 320 feet. Tree profiles are tall and slender, with leaves starting high up on the trunks. Structurally, the floor plate of the Perth overpass will be supported by a multitude of slender structural elements, instead of fewer large members. The language of the eucalypt forest will henceforth be carried through to the urban insertion, and imply a specific unique identity to the space that is directly representative of Perth's surrounding natural environment.

Figure 7.2.7

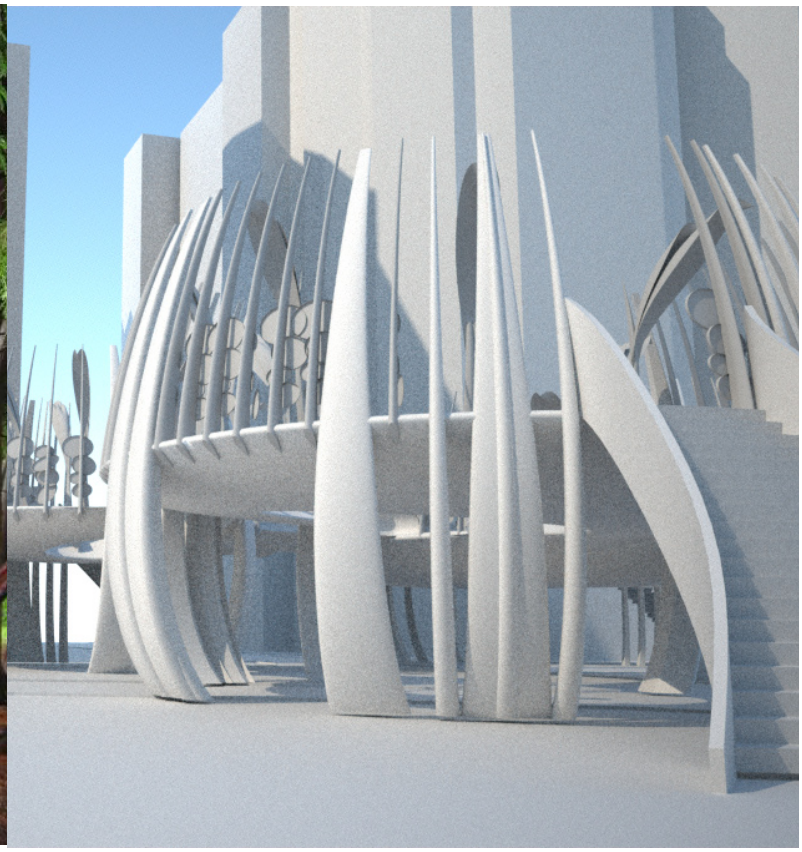


Figure 7.2.8

CLADDING PANELS/AIR QUALITY: EUCALYPTUS GLAND FORMATION

The eucalypt species is not only the main supportive species which comprises a large percentage of the Jarrah Karri forest, which is named after the *Eucalyptus Marginata,* or Jarrah tree, primarily farmed for its lumber. The species is fairly easy to propagate, because of its hardiness and resistance against pests, an ability derived from its essential oils. One of the most unique elements to the eucalyptus are the oil glands which develop as the leaves reach maturity. The glands are formed schizogenously, through the splitting of the common wall of contiguous cells, essentially forming an intercellular space, from otherwise abutting wall surfaces.[179] The oil produced is highly valued for both medicinal and cosmetic uses, and aids the tree in combating pests and grazers.

The shading device is based off of the schizogenous formation of the oil glands. As the leaves mature, the oil glands are formed from surface splitting, and the leaf volume is expanded.[180] Auxetic structures are a technology currently developing which expand in volume as they experience physical tension. Many auxetic materials available today are still in their research and development stage, but have promising attributes, and researchers hope to apply them to body armor and shock absorbing material.[181] In terms of translating the schizogenous formation to a shading device, auxetic foam will be employed, that expands when tensioned, in the direction perpendicular to the force. The foam units will be placed along a rigid frame, on the outer border of the overpass. The foam units will then be attached in a series, to a mechanically tensioning device, which is directly connected to the environmental indication systems sensor. Positive feedback will reduce the tension in the system, allowing contraction of the auxetic material, and a smaller physical profile. Negative feedback data will result in the tensioning of the mechanical system, which will then cause the auxetic material to expand to a point at which they meet, and block out both light and natural ventilation.

[179] Anton Bary, *Comparative Anatomy of the Vegetative Organs of the Phanerogams and Ferns*, (London: Oxford University Press, 1884), 207.
[180] S. List, "Functional Anatomy of the Oil Glands of Melaleuca alternifolia (Myrtaceae)." A*ustralian Journal of Botany*, accessed October 3, 2011, http://www.publish.csiro.au/paper/BT9950629.htm
[181] "Auxetic Materials – Applications," *Azom*, accessed October 3, 2011, http://www.azom.com/article.aspx?ArticleID=168

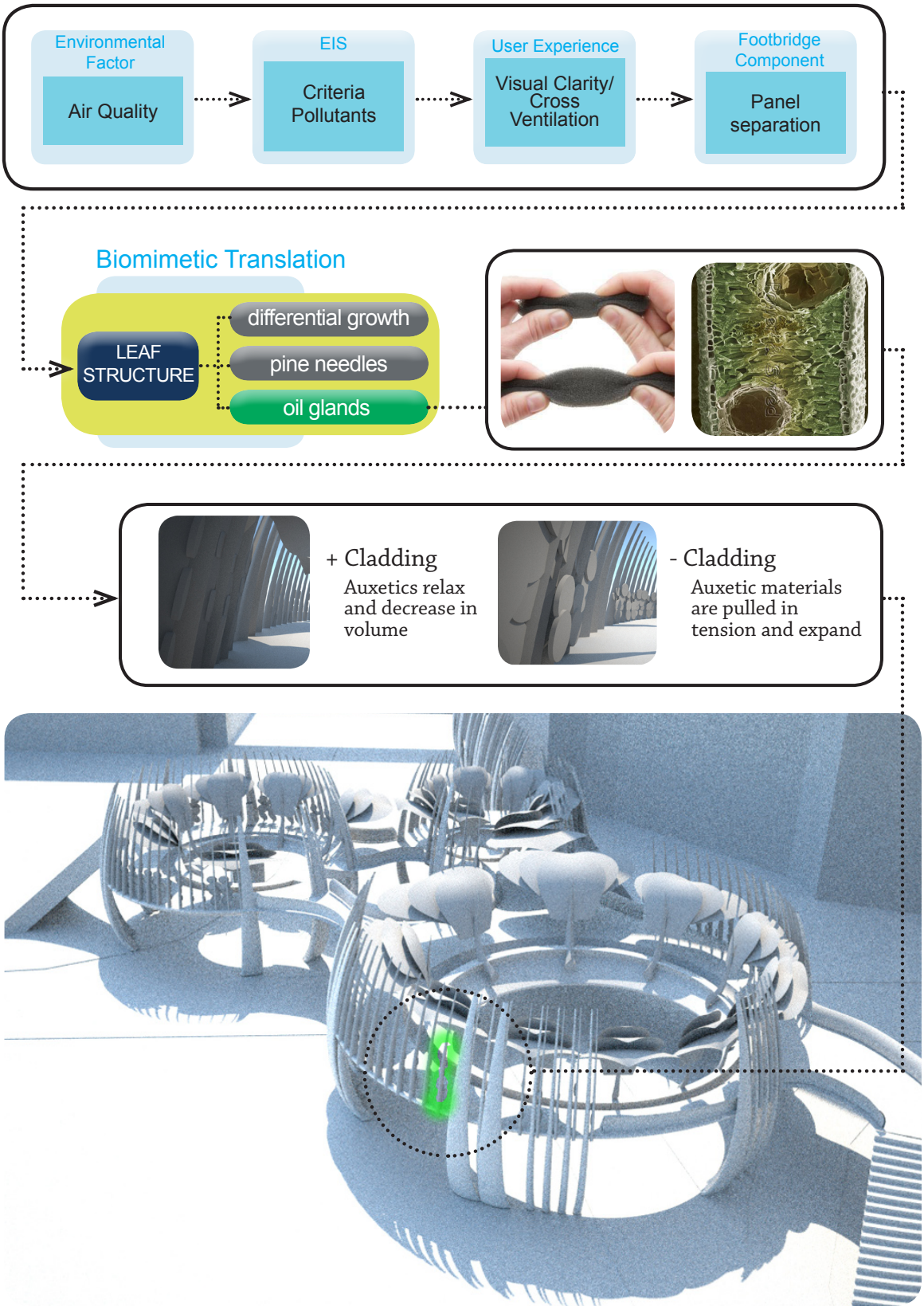


Figure 7.2.9: Perth cladding panel design process

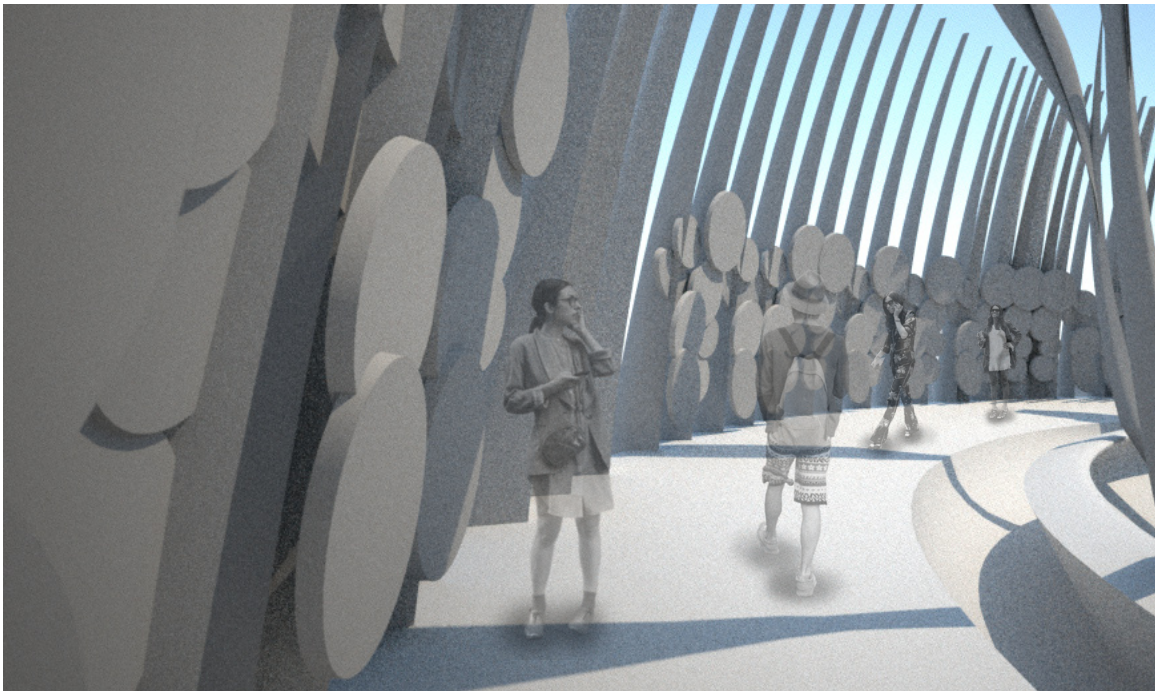


Figure 7.2.10 **- INPUT RESPONSE**

Figure 7.2.11 **+ INPUT RESPONSE**

WATER FEATURE/WATER QUALITY: JARRAH KARRI PONDS

The water in the Jarrah Karri forest has petroferric tensol soils, which are largely composed of clay, and cannot efficiently absorb large amounts of water. This results in topographically formed puddles, which do not maintain constant permanence, but remain a prominent feature in wet eucalypt forests, such as the Jarrah Karri. This is translated into the water feature, which also acts as a barrier for the interior edge of the overpass structure. The water features will be constantly present, with a width of at least six feet of water to separate pedestrians from the twenty foot drop. The water clarity and flow of water will vary depending on the quality of the water in the natural environment. A positive environmental data input will result in clear water that is flowing at a quick pace. Negative data will result in water that appears stagnant, and is murky in nature. The murkiness will be achieved through a chemical means, and deposited according to the environmental indication systems input.

