

CORRELATING PATTERNS IN THE URBAN LANDSCAPE:
BIOPHILIA AND LANDSCAPE CONFIGURATION

By

Kimberly Dietzel

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Environmental Design—Master of the Arts

2016

ABSTRACT

CORRELATING PATTERNS IN THE URBAN LANDSCAPE: BIOPHILIA AND LANDSCAPE CONFIGURATION

By

Kimberly Dietzel

As the demand for sustainability increases, innovators look towards natural ecology as a source for inspiration in the urban environment (Mostafavi 2010). Designers are attempting to identify connections between biomimicry, inspiration from nature, ecological design principles and biophilia, human beneficial connection and love of nature. This thesis aims to establish a relationship between ecological principles of landscape configuration and biophilic patterns currently existing in urban areas. Focusing on existing public parks and plazas within five European cities, patterns of biophilia were correlated against landscape configuration characteristics and principal components were extracted. This statistical analysis attempts to explain the identified relationships between public spaces and natural patterns, as well as the conditions which are conducive to both human and biological life, biophilic patterns, and cultural appreciation for nature. The purpose of this comparison is: 1) to illustrate how natural features are visually, physically, and spatially portrayed in the current built environment and 2) promote integration of natural ecosystems into urban culture. Ultimately this study acts as an analysis of the biophilic functionality of urban public spaces in addition to a predictive model of the urban landscape as an integrative ecosystem. Can design successfully integrate complex spatial landscape dynamics into the urban environment, for human and ecological benefit, through the development of biophilic patterns? What extent are these ecological patterns currently existing within the built environment?

This thesis is dedicated to:
Debbie for her compassion and guidance
Chris for his ingenuity and encouragement
Friends for entertainment and acceptance
Your support and passion to widen your
horizons continues to inspire me.
Tom for his everlasting spirit

ACKNOWLEDGEMENTS

I could not have completed this thesis without the contribution and support of everyone in my life. My major professor, Dr. Pat Crawford, deserves my utmost appreciation. She encouraged me to research one of my passions, strive to achieve my abstracted ambitions, and most importantly keep me grounded in realm of possibility. A special thank you to my committee members, Dr. Patricia Machemer and Karen Russcher who provided me with continual guidance and assistance in refining my test model and future applications of research methodology. Robert Dalton was essential to my statistical interpretations and patient explanations of thesis requirements, worthy of great thanks. I would also like to thank my family and friends who supported my excessive endeavors in landscape architecture after countless late nights in studio. You all saw something in me that I didn't want to see myself. Thank you!

TABLE OF CONTENTS

LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
CHAPTER 1: INTRODUCTION.....	1
The Disparity between Design Patterns and Nature.....	1
Path to Patterns.....	2
Process and Premise	3
CHAPTER 2: LITERATURE REVIEW	6
Human Impact on the Environment.....	6
A Necessary Transition of Societal Practices.....	8
Levels of Biological Influence	11
Learning to Use Nature as a Metaphor	13
Bio-innovation and Sustainable Performance	15
Distinguishing Patterns and Principles of the Natural Environment	18
Motivation and Speculation	24
CHAPTER 3: RESEARCH METHODS.....	26
Convergent Principles	26
Research Design	26
Data Analysis	31
CHAPTER 4: DATA RESULTS.....	35
Overall Comparisons	35
Natural Patterns in Urban Public Spaces.....	40
CHAPTER 5: DISCUSSION.....	43
Patterns in the Built Environment.....	43
Overview of Existing Patterns	45
Applied Patterns in Design	46
General Design Application	47
The Future of Patterns	49
Adopt, Apply and Adapt	51
APPENDICES	53
Appendix A: Aerial Site Photos for General Ecological Patterns.....	54
Appendix B: Perspective Photos for Landscape Configuration and Biophilic Patterns	56
Appendix C: Statistical Data Adequacy and Relevance	66