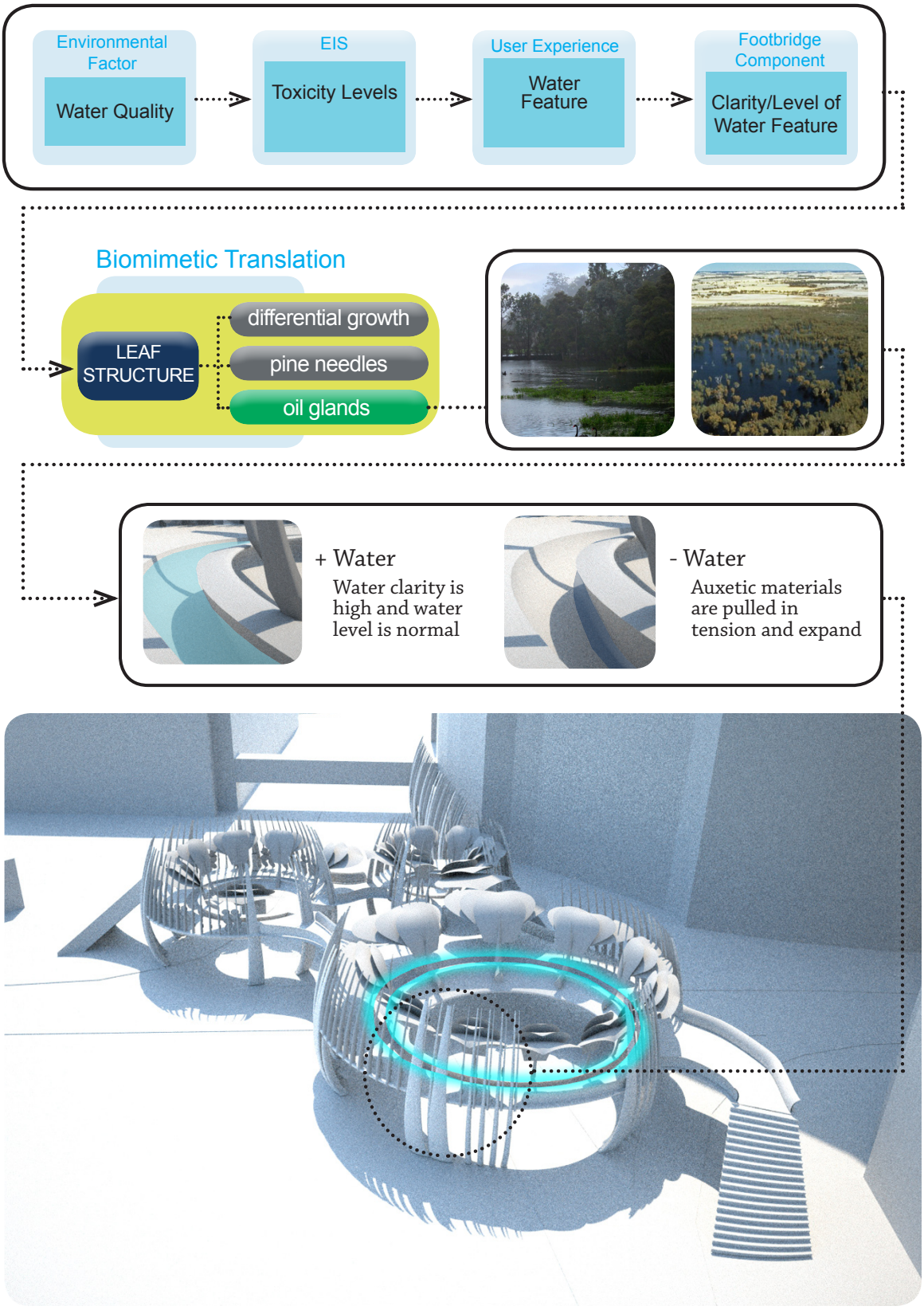


Figure 7.2.12: Perth water feature design process

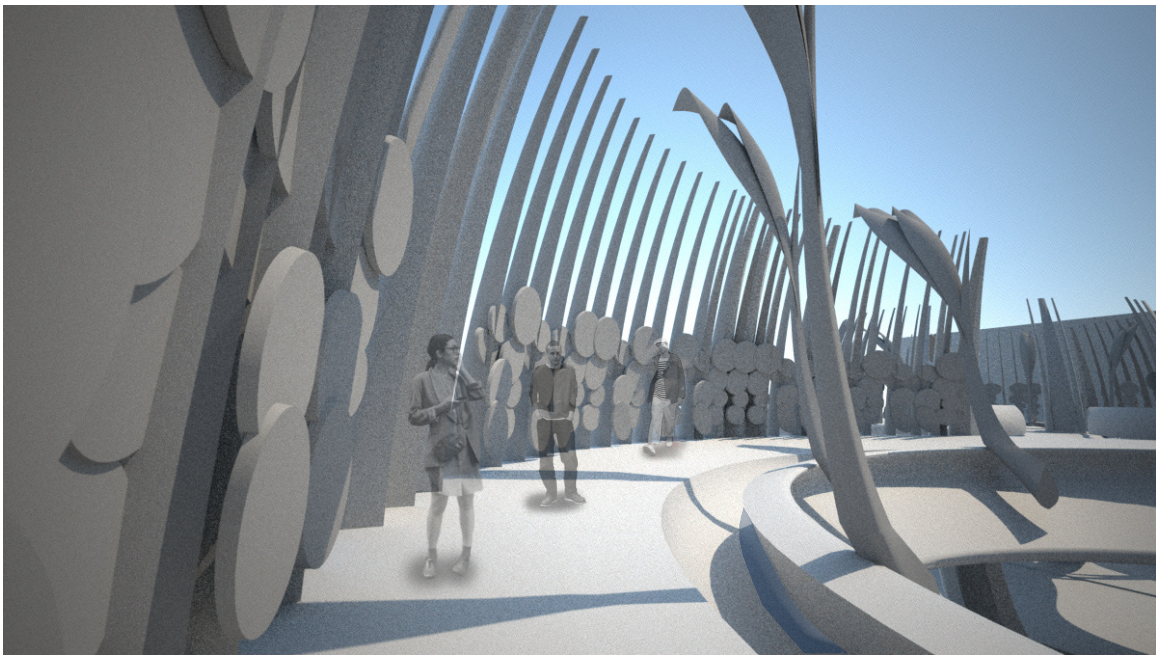


Figure 7.2.13

- INPUT RESPONSE

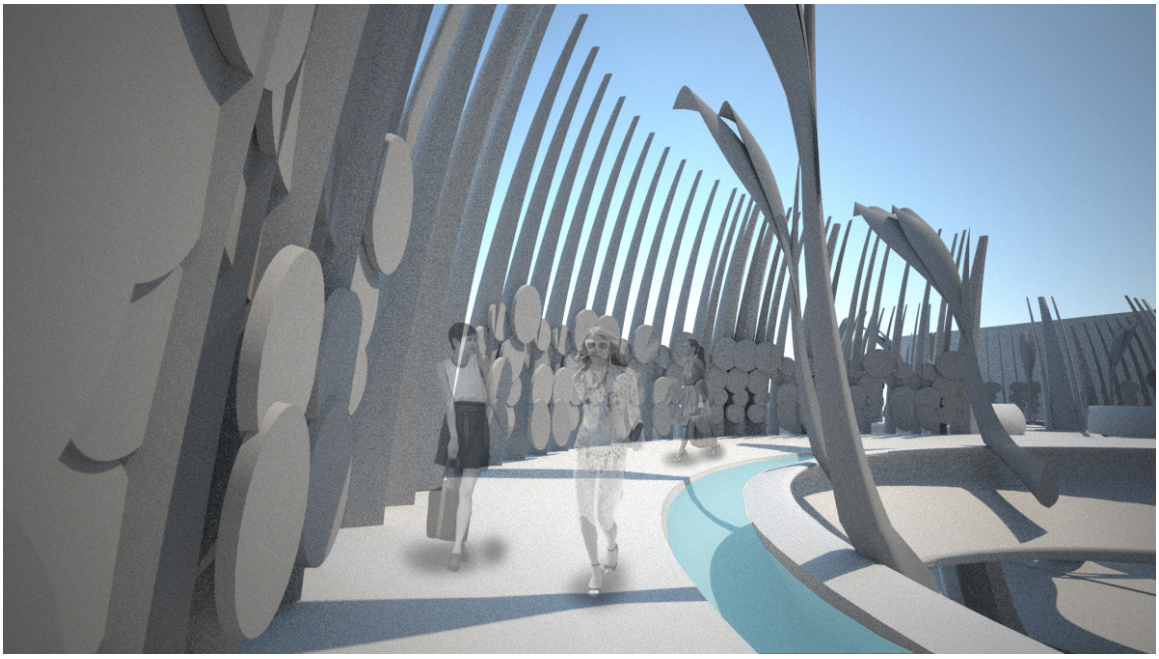


Figure 7.2.14

+ INPUT RESPONSE

SHADING DEVICE/CLIMATE: EUCALYPTUS FLOWER

Eucalyptus flowers are unique in that their petals have evolved further into a hard protective cap like structure, called an operculum.[182] Instead of attraction pollinating species with colorful flowers, the eucalyptus flower has evolved many colorful stamens, each with a stigma for depositing pollen onto the host insect. The opening action of the eucalyptus flower is propelled by a stiffening of the stamen structure as the operculum is shed. The stamen flip outwards and resemble thatching in the manner that they overlap with one another.

This translated into a shading device that offers coverage from an overlapping of thin elements, all of which are connected through a spherical central piece. Each thin element is of a reflexive material, most likely some type of metal alloy, leaving the shading structure dependent on the flexion of the material to deploy in reaction to a specific environmental indication system input. Each flexing element is cross joined at the center by a tensioning element, which pulls the members together, closing them, and offering little to no shade, in response to a negative data input. When the climate data is positive, the tensioning cross members will be released, and the flexion of the metal allow material will allow the thin members to expand and overlap. They will appear highly textured and almost fuzzy from a distance, much like the eucalyptus flower.

[182] Brian Johnston, "A Close-up View of Eucalyptus Tree Flowers," *Microscopy UK*, accessed October 2, 2011 http://www.microscopy-uk.org.uk/mag/artoct07/bj-eucalyptus.html

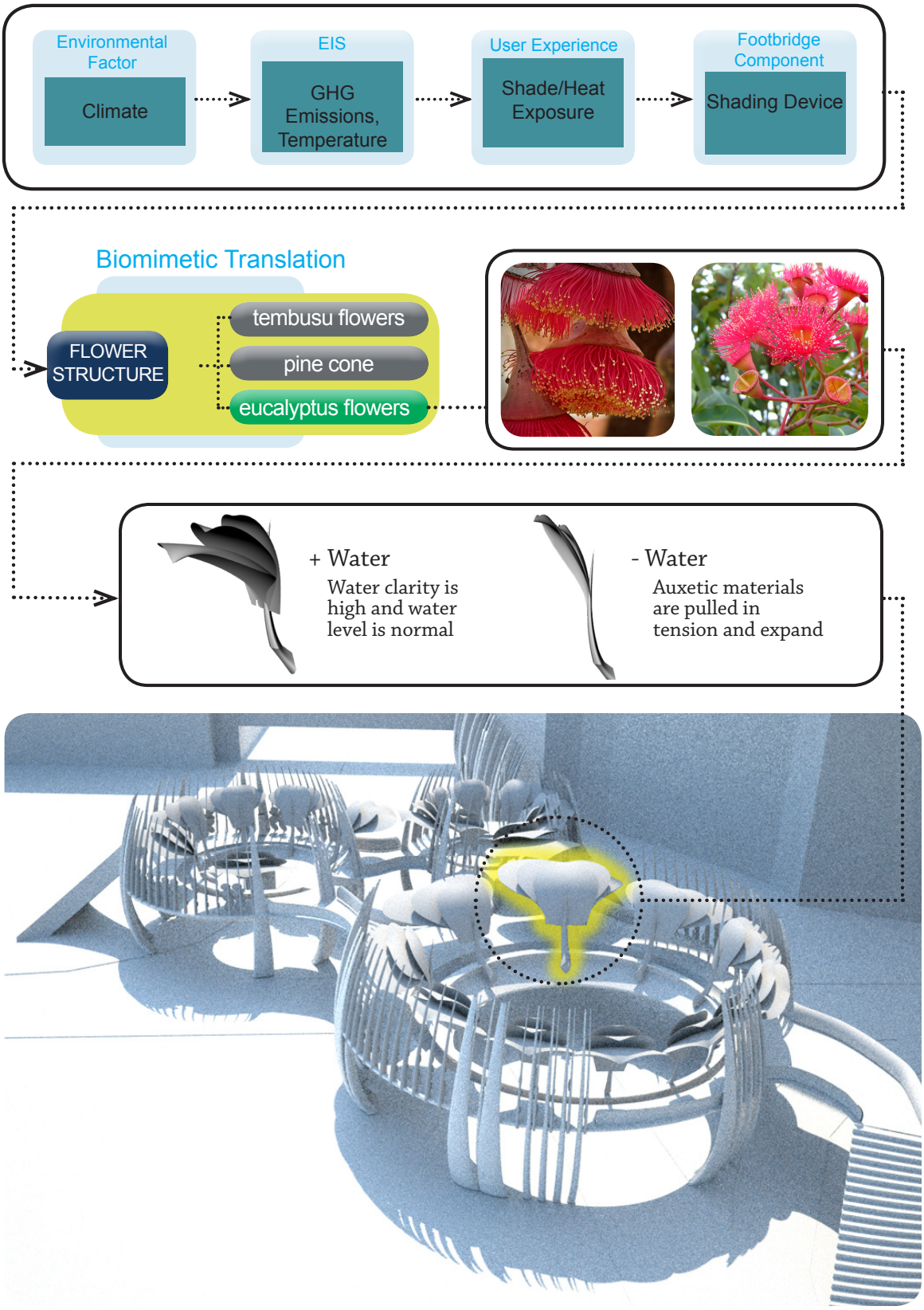


Figure 7.2.15: Perth shading device design process

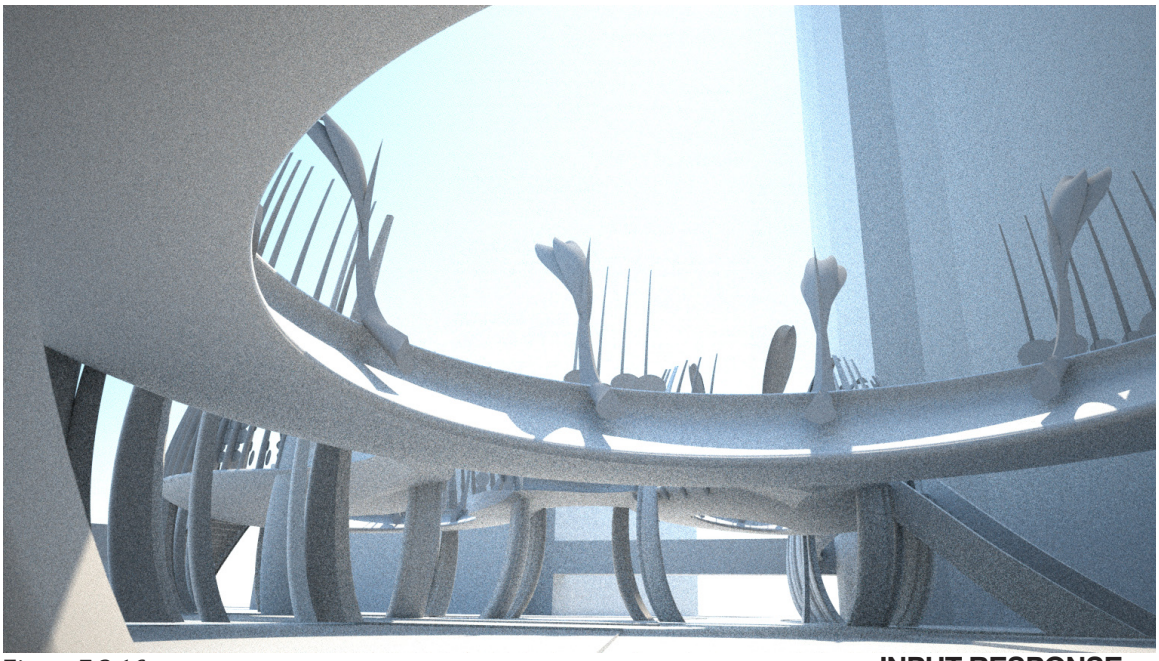


Figure 7.2.16 **- INPUT RESPONSE**

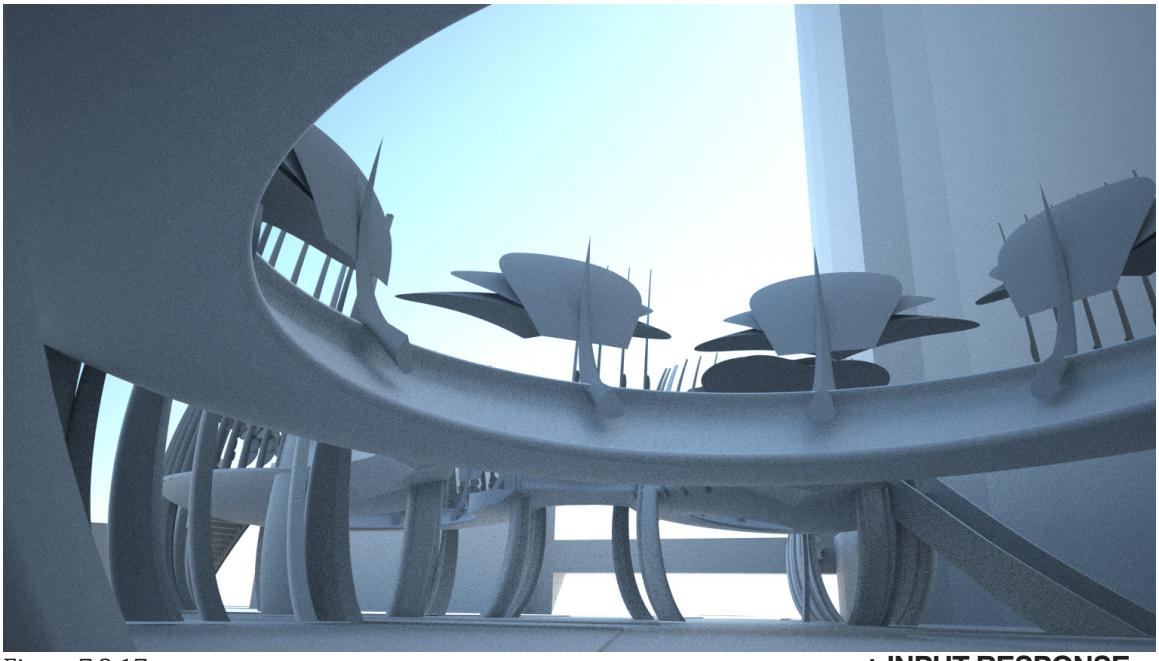


Figure 7.2.17 **+ INPUT RESPONSE**

GROUND COMPONENT/SOIL STATUS: LEECHED SOIL

This overpass element is also related to the poor quality of the clay like soil. As the ground becomes overly saturated, even the smallest indentations in the soil can bring forth moisture in puddles. This translated into the overpass floor structure through the installation of bi-chromatic tiles, a developing technology which allows for users to leave behind their footprints through pressure placed on liquid filled modular tiles. The flooring system on the overpass will relay different environmental systems input through the rate at which footsteps dissipate. This is controlled by the level of fluid pumped into the bi-chromatic floor structure. In reaction to positive environmental reading, more fluid is pumped into the tile, allowing for the footsteps to quickly dissipate, revealing a uniform floor color after a user has passed. When the environmental indication systems input data shows poor ecological performance, the amount of liquid in the bi-chromatic tiles is lessened, causing footprints to leave impressions for longer periods of time.

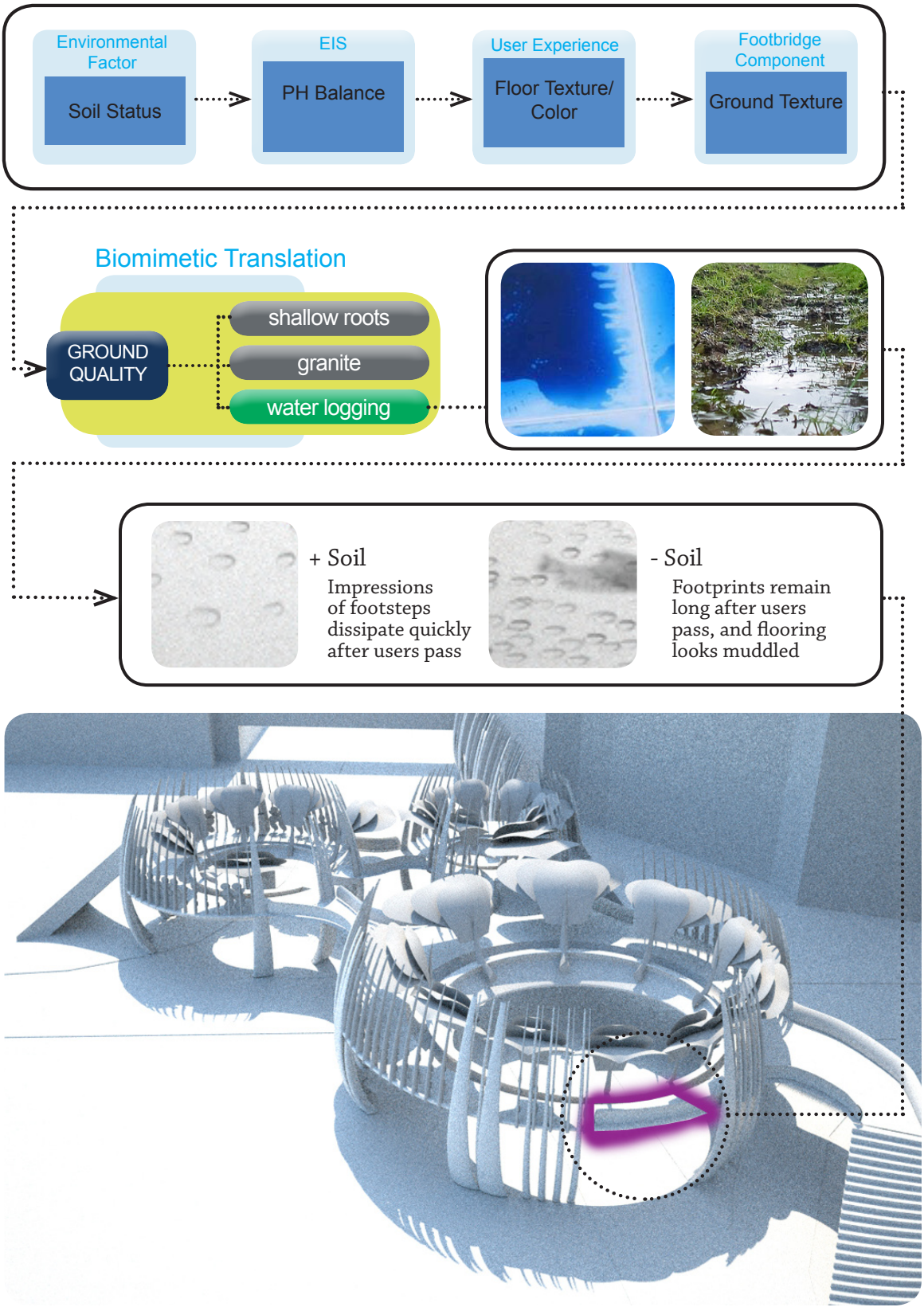


Figure 7.2.18: Perth flooring design process

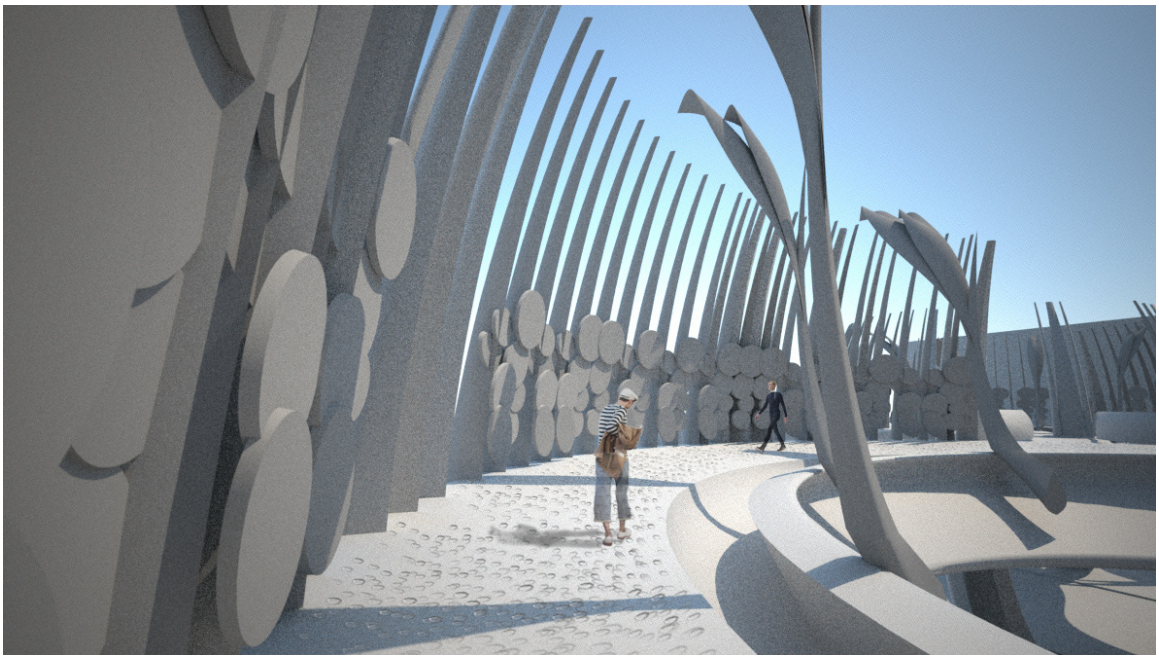


Figure 7.2.19 **- INPUT RESPONSE**

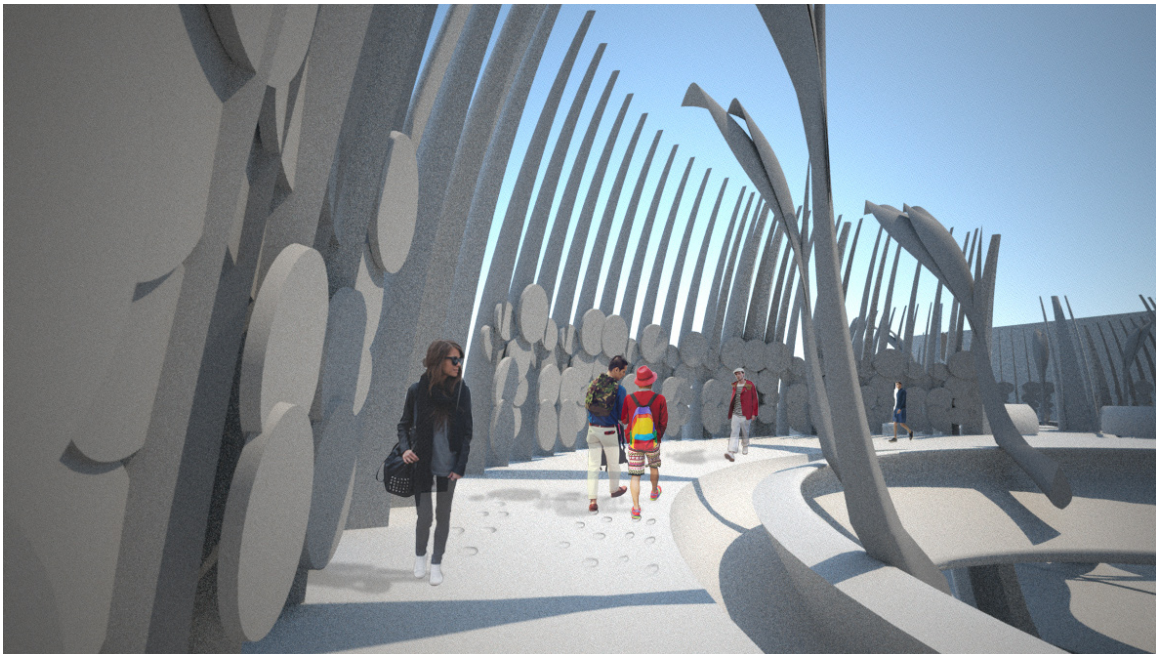


Figure 7.2.20 **+ INPUT RESPONSE**

PATHWAY CONSTRICTION/ECOLOGICAL EFFICIENCY RATES: FLOODING

Flooding occurs somewhat regularly due to high saturation levels of the soil, and can obstruct areas within the forest floor. This pathway constriction component is incorporated into the water feature, in that during a negative data result for the corresponding environmental indication systems data, the water feature will overflow onto the pedestrian pathway, constricting the width in which users can walk. The water feature drains back to a standard level when the efficiency rates are positive, allowing full width of the pathway to be used, accommodating the most people, which results in the fastest commute time with the least pedestrian congestion.

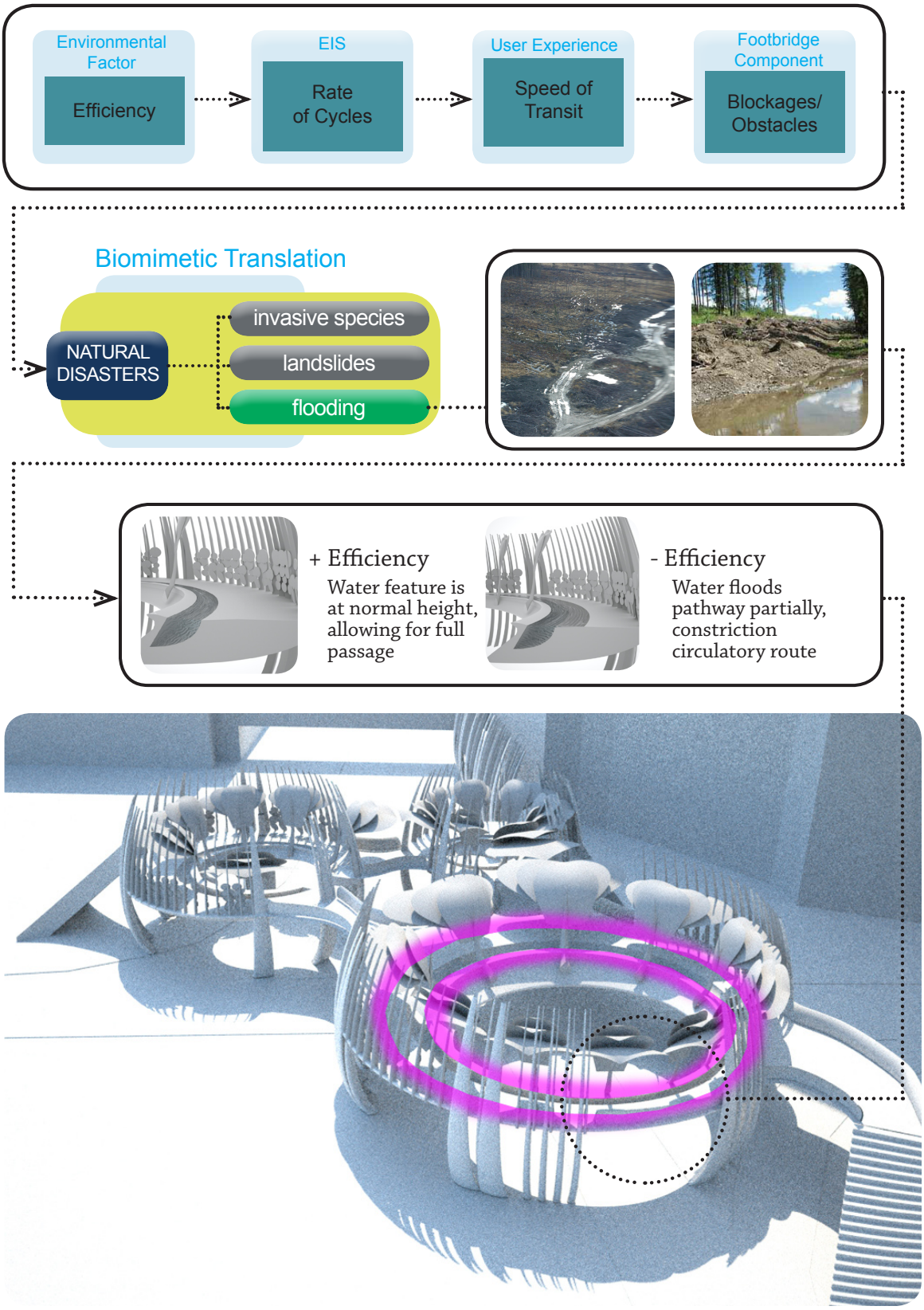


Figure 7.2.21: Perth pathway obstruction design process

Figure 7.2.22 **- INPUT RESPONSE**

Figure 7.2.23 **+ INPUT RESPONSE**

7.3 SUBARCTIC SITE: TORONTO, CANADA

Toronto is the capital of Ontario, and the largest city in Canada. It is a modern city that has expanded significantly over the past few decades, rising to be one of the top five largest cities in North America.[183] Toronto is the main business district and financial center of Canada, with more than 2.5 million residents, with a density of slightly more than half than that of Singapore. The ethnic demographic of the population shows that a little more than half of the inhabitants are of European descent, with the remaining percentage made up of primarily Chinese and South Asian.[184] The public transit system is known as the Toronto subway and RT (rapid transit), which employs both underground and elevated railways, as seen in Singapore. Roughly 950,000 people use the Toronto RT system daily, which consists of five lines, connecting outer city limits with the interior central business district.[185]

Figure 7.3.1

[183] "Toronto Overview," *Toronto*, accessed October 4, 2011, http://www.toronto.ca/invest-in-toronto/tor_overview.htm
[184] Laurent Martel, "2006 Censue: Portrait of the Canadian Population in 2006: Findings," *Statistics Canada*, accessed October 4, 2011, http://www12.statcan.ca/census-recensement/2006/as-sa/97-550/index-eng.cfm?CFID=13390&CFTOKEN=61631797#ggh
[185] Mathew Dickens, "Transit Ridership Report," *American Public Transportation Association*, accessed October 4, 2011 http://www.apta.com/resources/statistics/Documents/Ridership/2010_q1_ridership_APTA.pdf.

7.3.1 NATURAL CONTEXT: ALGONQUIN PROVINCIAL PARK

Biome Typology: Borreal Forest/Taiga

Nutrient Cycle

The efficiency rates of the nutrient cycle are seasonal, with a very short growing season of roughly 1-3 months in the summer. During the summer months, forest efficiency rates are high, with quick rates of nutrient processing. These efficiency rates are prompted by the increased temperature and higher exposure to sunlight.[186] Foliage decays rapidly and releases nutrients into the soils. Because of the seasonal aspect, the 1-3 summer months experienced by boreal forests have left the native species that exist well adapted to "storing." Both plants and animals stock up for the winter seasons, and while the nutrients are released quickly through the faster decomposition rates, they are also absorbed at a fast rate, and set to store for the winter, when the ground frost freezes available nutrients.[187]

Ecosystem Components:

Temperature: typically, the boreal forest sustains a temperature of -4 degrees Fahrenheit in the winter and up to 64 degrees in the summer.

Precipitation

The precipitation levels are low through the year, with roughly 20 inches a year, falling as rain in the summer months, and snow and fog for the remaining months.

Sunlight

The northern latitude of the Algonquin Provincial Park prevents high amounts of direct sunlight from penetrating the forest. However, the northern proximity also brings long summer days, up to 20 hours of sun exposure. The exposure is not strong, but it is lasting, and forces highly productive growing seasons within

[186] Canadian Boreal Initiative online, accessed October 27, 2011, State of Canada's Forests: 2004-2005, http://www.borealcanada.ca/boreal-did-you-know-e.php, 43.
[187] Canadian Boreal Initiative online, accessed October 27, 2011, State of Canada's Forests: 2004-2005, http://www.borealcanada.ca/boreal-did-you-know-e.php, 43.

the forest prepares for dormancy during the harsh winters.

Water or Moisture

Because of the high amounts of fog, precipitation levels are higher than evaporation levels, keeping moisture within the ecosystem. During the summer month, rainfall and warmer temperatures promote higher levels of decomposition, furthering the summer growth of the forest.

Soil Chemistry

The soils found in Northern Taiga biomes are generally very poor in quality. This can be attributed to the thinness caused by the cold, which acts as a major hindrance in the development of soils and decomposition of nutrients. Pine needles, being waxy in nature, decompose slowly, similar to the manner in which eucalypts decompose, however, they add to a higher level of soil acidification, preventing the adequate soil quality to promote higher levels of variation in plant species.[188] Referred to as spodsols, this soil type undergoes deep podzolization, strongly leached soil with high iron content, with parent materials of this soil found to be rich in sand.[189]

Biodiversity

Levels of biodiversity are lower than what is found in the tropical rainforests and chaparral eucalypt forests of the previous site. The forests are dominated by coniferous species which can withstand the harsh cold winters. Having very harsh climate conditions, the range of species which inhabit this biome is less varied, and the number of ecological niches that can be fulfilled by different species is lower.[190] This leads to the boreal forest housing only a handful of specialized plants and animals that can exist in this climate.