REFERENCES.....	68
-----------------	----

LIST OF TABLES

TABLE 1: CODING OF EXISTANCE OF REGIONAL ECOLOGICAL LANDSCAPE PATTERNS	31
TABLE 2: ORDINAL CODING OF LANDSCAPE CONFIGURATION, DOMINANCE AND BINARY BIOPHILIC PATTERNS	33
TABLE 3: AERIAL LANDSCAPE PATTERNS OF EUROPEAN CITIES	35
TABLE 4: LANDSCAPE CONFIGURATION DATA	36
TABLE 5: BIOPHILIC PATTERN DATA	38
TABLE 6: PRINCIPAL COMPONENT ANALYSIS OF URBAN PUBLIC SPACES.....	40
TABLE 7: PRINCIPAL COMPONENT ANALYSIS OF URBAN PARKS (SOFTSCAPES)	41
TABLE 8: PRINCIPAL COMPONENT ANALYSIS OF URBAN PLAZAS (HARDSCAPES)	42
TABLE 9: SAMPLING ADEQUACY FOR PUBLIC PARKS AND PLAZAS.....	65
TABLE 10: VARIANCE EXPLAINED FOR PUBLIC PARKS AND PLAZAS	65
TABLE 11: SAMPLING ADEQUACY FOR PUBLIC PLAZAS (HARDSCAPES)	65
TABLE 12: VARIANCE EXPLAINED FOR PUBLIC PLAZAS (HARDSCAPES)	65
TABLE 13: SAMPLING ADEQUACY FOR PUBLIC PARKS (SOFTSCAPES).....	66
TABLE 14: VARIANCE EXPLAINED FOR PUBLIC PARKS (SOFTSCAPES)	66

LIST OF FIGURES

FIGURE 1: VARIANCE OF PATCHES: THIS SHOWS THE VARIANCE OF PATCHES THROUGH VISUAL REPRESENTATION USED FOR DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS	19
FIGURE 2: VARIANCE OF CORRIDORS: THIS SHOWS THE VARIANCE OF CORRIDORS THROUGH VISUAL REPRESENTATION USED FOR DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS	19
FIGURE 3: VARIANCE OF EDGES: THIS SHOWS THE VARIANCE OF EDGES THROUGH VISUAL REPRESENTATION USED FOR DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS	20
FIGURE 4: VARIANCE OF MATRICES: THIS SHOWS THE VARIANCE OF MATRICES THROUGH VISUAL REPRESENTATION USED FOR DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS	21
FIGURE 5: GENERAL LANDSCAPE PATTERNS: THIS SHOWS THE FIVE GENERAL LANDSCAPE PATTERNS THROUGH VISUAL REPRESENTATION USED FOR THE DOCUMENTATION	21
FIGURE 6: LANDSCAPE PATTERN DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY USED TO DOCUMENT ECOLOGICAL LANDSCAPE PATTERNS.....	27
FIGURE 7: LANDSCAPE EDGE DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF EDGE PATTERN	29
FIGURE 8: LANDSCAPE CORRIDOR DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF CORRIDOR PATTERN	29
FIGURE 9: LANDSCAPE PATCH DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF PATCH PATTERN	30
FIGURE 10: LANDSCAPE MATRIX DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF MATRIX PATTERN.....	30
FIGURE 11: LANDSCAPE PATTERN CODING: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE REGIONAL PATTERN FROM AN AERIAL PHOTO.	31
FIGURE 12: LANDSCAPE CONFIGURATION PATTERN CHART: THIS VISUALLY SHOWS THE VARIANCE OF THE LANDSCAPE CONFIGURATION PATTERN CHARACTERISTICS AND THEIR RANGE OF SEVERITY	32
FIGURE 13: GENERAL LANDSCAPE PATTERNS: THIS SHOWS THE GENERAL LANDSCAPE PATTERNS OF LONDON CITY HALL PLAZA.	54
FIGURE 14: BARCELONA (HARDSCAPE): DIAGONAL MAR.	55

FIGURE 15: BARCELONA (SOFTSCAPE): PARC GUELL	56
FIGURE 16: LONDON (HARDSCAPE): CITY HALL PLAZA.	57
FIGURE 17: LONDON (SOFTSCAPE): HYDE PARK	58
FIGURE 18: PARIS (HARDSCAPE): LA GRAND ARCHE	59
FIGURE 19: PARIS (SOFTSCAPE): PARC ANDRE CITROEN	60
FIGURE 20: ROTTERDAM (HARDSCAPE): MUSEUMPLEIN	61
FIGURE 21: ROTTERDAM (SOFTSCAPE): HET PARK	62
FIGURE 22: STOCKHOLM (HARDSCAPE): KING’S GARDEN	63
FIGURE 23 STOCKHOLM (SOFTSCAPE): LONGHOLMEN	64