Flora

[188] A.P. Sayre, *Taiga*, (New York: Twenty-First Century Books, 1994) 16.
[189] Michael Pidwirny, "Soil Classification," *Fundamentals of Physical Geography*, accessed October 3, 2011 http://www.physicalgeography.net/fundamentals/10v.html.
[190] A.P. Sayre, *Taiga*, (New York: Twenty-First Century Books, 1994) 16.

The major plant groups found in this region are the coniferous tree species, a few deciduous trees, and a wide range of moss and lichen species, which provide a large percentage of food for the wildlife. Plant species in this biome tend to have darker leaves or needles, allowing further heat retention, and the ability to photosynthesize sooner during the long winter nights.[191]

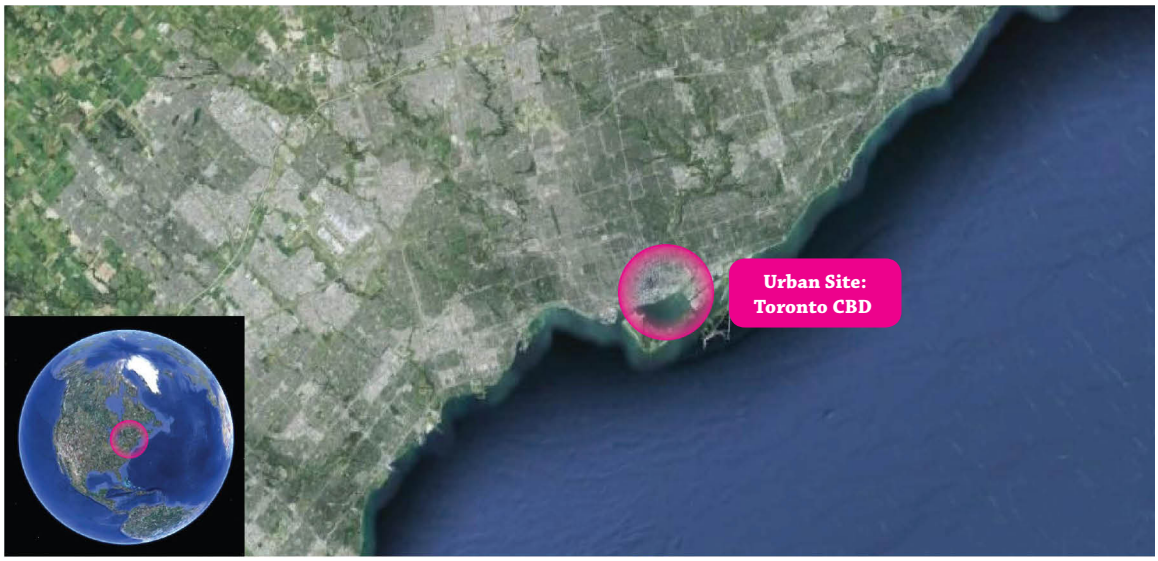
Fauna

There are high amounts of large hoofed animals living in boreal forests, such as deer, elk, and moose, along with large predators, such as the grizzly bear, black bear, and wolverine. There are many species of insects, which play a large role as detrivores, carrying out decomposition that would otherwise not occur in the cold environment. There are also many species of rodents and birds, which prey upon the close to 32,000 insect species.[192]

Current Environmental Status

The boreal forests are large producers of raw materials, mainly timber, and therefore, are often deforested at rates which severely decrease biodiversity, and release large amounts of carbon into the atmosphere. Like tropical rainforests, boreal forests do not have the wide variety of nutrients needed to support farming efforts, and deforestation for agricultural land has been widely in vain. Much of the forests soils have been contaminated from oil and gas exploration, which has damaged the ecosystem at every trophic level. Currently, awareness for the forest degradation is growing, and the boreal environmental status, efficiency rates, and biodiversity levels are slowly recovering.[193]

[191] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed*. (San Fransisco: Benjamin Cummings, 2011), 22.
[192] Richard T. Wright, and Dorothy Boorse. *Environmental science: toward a sustainable future. 11th ed*. (San Fransisco: Benjamin Cummings, 2011), 22.
[193] "Protecting Canada's Borreal Forests," *Environnement Canada*, accessed October 3, 2011, http://www.ec.gc.ca/scitech/default.asp?lang=En&n=4B40916E-1&xsl=privateArticles2,viewfull&po=3AB28EB3



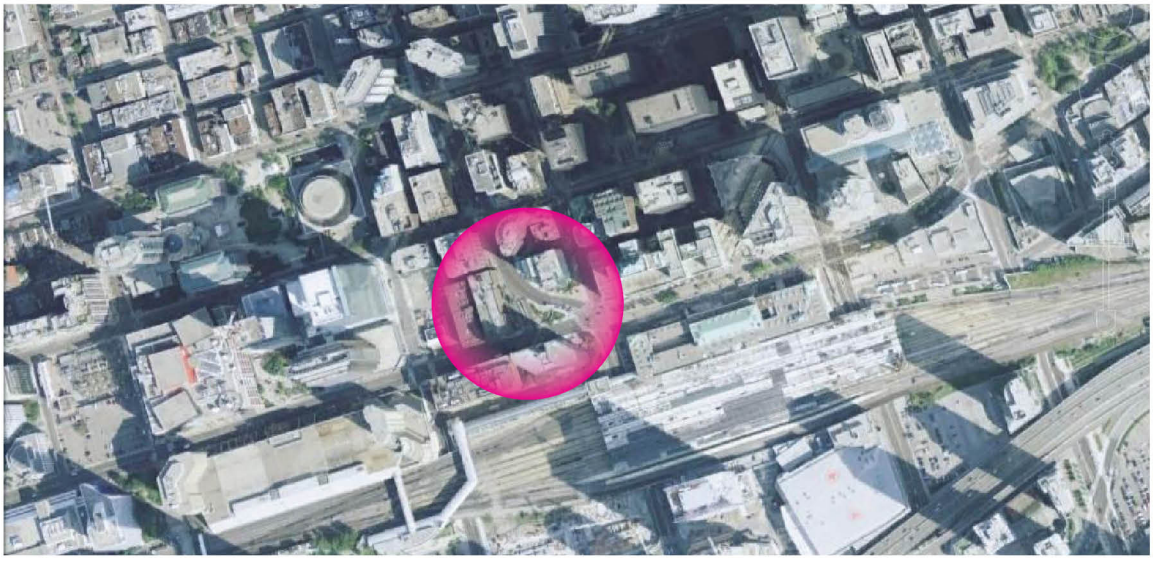


Figure 7.3.2 URBAN CONTEXT LOCATION MAP

7.3.2 URBAN CONTEXT: UNION STATION

Specific Site Information: Union Station is the primary transport hub for all intercity transit in the city of Toronto. It sits on the Yonge-University-Spadina line, which runs north-south, and intersects all other major lines. Union Station is at one of the busiest points in the city, and traversing various intersections to walk to the central business district is often dangerous and time consuming, with Front Street W, the road on which the station sits, as having the most traffic accidents in Toronto.194 Pedestrian and vehicular traffic is amalgamated into fused intersections, making it difficult to navigate during rush hour, with pedestrians having to cross up to five intersections to reach certain areas of the central business district.

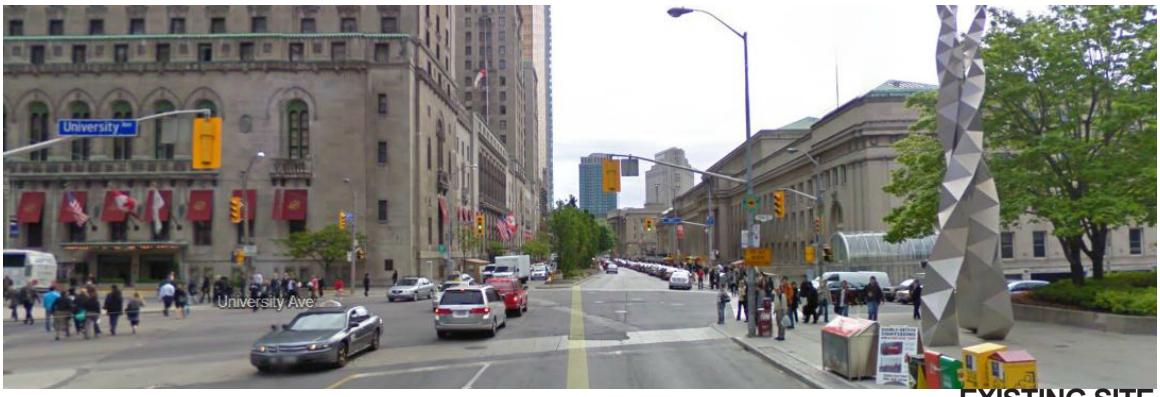


Figure 7.3.3 **EXISTING SITE**

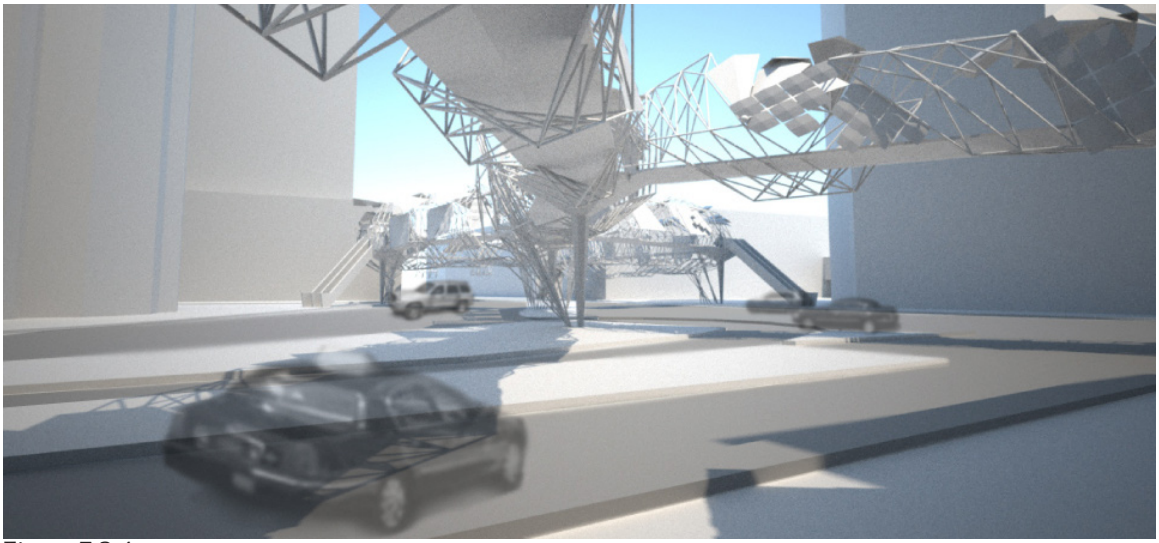


Figure 7.3.4 **SITE WITH OVERPASS**

[194] "Monroe, Michigan Top 10 Auto Accident Locations," accessed October 4, 2011, http://www.michiganautolaw.com/auto-lawyers-blog/2011/09/23/t10-monroe-high-crash-intersections/

7.3.3 DESIGN SOLUTION

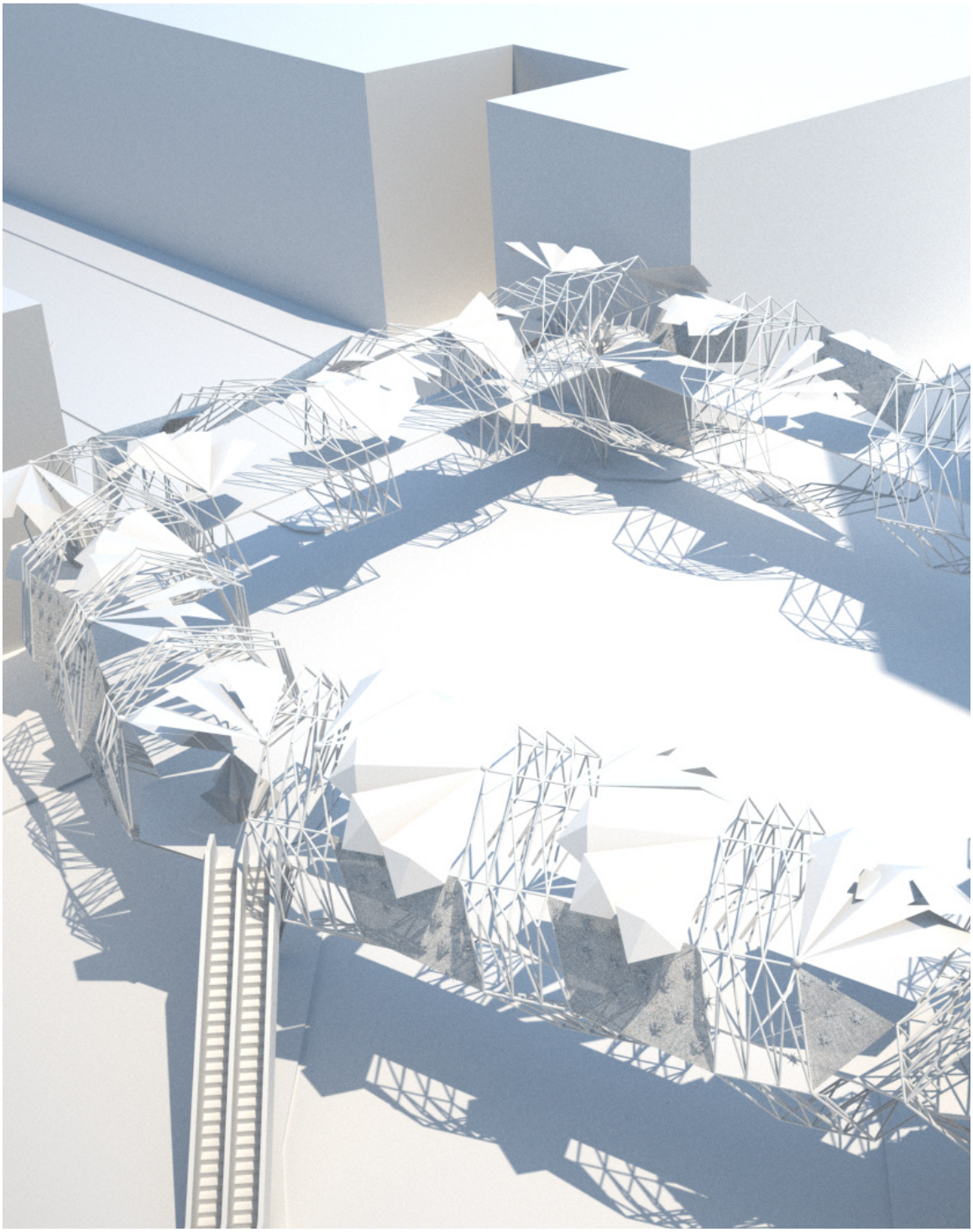


Figure 7.3.5

SOUTHWESTERN AERIAL VIEW

STRUCTURAL BASIS: RED PINE

The Red Pine occupies an area centralized around Toronto, and prefers environments with dry soils and high sun exposure. Red Pine grow tall and straight, with needle growth starting higher on the tree, older trees adopt a dome-topped profile, due to the tree's ability to self prune dead branches that are no longer efficient. This leaves the appearance of the tree very clean, with a bark color gradient from light grey at the base of the trunk, to red towards the middle and top. There is very low genetic variation throughout the entire species, which would suggest that in its recent history, the population was brought to near extinction. This has resulted in constant morphological identity across the species, leaving a very uniform forest aesthetic. [195]

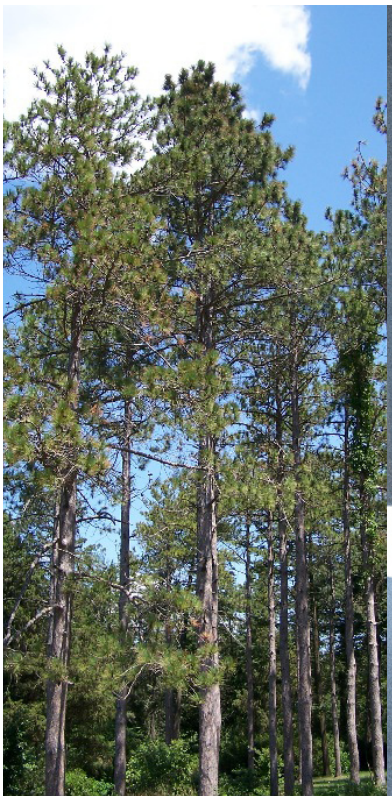


Figure 7.3.7

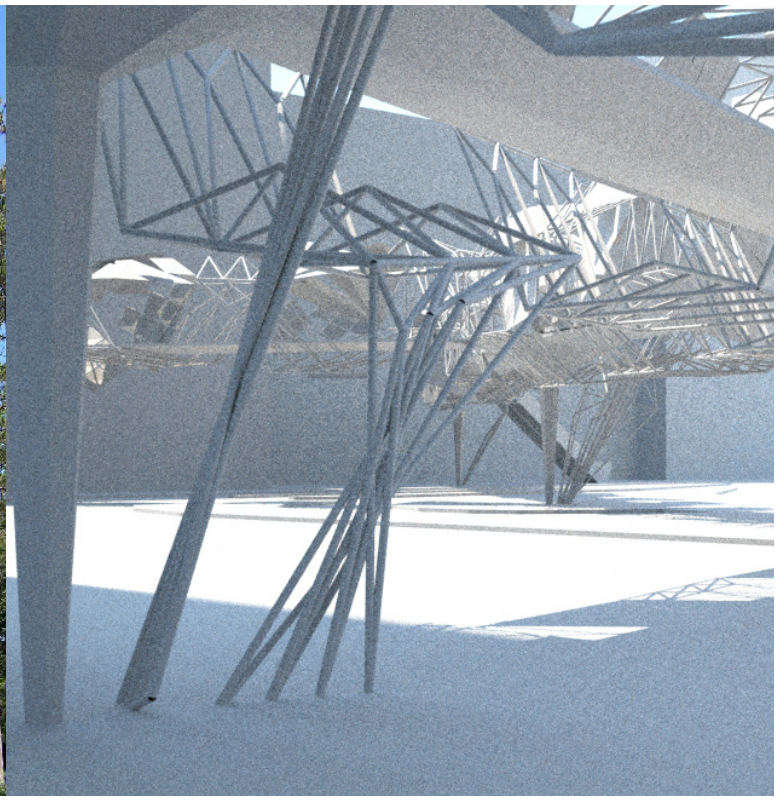


Figure 7.3.8

[195] Fowler, D. P.; Morris, R. W. (1977), "Genetic diversity in Red Pine: evidence for low genic heterozygosity," Canadian Journal of Forest Research 7(2): 343–347. doi:10.1139/x77-043

CLADDING PANELS/AIR QUALITY: PINE NEEDLE GROWTH

Pine needles grow in a radial manner, developing in a twisting pattern around a central stem, and are bundled in clusters, or fascicles of up to six needles per fascicle. Needles are modified leaves, and while they perform photosynthesis in cold harsh conditions, they are very brittle, and snap in half easily. They are a darker shade of green, to absorb higher amounts of heat, allowing for a higher efficiency rate of photosynthesis.[196] The radial manner in which the pine needles unfurl is the element translated over to the cladding system employed in the overpass.

The cladding system will be assembled as a wall of tubes, each of which have a central stem that is held in the center point of the tube with cross structural members. This stem has a thick line of needle-like fibers attached to it, running in a straight line. The cladding system will communicate changes in environmental systems indication data by the torquing, which spreads the lined bristles and causes them to block out both light and natural ventilation. Positive data input will provoke a relaxing of the tension in the torque system, that will in turn re-align all the bristles in the shading device, allowing air and light through.

[196] D. M. Richardson, (ed.) *Ecology and Biogeography of Pinus*. (Cambridge: Cambridge University Press, 1998), 530

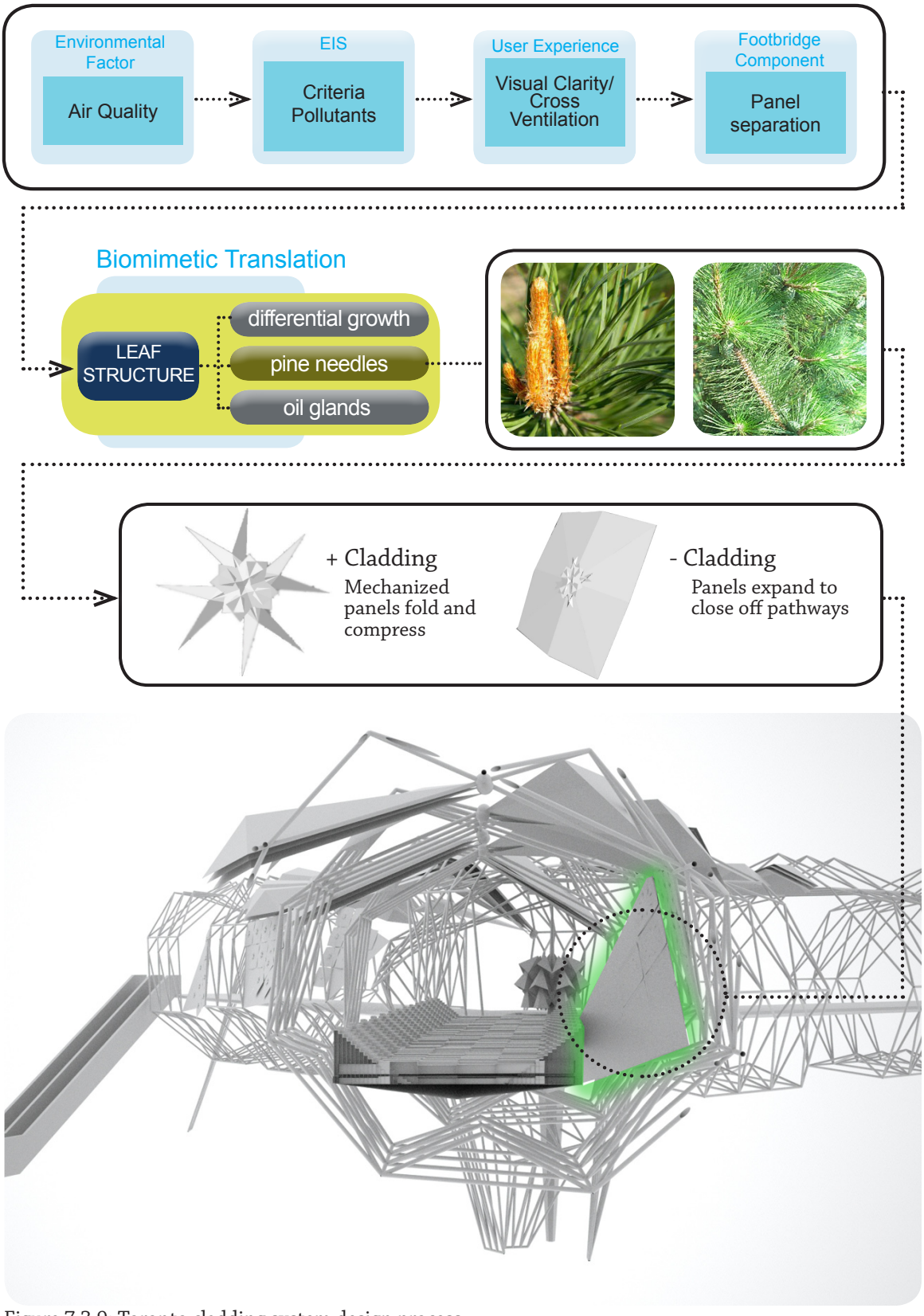


Figure 7.3.9: Toronto cladding system design process

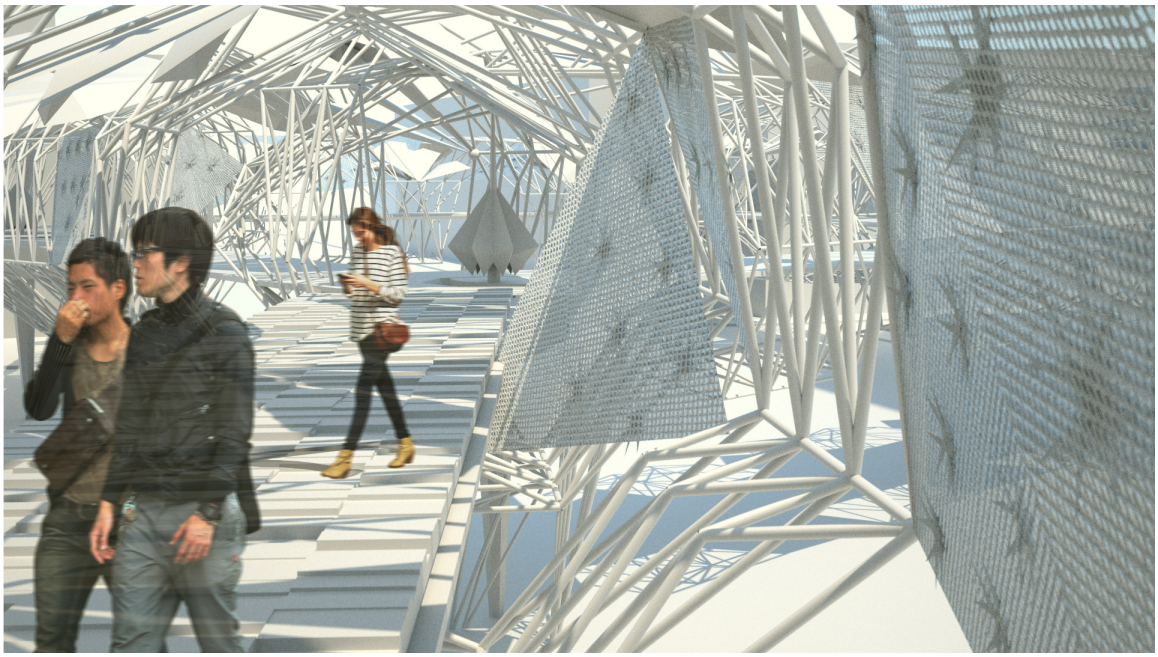


Figure 7.3.10 **+ INPUT RESPONSE**

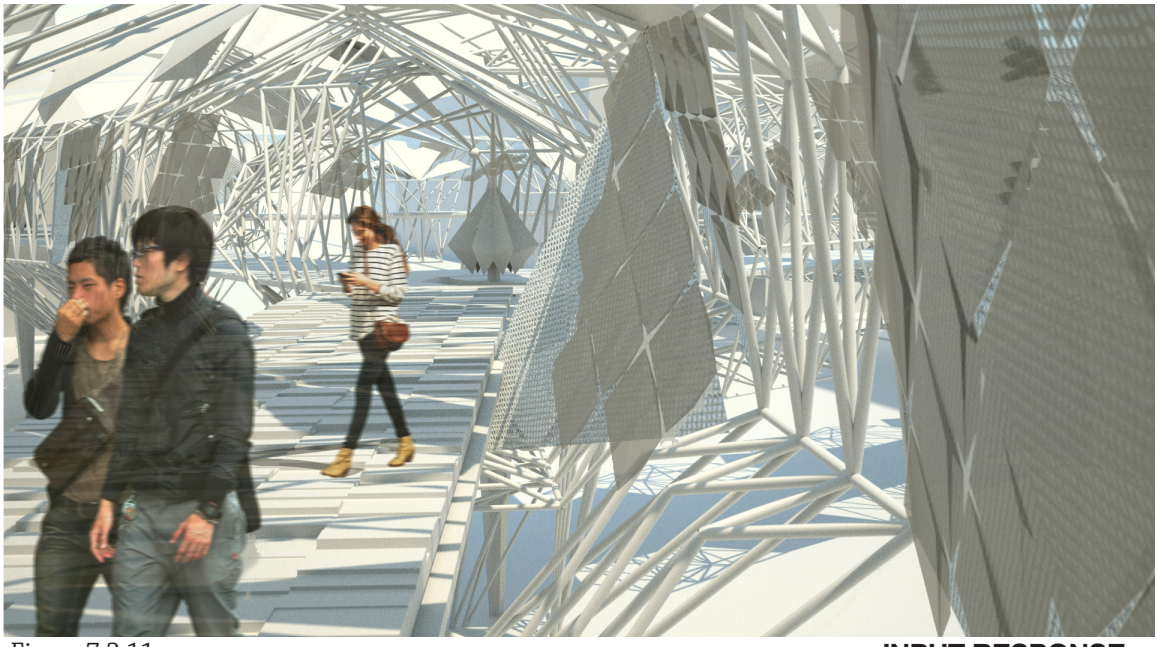


Figure 7.3.11 **- INPUT RESPONSE**

WATER FEATURE/WATER QUALITY: PINE CONE MOVEMENT

Pine cones come in both the male and female sex, each of which have evolved to perform specific tasks. While the female pine cone is responsible for only the receiving of pollen, it is the male pine cone that is responsible for the dispersal. Germination occurs most favorably when the weather is warm and dry, instead of cold and wet, and male pine cones will react to changes in temperature and moisture level, to ensure the best reproductive rate. Even after the male pine cone has fallen from a tree, it can still open and close because its exterior material is highly sensitive to water, and swells the scales shut when exposed to moisture. When the climate is dry, the outer scales contract, and pull outwards, once again revealing the interior pollen.[197] This sensitivity and reaction to water is carried over to the water feature within the overpass, which communicates the current water quality of the immediate surrounding natural environment.

The water features occur at every structural member, and consist of three sets of three fins, organized in a radial fashion, tiered, with the largest set of fins at the base of the water feature. Water is constantly shot up to the fins, which direct the flow of water into a small basin at the floor level, where water quality can be assessed by users. The angle of incidence from which the fins are swiveling from the central structural member is responsive to the environmental systems data. Positive environmental indication systems data will prompt a larger angle of incidence at which the fins are configured. This allows water to flow farther away from the center, and fill the basin. Negative data readings will cause the fins to contract, with a very low angle of incidence to the central member, directing water back down to a drain system formed around the column base. This leaves the water basis very shallow or empty.

[197] D. M. Richardson, (ed.) *Ecology and Biogeography of Pinus*. (Cambridge: Cambridge University Press, 1998), 530