CHAPTER 1: INTRODUCTION

The Disparity between Design Patterns and Nature

In order to competently design the urban environment in which we live in, there is a need to fully comprehend the dynamic relationship between the built environment and their human impact upon it (Tzoulas 2007). Acquisition of this knowledge is imperative to our cognitive performance as designers and much more research needs to be done here. Although, some designers attribute the human devaluation of nature to the disparate triad of aesthetic, social, and environmental concerns (Thompson 2003). No matter the cause; all cultures have been impacted by the change in climate; despite the gradual changes which are occurring at a small scale around the world. Integration of ecology into the urban environment with societal support is needed to support the world's ecosystem services and the human population. Reasoning and science backing ecological design from widespread application is unknown. The future of healthy urban life depends on the integration of ecosystem services into the built landscape (Center for Neighborhood Technology 2010). Without collective implementation of natural elements, society will struggle to contribute and consequently supporting services will dwindle within the built landscape (Gartner 2014).

This report will define the potential benefits of biophilic patterns through biomorphic forms, functionality of materials connection with nature, and spatial complexity and order within urban parks and plazas. Site-specific ecological context for design guides the layering and configuration of landscape features through holistic analysis. Biological innovation from nature has been associated with sustainable feedback within defined ecosystems (Benyus 2005). Ecologically designed experiments, such as the *Edison Environmental Center's Green Parking Lot*

Project (A. M.-Z. Felson 2013), and site-specific case studies have utilized biometrical and biophilic principles, for example *Learning from Termites How to Create Sustainable Buildings* (Biomimicry Guild 2014), as part of the design process. Despite the available research applications, an extensive connection between sustainability and contribution to ecosystem services has yet to be established and endorsed as a certified method (Global Sustainable Development Report 2015). Measurement methods determining and quantifying the efficacy of sustainable design are available both for economically as well as ecologically focused tools (Baird 2009). The amalgamation of design and science knowledge has yet to confirm the application of landscape configuration, biomimicry, and biophilia to ecological sustainability.

Path to Patterns

This research evolved at a personal level fueled by curiosity and interest of potential applications. The following section spells out the path of associated research topics which lead to the development of the research question. The discovery of natural patterns forms and the human ability to derive their characteristics from the natural landscape grew into a desire for application within the built environment (Dubé 1997). Through natural patterns as a method of metaphorical design, this curiosity evolved into potential applications and the benefits, if there were any, of pattern application (Salingaros 2000). Pattern research lead to a variety of related types of patterns- two dimensional patterns, as well as formation patterns (Bell 2012). This broadened into the general use of nature as a template for design inspiration (Peters 2011). Natural inspiration branched into imitation and application of nature- otherwise known as the study of biomimicry (Benyus 2009). Biological integration with design and technological innovation contributed to further research in addition to broad potential for design applications

(Meyers 2014). At this point external guidance was needed to compile the massive influx of information and refine into a manageable study. Through elimination of design applications with little-to-no dynamical influence, a series of patterns were chosen: biophilic patterns dealing with human benefits from the application of natural patterns (Browning 2014), landscape ecology principles of spatial configuration (Dramstad 1996), and a spin-off of the original natural patterns forms- but generalized at the regional landscape scale (Bell 2012). Once the series of patterns for the study were solidified, their combined potential impact on design application was considered, and interpreted to include sustainability and contribution to ecosystems services. Compelled to discover some overarching value which might bring these concepts together; this was established as overly ambitious and a modified cleaned-up version of the ideal, “change the world” thesis, was developed into the following study.

Process and Premise

The dynamics of space exist through layering of elements, this relates to the manner in which our eyes perceive things- beginning at the most distant visual; the background. By layering other elements visually, a hierarchy is created. This is how humans understand perspective and can distinguish movement in relation to distance and space (Bell 2012). This concept also applies to the hierarchy within an ecosystem. Ecosystems are more than just a web of interconnecting elements, it is a layering of landforms setting the background, truncated by organisms that function within the space, and energy flows of nutrients, water, and energy throughout (Dramstad 1996). It is almost inconceivable to understand all the intricacies and processes that occur in a single ecosystem from the regional scale to the microbe, but it is possible to comprehend the layers that exist within a given space (Stevens 1974). The processes

or services which an ecosystem is able to provide is restricted by the local history and ecology- this sets the background (Bell 2012). This is the framework that regulates, supports and provides for the rest of the system (Millennium Ecosystem Assessment 2005). Beyond that layer, the inhabitants of the system exist in a complex interconnected system. Organisms interact with one another all the while independently operating for survival. Hierarchy of a natural environment is independent, adaptive, resilient, and diverse. Conclusively, a landscape without ecology doesn't exist (Dramstad 1996).