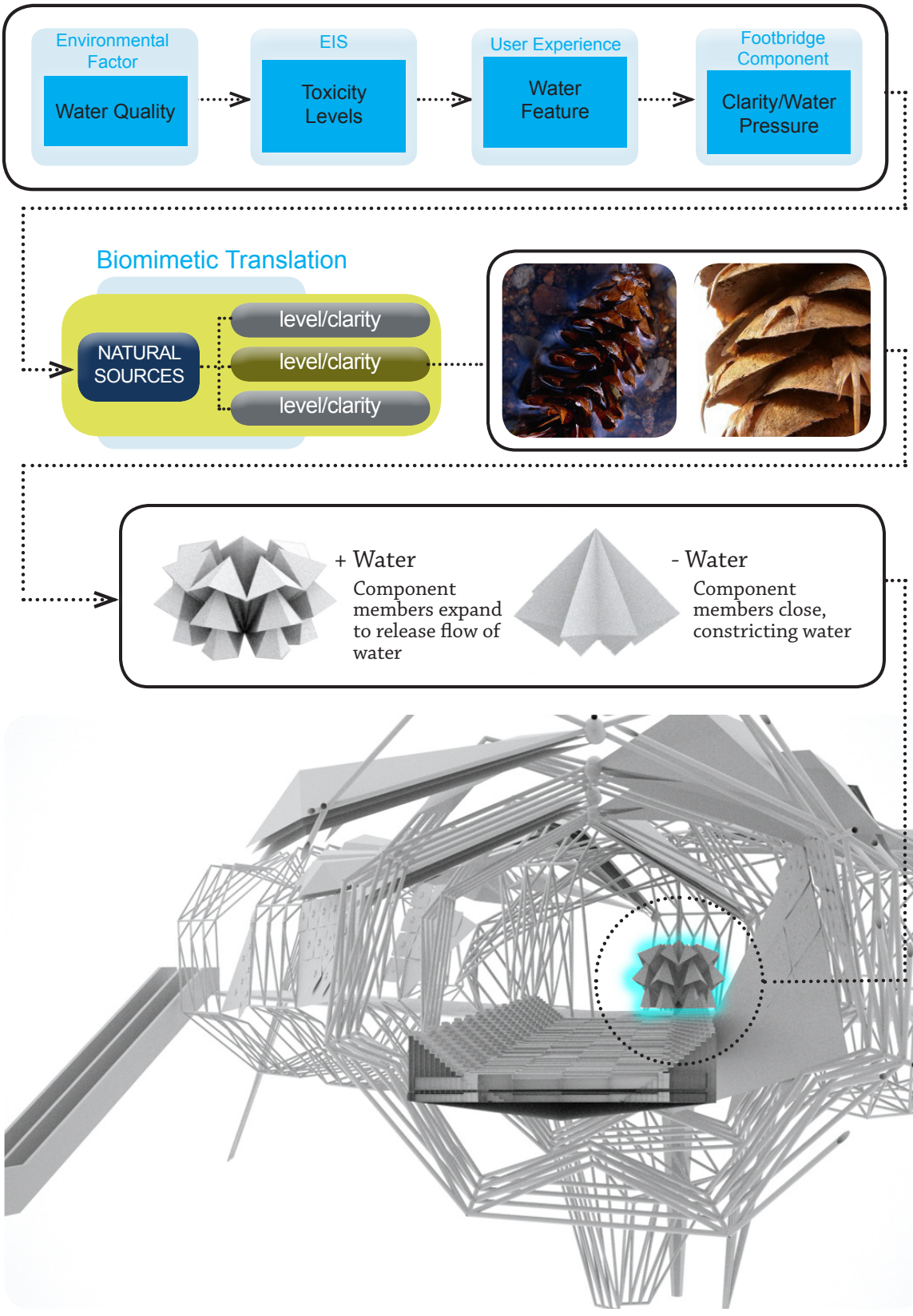


Figure 7.3.12: Toronto water feature design process

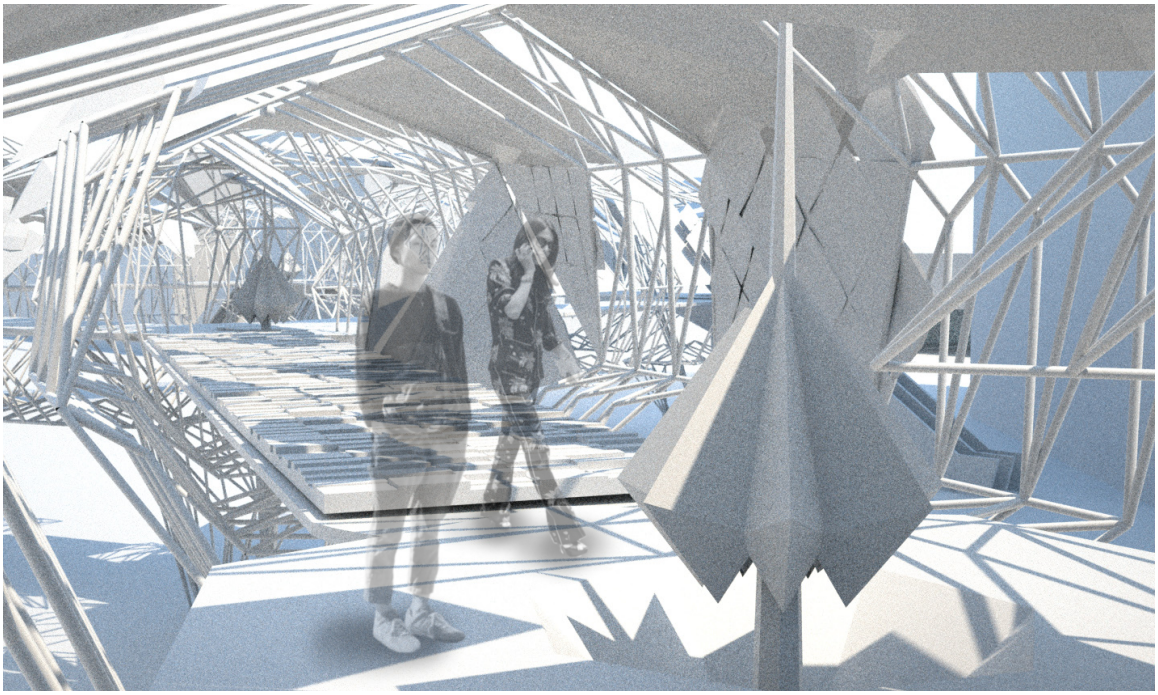


Figure 7.3.13 **- INPUT RESPONSE**

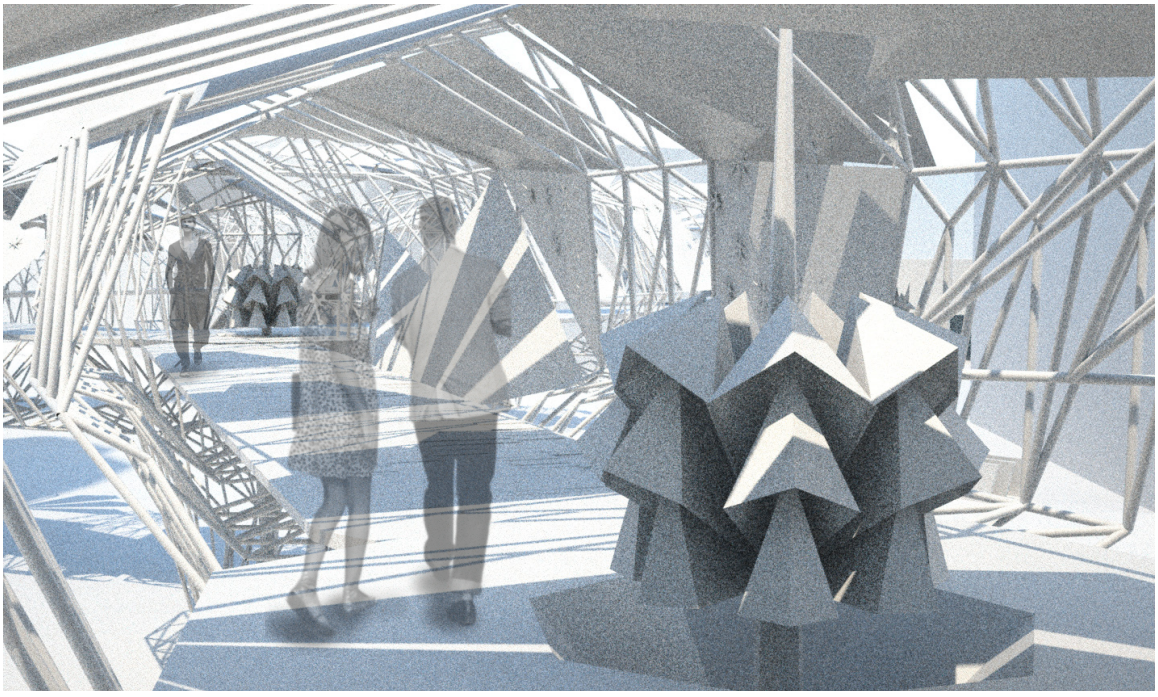


Figure 7.3.14 **+ INPUT RESPONSE**

SHADING DEVICE/CLIMATE: PINE CONE GROWTH PATTERNS

Pine cones have a spiral arrangement of overlapping scales, similar in growth formation to the pine needles which orbit their specific branches. The radial patterning of the pine cone scales creates implied diagonal lines revealing their growth pattern.[198] The shading device is a series of three blades that fan out in the same radial pattern seen in the pine cones. Nesting underneath one another, the blades can extend to occupy a ninety degree angled surface, sufficiently covering the pathway. The blades expand and contract, nesting and un-nesting in response to positive and negative environmental systems indication data. The shading system contracts in reaction to negative data, exposing users to sun, and precipitation. When climatic conditions improve, the shading device will open to specific degrees that correspond with different levels of health.

[198] Colin Dawson; Vincent, Julian F. V., Rocca, Anne-Marie, "How pine cones open." *Nature 390, 1997*, 668.

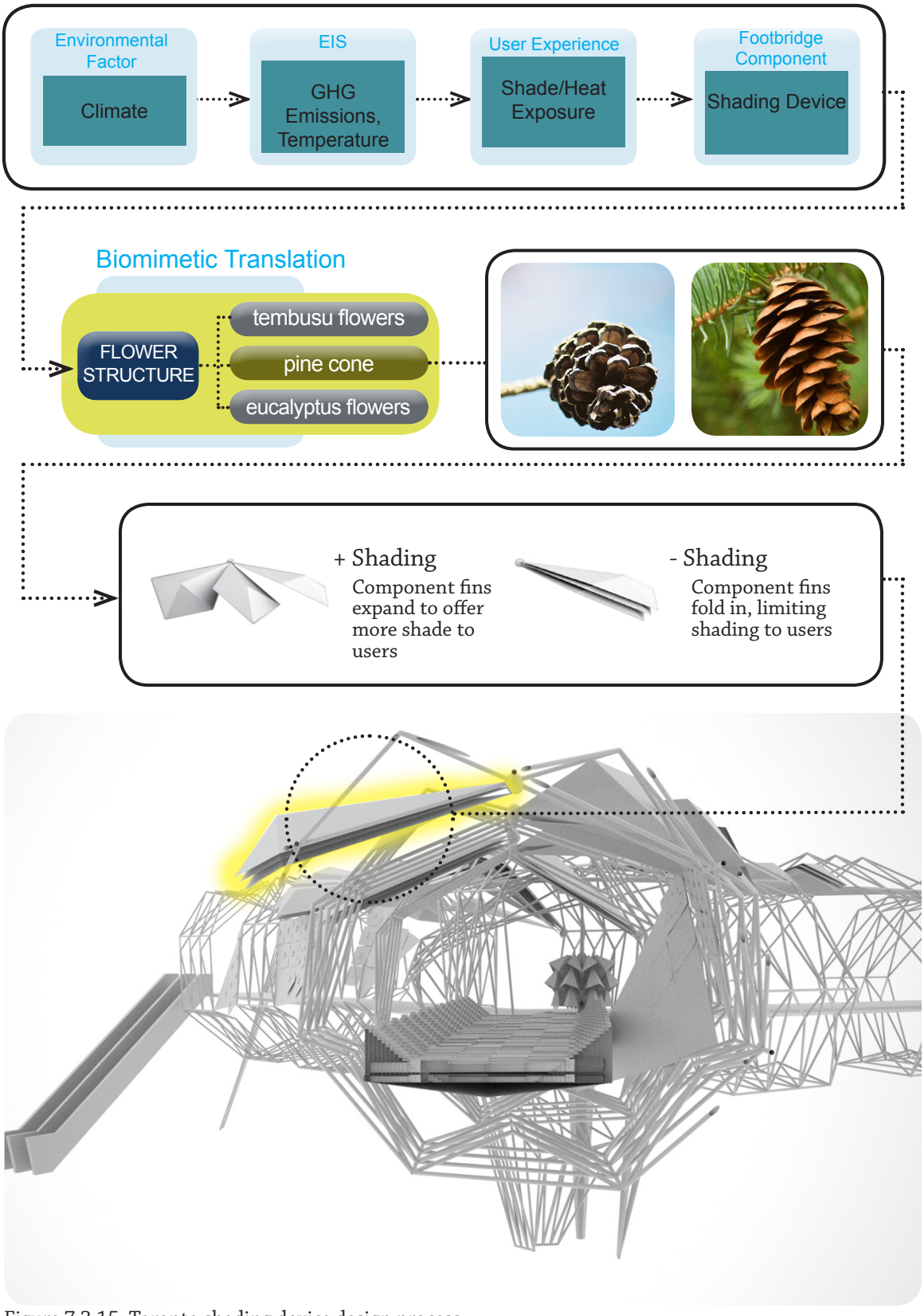


Figure 7.3.15: Toronto shading device design process

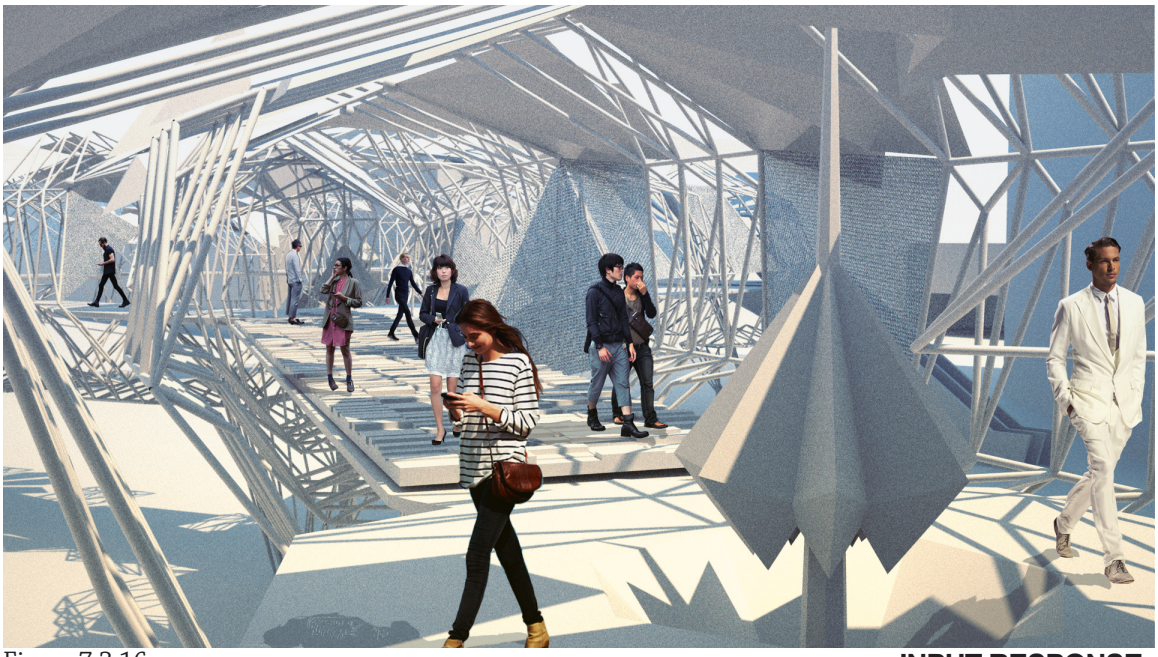


Figure 7.3.16

+ INPUT RESPONSE

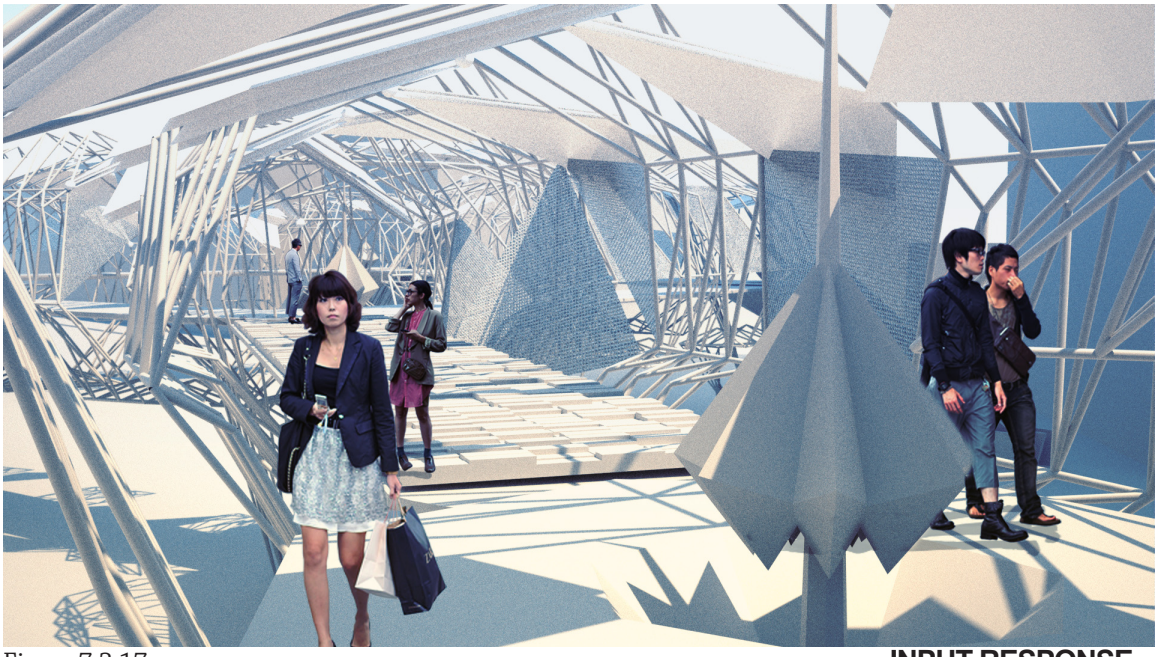


Figure 7.3.17

- INPUT RESPONSE

GROUND COMPONENT/SOIL STATUS: SPODSOL TEXTURE

Boreal Spodsols are formed by cold climates, and the highly acidic conifer litter shed from the dominant coniferous tree species that inhabit the area. The spodsol profile has a sandy-textured underlying layer, which is over laid by a layer of ash, giving it a distinct two-toned characteristic. The unique texture of the soil is translated into the overpass as a ground plane that changes textures depending on the data set read from the environmental indication systems. The floor is fractured and split into floor plates, each of which has a separate mechanism which changes the elevation of the plate off the floor base. When positive environmental indication systems data is recorded, the floor plates will remain at zero elevation, and will not differ from one another in terms of perceived thickness. When negative data is recorded, the mechanical systems will raise the floor plates to varying heights, causing the floor to fragment, much like randomized stairs. The heights will not vary more than an half an inch, but will be enough to where users can feel the height change of the floor plates underfoot.