Culture has disengaged society from nature (Wilson 1995). Instead of learning to live amongst its processes and adapt in the natural environment, humans have evolved beside it, inhabiting constructed environments (Wilson 1995). Within this human environment the hierarchy can be interpreted differently (Dubé 1997). Design relates to visual patterns and either a) artistic creation or b) natural science and mechanics (Bejan 2012). These visual patterns found in nature are scientific and operationally predictive. Evolution is the change of design and life over time (Rocha 1997). As a profession, designers seek to bring positive changes to the environment through their designs and therefore must propose their preferred methods of the implementation process (Thompson 2003). Despite personal preference in the design process, universally: 1) design arises in a contextual need for action 2) design is prescriptive; deals with questions that ought to be, and 3) design involves subjective value judgements (Lawson 2006). Theoretically humans are able to learn from nature and use visual patterns as a design model. Accordingly, if these design models can prescribe aesthetic solutions, what are the barriers to incorporating these methods to use as a predictive procedure to establish a symbiotic relationship between culture and nature?

Design is more than “just stylizing or decorating but building the decisions as a society so we can create the world you would like to live in” (Ingels 2015). If design incorporates spatial landscape dynamics through biophilic principles in the urban environment, for human and ecological benefit, will the built environment function as a sustainable urban ecosystem? Additionally, to what extent do these ecological patterns currently exist in the built landscape?

CHAPTER 2: LITERATURE REVIEW

This literature recounts the circumstances facing future urban developments and conceivable design solutions to combat an expanding degradation of natural resources, worldwide energy usage and material consumption (Beck 2013). The Millennium Ecosystem Assessment is used in this research as the precedent of global awareness and action against climate change. The ecosystem services required to sustain the fuel, food, and water of urban communities cannot endure the growing rate of expansion (Millennium Ecosystem Assessment 2005). This demands systems of design, manufacturing and consumption to adopt a new way of thinking which environmental resources are conserved and ideally replenished gradually (Global Sustainable Development Report 2015). During the approaching ecological transition, it is fundamental that the United States and Western Europe accept the responsibility of acting as a model for environmental resource management techniques and economic solutions to ecological design for the rest of the world (Columbia Law School 2014). The subsequent challenge is the reorganization of socioecological systems to ensure the prosperity of the world's population is maintained through technological and design innovation (Millennium Ecosystem Assessment 2005).

Human Impact on the Environment

In order to continue to benefit from ecosystem services, humans need to invest in restorative ecological practices, as an effort to contribute to the services which the ecosystem supplies: provisional, regulating, cultural and supportive. Provisional services maintain a constant availability of food, water, and fiber. Regulation services control climate, water, and human diseases. Cultural services influence cognitive development, reflection, and recreational

opportunities. Support services sustain production of biomass and oxygen, soil formation, nutrient and water cycling (Smith 2015). If carbon emissions continue at the current rate, the Earth will be mostly uninhabitable before 2300 (Maser 2012).

Since the transition to an agricultural society approximately 12,000 years ago, the natural landscape has been in a continuous state of transition and degradation of its resources (Cumming 2014). Within the past few centuries, urban areas have grown increasingly popular, and it is projected to continue to 70 percent of the world's population in the coming decades. In relation to the insurgent population of an urban majority, the structure of nature within the built environment becomes increasingly important (Browning 2014). Urban growth has been criticized as one of the most predominant environmental problems due to the complex qualities of gradual disintegration of the urban environment and the constant struggle to maintain durability, performance, and efficiency (Beck 2013). There is urgency among designers to challenge the perception of isolated built and natural environments, reunite urban systems with landscape ecology, and re-evaluate their methods of development (Meyers 2014). Recently, designers have sought to create spaces that will interact and work in conjunction with the environment, in hopes that it will 'survive' longer than spaces that work against natural processes (Marsh 2011). The pressure of climate change is accelerating the urgency to dissolve society's reliance on inefficient industrial machines and replace them with the similar processes by microorganisms and plants. These adaptable solutions recognize the fragility of nature and our responsibility to preserve it for future generations (Meyers 2014).

Advanced practices, ethical and regulatory approaches have recently been developed to steer away from human-engineered infrastructure for water resources and to better

understand sustainable efforts (Isenmann 2003). One such project, the Prospective Economic Analysis, demonstrated that natural infrastructure costs were significantly lower than the cost of built infrastructure (Forest Research 2010). Natural infrastructure and the “strategic use of networks of natural lands, working landscapes, and other open spaces to conserve ecosystem values and functions and provide associated benefits to human populations” (Allen 2012). If designers can look at ecological design with a different mentality, then perhaps buildings and places can be created using integrated system-based strategies, local ecology at various scales, and a relationship between products and their long-term performance (Isenmann 2003). Recently designers are becoming aware of the shortfall of aesthetic-based design and are exploring biologists’ expertise. Guiding the enhancement of built environments, the integration of natural systems and ecological performance is more discernable in modern design practices (Meyers 2014). Key scientific evidence is needed for the catalyst between human biology, nature, and the built environment (Gartner 2015).

A Necessary Transition of Societal Practices

Realization that everything in life is interconnected, ecosystems offer inspiration for human development. By evaluating the way in which we impact the environment, designers, scientists and biologists can govern how industries produce materials, how resources are managed in agriculture and how urban environments work with natural processes (Benyus 2005). Several agencies are developing toolkits to measure, assess, and gauge the monetary values, human benefits, and ecological gains of designed interdependence (Smith 2015). These assessment programs include but are not limited to: the Phoebe Framework, LEED, the SITES initiative, and the Directive on the Energy Performance of Buildings (Berardi 2012).

The UNEP determined three areas which dictate resource consumption: the impact of global warming, land use competition, and human toxicity (UNEP 2015). Information modelling and simulation is one method of testing current and newly innovative infrastructure before widespread implementation of design solutions (Marsh 2011). 'Optioneering', or testing multiple design solutions, uses real-time life-cycle simulation, supporting a design from conception, through continuous improvements, into automated deconstruction. Another method of examining current development is through ecologically designed experiments, which begin with ecological assessments, targeted outcomes and systems which are devised to attain integrative human and environmental benefits (Felson 2015). The intention of these design methods is to incorporate a comprehensive fusion of ecological processes and natural phenomenon into professional practice and implementation. This is a critical step in the prevention of global climate change and sustainable design (Meyers 2014).

In order for human and local ecosystems to act interdependently and sustainably while remaining cost competitive, an alteration of society's current industrial processes and operational systems is imperative (Garvin 2015). Innovation from nature has yet to be propagated in the realm of industrial design, but is commonplace in other related design disciplines such as computer sciences; where the derivation of genetic algorithms has advanced digital software (Benyus 2005). Consequently, a shift from industrial to biotechnical manufacturing could revolutionize material production and construction. Conventional technologies squander scarce resources, unlike biological processes (Meyers 2014). Waste does not exist in natural systems. Through cyclic flows, resources expelled from one organism or community are harnessed by another (Smith 2015). Human methods of manufacturing,

material production, and construction generate 4% of product to 96% waste (Benyus 2005).

Contained biotechnical systems are considered a viable alternative; adopting organic processes in fabrication techniques saves energy and resources, therefore reducing its environmental impact (Meyers 2014). Prospective manufacturing and industrial methods are symbiotic in design, collecting and processing waste material generated and translate the byproduct into raw material for another fabricated good, (Frosh 1989) or into energy production. It can occasionally can be restored within the local ecosystem (Marsh 2011). Businesses benefit from shared commodities and exchanged resources which in turn increase revenue and reduce negative impacts on the environment (Smith 2015).

Moreover, human health and wellness demands ecologically sound practices for employees in manufacturing and building services, addressing the need to broaden the scope of ecological benefits and engage the living world in daily life (Meyers 2014). For a system that functions sustainably to exist, an integrated relationship between the biological sciences and businesses is necessary for industrial development to grasp the fragility of local ecosystems and align their performance with living organisms and the environment (McDonough 2002).

Embracing a complex circulation of energy and resources (through exploration and experimentation of biological advancements within defined business models) specified to an individual site, would enable designers to consciously create the built environment. Instead of working against environmental stresses, integration of natural systems into human environments maintains wildlife biodiversity, and demonstrates foreseeable biological benefits, an additional incentive of the protection of local water, soil, and air quality (Meyers 2014).