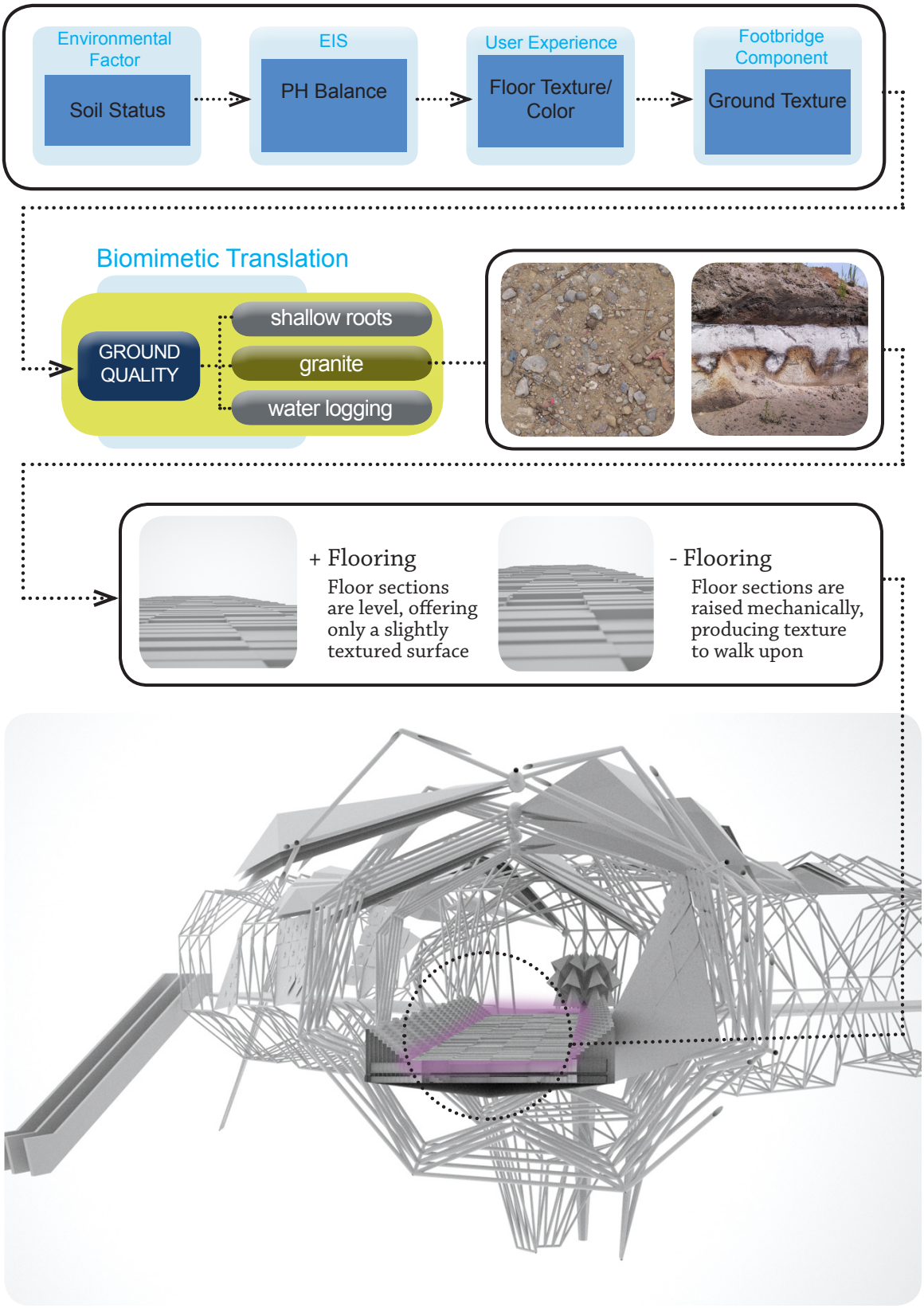


Figure 7.3.18: Toronto ground texture design process

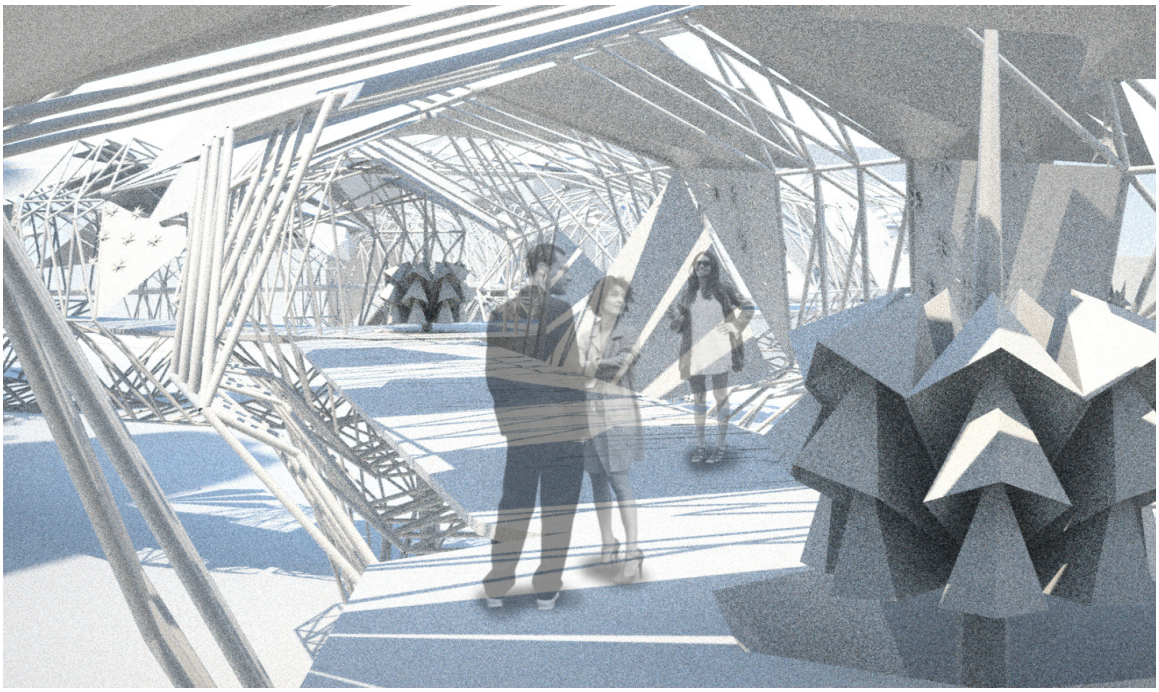


Figure 7.3.19

+ INPUT RESPONSE

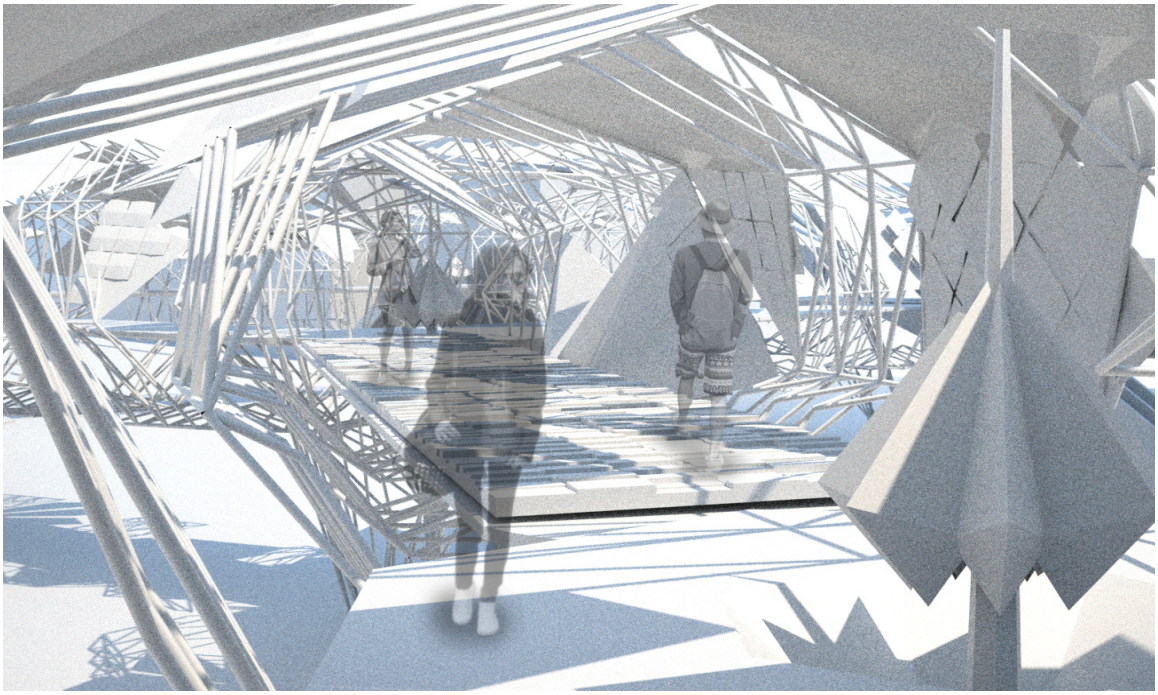


Figure 7.3.20

- INPUT RESPONSE

PATHWAY CONSTRICTION/ECOLOGICAL EFFICIENCY RATES: EROSION

Soil erosion is problem in the boreal forests of Toronto, caused by a multitude of different reasons, including invasive species, deforestation, human mistreatment, and flooding. Erosion of the soil is vastly detrimental to the overall well being of the ecosystem, in that nutrients are lost, and rivers and ponds become subject to possible eutrophication. Erosion leads to an imbalance in ecosystem features, which greatly lowers efficiency rates. In the overpass, the pathway constriction will function in a manner similar to the changing floor plates that communicated different levels of soil quality, that floor plates will be elevated in response to negative data. The floor plates towards the edge of the pathway will have a smaller surface area, and will rise to a height of three feet, shrinking the width of the pathway, and causing people to walk in a condensed manner at a slower pace. Similarly, in response to positive data from applicable environmental indication systems, the floor plates will retract, with zero elevation, leaving the walkway open for pedestrians.