Despite the wave in popularity of sustainable living, the concept of ecological development is not a new field in design (Wilson 1995). On a daily basis, the constraints of ecosystem services force designers to employ environmental sciences and examine organisms' functionality in nature. Innovation from replicating these natural systems, can be considered a step towards a specific correlation between mimicking biology and sustainability (Meyers 2014). The desire for an increased connection among people, nature, and the built environment, works as an approach for the implementation of biomimetic practices and sustainable design (Loise 2012) .

Levels of Biological Influence

Imitation of nature in design is an old phenomenon (Wilson 1995). Over the years form-driven design has progressed to more functional, and systematic applications (Benyus 2009). Biomimicry, the replication or translation of natural biological features, can be conceived at various levels: from the basic, reductive to the advanced holistic view (Loise 2012). Biomimetic design techniques have been developed at each of these levels and will be discussed in the ensuing paragraphs. Its potential applications within the built environment similarly expand into a range of natural patterns, forms, functions, and processes.

Reductive biomimicry is the most simplistic level, offering only a superficial likeness to the natural world, specifically for decorative, symbolic, or metaphorical purposes (Meyers 2014). Through direct reproduction of two-dimensional patterns and three-dimensional forms, an aspect of the natural environment is visually represented for aesthetics (Stevens 1974). Most notably, Richard Dubé describes his process of observing and documenting features of the natural environment in his book *Natural Pattern Forms* (1997). The process consists of

deconstructing three-dimensional features of the natural landscape into two-dimensional patterns by characterizing elements of distinctive environments to be later applied conceptually through constructed materials (Dubé 1997). Dubé's template could be used in the field to construct a two-dimensional pattern outline representative of the original landscape attributes. Identifiable attributes are: scale, natural formation, viewshed, associated elements, internal ratio, aesthetic contributions, and the observer's emotional response. By distinguishing a conceptual pattern through defining attributes of the natural landscape, a metaphor or motif is generated, and feasibly imitated as part of a design application (Bell 2012). Reductive biomimicry is the translation of two-dimensional natural patterns to applications in the field of art, material sciences, mechanical engineering, and structural architecture. Despite the variety of design applications, reductive biomimicry has little to no ecological benefits (Loise 2012).

Dynamic biomimicry, or bio-design, is described as the abstraction and translation of biological principles into the built environment to solve a human problem, as well as determine if a design concept creates conditions conducive to life (Smith 2015). Bio-design applies biological functions found in nature to designed operational, mechanical and structural elements (Vincent 2009). This form of biomimicry goes beyond stylistic applications of landscape features and has the potential to harmonize and function with natural elements, although delivering enhanced ecological performance has yet to be established (Meyers 2014). Classified as the superlative form of dynamic biomimicry, holistic biomimicry exists, where imitation of entire natural systems are emulated in a design. A specific field of holistic design, bio-utilization, uses organisms or ecological materials to fulfill a human need (Smith 2015). It is generally accepted that the inclusivity of nature and ecology into design encourages natural

processes and does not further harm the environment (Loise 2012). Designers are continuing to explore the realm of possible applications; by harnessing ecological processes and use living materials to experiment and learn how to execute a design with perfect energy and resources economies or allow for nature to run its course once implemented. High-level biomimetic designs strives to achieve adaptability, efficiency and interdependence. This requires ecological know-how in order to experiment with complex natural systems (Meyers 2014).

Learning to Use Nature as a Metaphor

The use of nature to influence and enhance design has been deemed 'bio-innovation', and is seen as an approaching design revolution. "This is the century of biology" (Benjamin 2011). Continuing along this path, designers will learn to incorporate life itself into the built environment through the use of metaphors (Meyers 2014). Metaphoric design is defined as the transformation of a physical construct in a new manner using symbolism to translate the abstract concept of a natural function to an unrelated physical form. Metaphorical design relays the observed attributes of the natural environment to logical applications within the built environment through a process of understanding and creativity (Dubé 1997). Nature is equipped with a vast collection of biological systems that process and manage information, materials, and energy; perfected over the past 3.8 billion years (Benyus 2005). Organisms have established methods of constructing structures using only the resources that are locally available, utilizing only 5 polymers, while humans use over 350, including toxic polymers. If society employs nature as a library of time-tested technological solutions (with between 10-30 million species on earth, each adapted for a unique environment and specialized function), then utilizes metaphorical design principles, a connection is forged from the logistical framework of

functional needs with the natural examples represented in a concise design solution. With nature as a metaphor, the scope of applicable knowledge is expanded to the limits of the ecosystem; and design integrates the biology of the site, its natural processes and functions into a systems application (Benyus 2005).