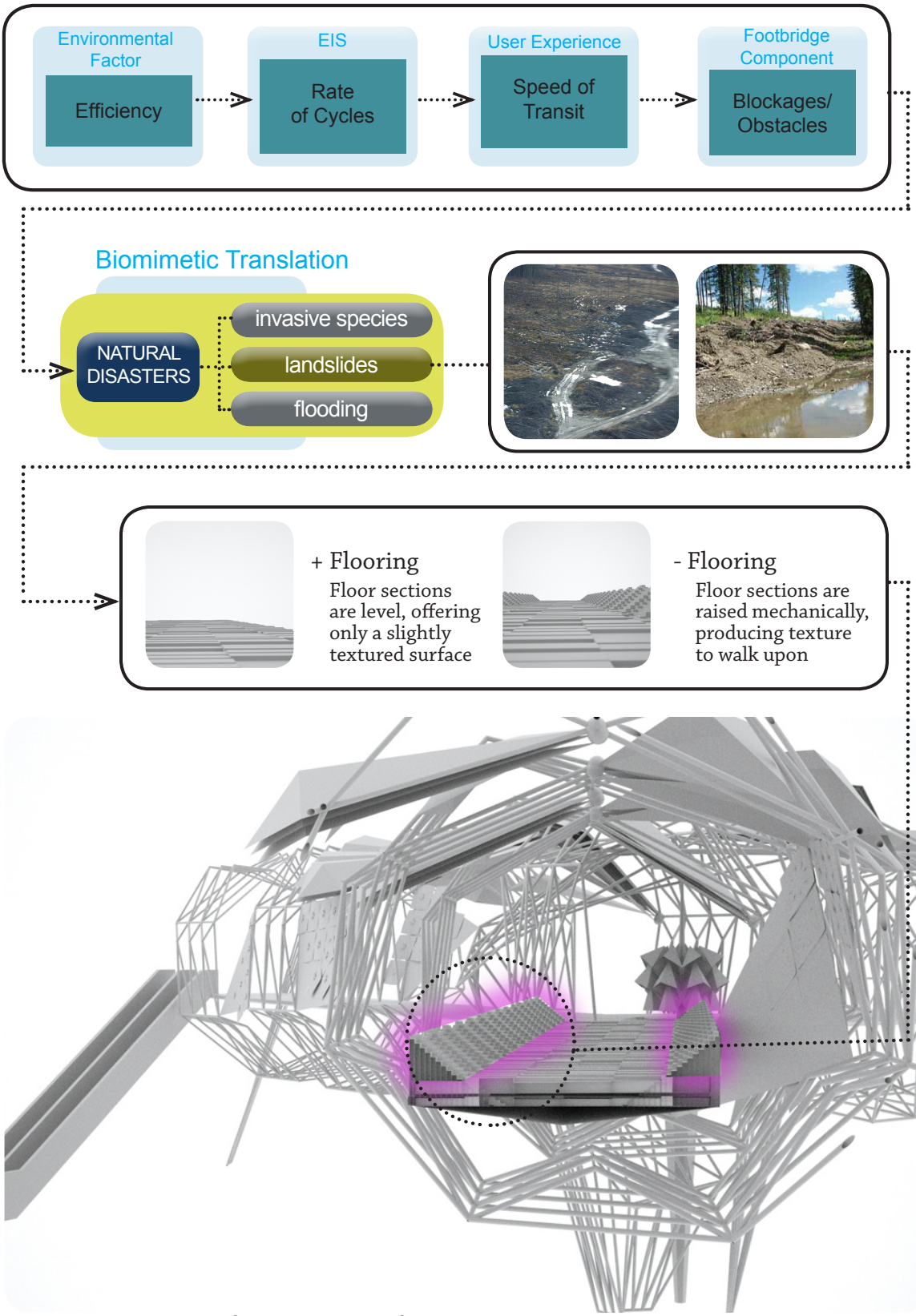


Figure 7.3.21: Toronto pathway constriction design process

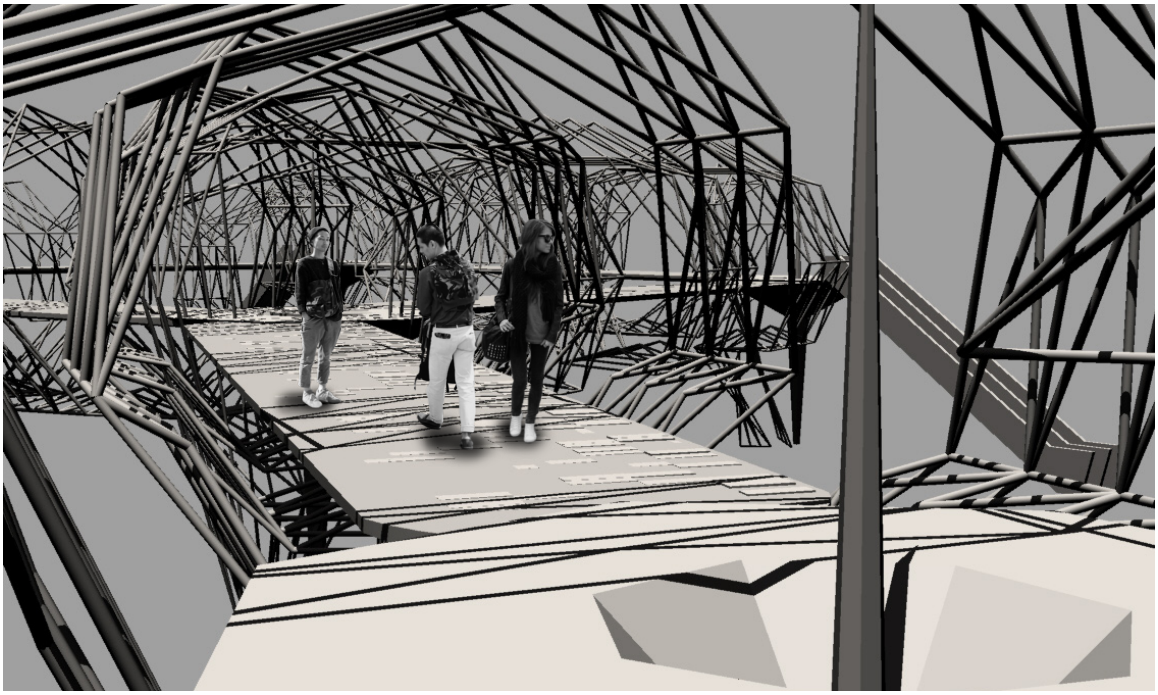


Figure 7.3.22 **+ INPUT RESPONSE**

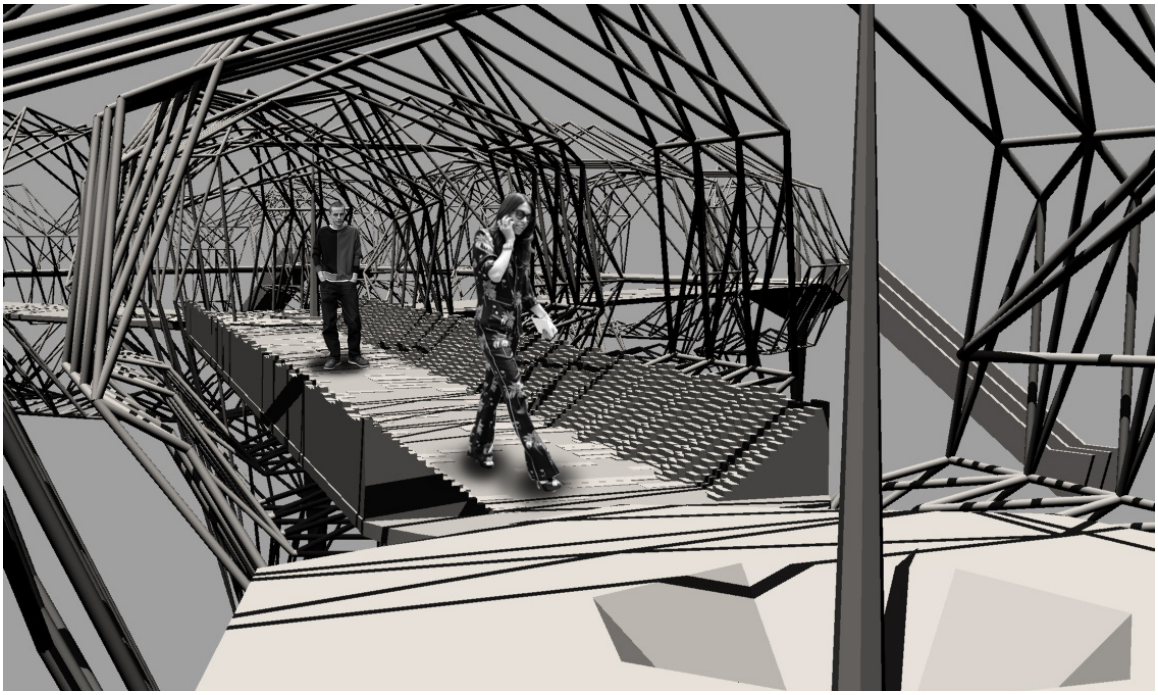


Figure 7.3.23 **- INPUT RESPONSE**

VIII. ANALYSIS

This chapter summarizes the outcomes of the design methodology, and analyzes the effectiveness of each overpass component in communicating environmental status. While effective communication of climatic status, air quality, water quality, soil degradation, and ecological efficiency will be considered, the design language employed will also be analyzed in terms of ability to translate a particular ecological identity. Both these qualities were sought after in terms of bringing the three overpasses to design fruition. The design intent was to create a functioning urban insertion that would inform the users of both the health and identity of their natural surroundings. While the health status of these natural surroundings will vary from day to day usage, the identity of the natural surroundings will be more ingrained, in a way re-establishing a new methodology with which to define a "sense of place."

The design for each of the three overpasses aspires to reconnect the urban inhabitant with his immediate natural surrounding environment by instilling an understanding of dependency within the user, and change their perspective to that of concern and curiosity. As the user approaches on a daily basis, he will anticipate the information he is about to receive, through experiencing the spatial quality of the overpass. The relationship with the overpass will be cyclical and responsive, in which individual users will act accordingly in response to their daily experiences, which will reflect the status of environmental elements in which they are directly dependent. This is expected to prompt the individual to change his daily activities in response to the space he experienced on his normal route to work. This proposed method of reconnection through space, has been carried out in the design phase in two dimensions of aesthetic, within each of the overpasses. The first dimension is the overall spatial language used in the overpass, which aims at visually relating the overpass to the natural environment, through nature-derived structural forms. The second dimension of aesthetic deals with the five overpass components, and the differences in quality of space between their responses to positive and negative environmental status inputs. The following comparisons first analyze the spatial reactions of the respective components within each of the three overpass sites, in terms of the extent to which space is manipulated, and the impact it places on the user.

Air Quality/Cladding Porosity Alteration

The Singapore Fragrea fragrans leaf differential growth is an expression of differential growth rates which result in cladding system members that change from wide to thin, in terms of coverage. This changes the porosity of the cladding system in a vertical linear fashion, and impacts the user at all heights. The pattern generated with the different responses of the component is however, very regular and can become repetitive in nature when users pass it. While the impact is high from the full height difference in scale, the regularity in patterning could perhaps nullify this affect through redundancy. In the Toronto site, the Pinus resinosa needle growth-based cladding system differs in that the porosity created through randomized scaling of each system structure. The system members are made of stacked tubes within which the spreading needle devices are housed. These are effective at all scales, and when randomized create and undulating texture for users to walk alongside. This texture allows for less of an aesthetic redundancy, and is perhaps more visually attractive while walking alongside it for the length of the overpass. The last cladding system, based off of the Eucalyptus marginata's schizogenous oil gland formation, which illustrates an expansion through tension visual through employing auxetic nanotechnologies. This component is both visually varied, as well as dramatic in terms of positive and negative reaction to input data. The technology employed also has the ability to appear most biological in growth, in that the auxetic materials expand purely through form, opposed to mechanical means. Overall, the most effective means of communication through a cladding system is through the employment of both a randomized surface texture, and a method of changing that relies on a less mechanically derived movement.

Climate/Shading Canopy Coverage Alteration

The shading devices in each of the overpass urban interventions were based upon the flower movement found in the main species of each perspective site. For the Singapore location, the shading device was based off of the Fragrea fragrans flower. The components reaction to both positive and negative data correlates to the opening and closing of this five petalled flower, and the manner in which the petals unfurl. The resulting shading device has components at different scales, all working together to shade the users. Similarly to the cladding system in the Toronto site, the randomization of the component members offers an experience with more variation and excitement opposed to repetitious component members all of the same size and function. What could possibly add another dimension of excitement to the shading device could perhaps be a

correspondence between different sections of the shading structure, to different areas within the bukit timah nature reserve. Each could communicate the status of a specific region within the reserve and would somewhat vary from one another in terms of the shading they would provide. In the same way that the Singapore overpass shading devices are based off of the Fragrea fragrans flower, the shading system in the Perth site is based off of the Eucalyptus marginata flower, which blooms multiple stamens opposed to petals, in a similar motion. These shading devices each have a separate holding mechanism which binds them to the structural system, allowing the scale of each shading system to differ, in the same distribution patterning seen in the Singapore site. The randomization of shading structure scale and distribution allows for a lessening in repetitive experience as the user encounters the shading surfaces.

Soil Quality/Floor Texture Prominence Alteration

Based off of different ground quality conditions, the manner in which soil quality is communicated was intended to be experienced in a tactile manner through the surface upon which the user walks. For each of the sites, the different responses to environmental information correlate to the level of texture user's experience. The flooring system in the Singapore overpass site simulates walking across the exposed root systems found in tropical rainforests. Underfoot, the translated root system feels like walking over a grated surface with raised lines running parallel to the direction in which the users walk. This texture fades and becomes more prominent in response to positive and negative environmental information. Comparatively, the floor texture in the Toronto overpass is based off of the granite content within the soil, providing grainy areas. This was expressed through the varied prominence of what would feel like cobblestone underfoot.

The cobblestone floor texture differs in feeling, as well as variation. While the root based lines provide strong texture it is consistent, with little variation. This could perhaps cause the experience of walking along the surface for up to five minutes bothersome, and perhaps can be lessened to only key areas; major nodes within the overpass for example showing potential. The Perth overpass site plays off of the soil leeching that occurs in clay ridden soils. Unlike feeling bumpy texture underfoot, the Perth soil communication component exhibits a sponge like texture. While the texture varies slightly from positive and negative data input, the visual effect of the footprints left behind are also more prominent than the change in texture seen in the other two sites. As the textures are constantly repeating, they may perhaps, require the full attention

of the user in navigation, which could possibly compete with the other components. Perhaps distinct sections of each overpass can be dedicated to the experiencing of one communicating component so that the user can focus on one piece of information at a time. Competition for the user's attention could have adverse affects and dissipate the impact of the spatial experience.

Water Quality/Water Pressure Alteration

The water quality aspect of the overpass deals strictly with an aesthetic mode of communication, and relies on user's observance and close proximity to display data rather than through an entirely spatial sense. The water features were not based off of a specific plant species but instead occurrences of water within each respective natural environment. In Singapore, the water features are based off of the water caught between buttress roots on the forest floor of the tropical rainforest, and the Toronto water feature is based off of the pine cones reaction to water subjugation. The Perth water feature is connected to the efficiency communicating component, and is lacking a solid ecological basis like the others. The water feature aspect was perhaps the most unsuccessfully translated in terms of finding parallel ecological elements with which to base the components. The buttress roots capturing water, pine cone reaction, and ponding that occurs in Perth are not as coherently developed as the other components expressing environmental status for air or soil quality.

Much of the water quality components also fail to form space in which users encounter, and rely more heavily on exposure. This could potentially prove faulty in the same manner that mere exposure of natural installments in urban environments has failed to reconnect people with their natural environments. While the components are still communicating information, they still may have more impact on the human perspective than a few square feet of domesticated wildlife, but will not affect users on the same level as truly spatial components are capable of. To improve the communicative nature of the water feature element in expressing ecological information on water quality, two improvements can be made. Firstly, to find a natural element which provide a parallel base for all three water features. The natural element would most likely deal with some type of water-based process, but will provide the ability for users to understand the parallel design of the components across all three overpasses. The second improvement can be made to further the way in which users encounter the component. Design methods could be implemented which could ensure that the water features were design in a more spatial manner, so that users would have access through the component rather than around it.

Efficiency/Circulation Path Constriction

The last set of components is perhaps the most effective in communicating through space, as it changes the boundaries of the circulation paths. All three of the efficiency components compress the flow of pedestrian traffic and physically impede users. They achieve this in different methods all of which are based off of ecological hindrances found in each of the natural environments. The Singapore efficiency component is based off of an invasive species of climbing weed, the Toronto component is based off of soil erosion, and the Perth component is based off of flooding. These three components are the most easily experienced as they force the user to respond by slowing down the pace in which they cross the overpass. In contrast to a shading device which restricts glare and sun exposure, users need to adjust physical activity to response to the overpass, instead of adjusting to discomfort by taking off a jacket or putting on sunglasses. Being able to transfer this type of forced physical adjustment to other components would make the overpass system more impactful. The goal is not to create an obstacle course but to offer up new ways in which people take in information.

While gathering information spatially is impactful, a more direct methodology can be employed to return more involved responses from users. By literally communicating environmental status, as well as displaying it in a spatial manner, users can experience the overpass, understand through experiencing space t he current environmental status, and from then on, pass information boards that communicate specifically what they can do to help lessen the strain on the environment so that it may return to the most stable status possible. This forms a cycle of action and reaction, in which users understand how they affect the environment, by fulfilling suggested measures indicated on communication boards. For instance, if the air quality on a particular day were poor, a user would experience a closed off cladding system, in which views and ventilation are restricted.

As the user passes the information center of the overpass, he can gain a more thorough understanding of why the air quality is poor, and what specifically he can do to help remedy the situation. For example, summer in Singapore brings poorer air conditions because of slash and burn farming techniques in Indonesia. This could be remedied by inhabitants turning off air conditioning units, which add further green house gas emissions which result in poorer air quality readings. The day to day readings will change as more users react and respond to the information gathered on the overpass, and positive environmental reactions to user activity will

start to form a strong basis of connection and dependence.

Future Applications

The hope in experimenting with design methods such as this are to help shape the future of our built environments so that they are more in tune with the surrounding natural environment. It is the responsibility of people to ensure that its populations ar e well educated on environmental matters, as they directly effect their well being and livelihood. The manner of communication that is experimented with in this thesis could potentially be applied to all aspects of the build habitat, in which our surroundings constantly inform us in different ways. All aspects of a simple dwelling unit can be altered to communicate some level of environmental status, from seating and appliances to materials. Having constant exposure to and awareness of the natural environments status will allow us to continue to evolve as a society in a manner that ensures a strong connection between the urban and natural environments. Ultimately, a state of constant awareness can be reached, in which urban inhabitants, through exposure to communicative spaces, can develop a "sense" for the status of the natural environment, without reading statistical data.

Built environments of the future have the potential to evolve into spatial communication devices, for not only ecological conditions, but other pieces of information. This design methodology could be applied in a custom manner, for instances where a user would like a certain space in his dwelling to communicate a specific data set. Such example could be economic trade rates, for someone working in brokerage. The methodology can be applied to entirely customize the spatial needs of an individual. Users can dedicate specific spaces in their dwellings to communicate a specific set of data. Someone interested in surfing or fishing can apply the design methodology to the hallways in their dwellings, set to communicate the current status of the ocean. In changing the way people relate to their surroundings, the hope is that our society can move forward in efficiency and communication. As urban environments evolve towards the future, this design methodology can maintain its connection to the natural environment. This will maintain the health and well being, as well as unique identity of the urban inhabitants as their sociocultural progression continues alongside all other urban centers world wide.

IX. CONCLUSION

Information communicated through space has the potential to influence users beyond the notion that they are receiving facts, but transform the way in which users sense space. This thesis explored the possibilities of exhibiting information that would serve the populations benefit. Three main design challenges were undertaking, in the development on this methodology. The first dealt with ways in which individuals living in dense urban space could be reconnected with the immediate surrounding natural environment. This reconnection meant establishing a sense of dependency on the natural environment, an understanding of which is difficult to grasp and intangible to people isolated from nature. The second issue dealt with in the design methodology was the lack of regional identity found in many of the dense urban environments millions of people inhabit. Bringing a biomimetic component into the design methodology offered the possibility to draw a specific design language from the immediate surrounding natural environment. The third goal of this project was to use this design methodology to implement the way in which users "sense" space.

The methodology employed for establishing a way to reconnect urban users with the natural environment entailed gaining and understanding of how the relationship between man and nature has evolved throughout the progression of urbanization. The built environment slowly shifted towards an entity which isolates man from the natural environment, while providing a lifestyle with high levels of convenience and comfort. This isolation has numbed human understanding of their dependency on the natural ecosystems for clean air and water, among many other services. While our modern societies are unlikely to revert to more "natural" lifestyles, this thesis explored ways to alleviate this "numbness" in terms of human impact on the natural environment. The overpass design solution proposed a way for users to begin to slowly "feel" the natural environment through varying spatial sequences. Over extended periods of time, daily users of the overpasses will develop somewhat of a relationship with the spatial experience, slowly changing the way they sense the space while on the overpass.

Changing the way users sense space is vital to the design methodology that has been developed. In relating key environmental factors to specific spatial components on the overpass, users will

begin to "sense" rather than read the daily environmental status data. Sensing data brings users back to the way humans once interacted with the natural environment, when awareness was essential to survival. Taking in information through space will ultimately ingrain data into users enough to prompt them to change consumption or behavior patterns in ways that will benefit the natural environment, on a day to day basis. As a regular user of the overpass senses on their daily commute that the status of the natural water supply is low, the hope is that sensing negative data from the overpass will urge them to use water resources more sparingly. When large populations all sense the same data, and all react accordingly, the environment will be alleviated stress, and users will receive positive spatial information on the next commute.

As well as reconnecting individual users with the natural environment, the design methodology hopes to produce architectural forms that will further the connection between the urban environment and nature. Pulling architectural forms from species native to each area results in an overpass representative in a visual sense, of the immediate surrounding natural environment, as well as a functional sense. The overpass becomes a small urban insertion that represents holistically the identity and status of the natural environment. The design process developed can potentially be applied to many different types of space, and could display data pulled from many different sources, thus giving the built environment another role in our evolution. As we evolve alongside the environments we build for ourselves, our relationship with our surroundings will change. Dependency on the natural environment is inevitable, and to successfully move forward our built environments must be well connected and responsive.

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