“People often look to science for clear cut answers, not a complex way of thinking about and responding... because science is more art than science. We must interpret the data that is set before us and through the art of creativity develop a complex solution to solve the dilemmas of our time” (Harmon 2013). Innovative companies are beginning to research biological anomalies and examine characteristics of organisms for inspiration and direction in solving human problems. One technological paradigm was the transcription of the kingfisher birds’ aerodynamics (the manner in which it seamlessly flies into the water without splashing) to the design application of a high-speed train; minimizing its turbulence, increasing its rate of acceleration and its overall energy efficiency (Benyus 2005). Currently, the majority of industrial companies, governmental policymakers, and educated individuals in the United States have yet to be familiarized with the concept of biomimicry as the solution to society’s challenges (Smith 2015). This demands a pervasive shift in societal priorities, the education of sustainable alternative methods of construction and manufacturing, as well as increased collaboration of biologists, designers, and businesses (Meyers 2014). Through careful documentation of case studies and simulation techniques, designers are able to use biomimicry as a tool to determine specific solutions to design problems (Benyus 2009). Abstracting ideas from nature allows us to profit from nature: utilizing innovation to increase revenue, mitigate risk, reduce costs, and support the development of a regenerative society (Benyus 2005).

Bio-innovation and Sustainable Performance

“Not trying to imitate nature; trying to find the principles she’s using” is one approach to solve human problems in the context of the earth through the conscious emulation of life’s genius (Buckminster Fuller 1972). Bio-innovation promotes design discovery from nature but also to emulate biological processes by embedding sustainability into the development of new products and techniques (Smith 2015). Through the biomimicry guild, Janine Benyus has compiled performance metrics to assess ecological aspects that contribute to sustainable design and to shape nature’s performance capabilities. Identifying the Fully Integrative Thinking (FIT) ecological performance standards, ‘genius of the place’, and ecosystem services are combined to establish strategies of maintenance to the built environment (Lazarus 2011). By assimilating biological thinking and architectural practices, the group is able to restore environments of varying scales (Biomimicry Guild 2014).

Sustainable design is to create conditions conducive to natural systems and human life; which integrate and challenge biology in design. This occurs when function is identified, content is defined, a specific challenge is biologized, natural models are discovered, design principles are abstracted, natural strategies are emulated, and finally the design must fulfill the “life principles” defined by the guild (Peters 2011). These principles include: evolution for survival, material and energy resource efficiency, adapting to changing conditions, integrating to growth and future development, being locally attuned and responsive, and by using life-friendly chemistry. Utilizing the life principles further develops a relationship with the surrounding ecosystem, and contributing to a sustainable design (Peters 2011).

Sustainable metrics were created through a series of case studies, focusing on intimate natural processes as well as complete ecosystems (Maser 2012). Synthesis of these metrics provided insight that nature doubles up on functionality within elements, encouraging designers that true biomimicry is more than mimicking natural forms on a surface level but joining a collection of natural forms, functions, and processes into nesting patterns, or layers (Garvin 2015). Where each pattern acts as a separate element within an overarching design that contributes to the surrounding ecosystem. The replacement of mechanical or industrial systems with natural processes and integration of living organisms as design components blur the line of biomimicry, and verges on hybrid technology (Meyers 2014). “The biggest innovations of the 21st century will be at the intersection of biology and technology. A new era is beginning” (Jobs 2011). Integrating with natural systems is the key to mitigation, resilience, and adaptation to climate change, whether it is through biophilic design, ecosystem restoration, urban ecological planning, or bio-inspired innovation (Garvin 2015).

Bio-inspired innovation describes the ways in which mimicking the forms, functions, and processes of natural systems can be used as mechanisms driving sustainable design (Garvin 2015). “The significance of biophilia in human biology is potentially profound, even if it exists solely as weak learning rules. It is relevant to our thinking about nature, about landscape, the arts, and mythopoeia, and it invites us to take a new look at environmental ethics” (Wilson 1995). Exploiting man’s deep-seated connection with nature, or biophilia, by incorporating natural elements into design, whether through metaphoric design or cleverly placed houseplants, there are human health and economic benefits. Performance metrics show that

productivity, emotional well-being, stress reduction, learning, and creativity are all increased (Browning 2014).

The *14 Patterns of Biophilic Design* defined by Terrapin Bright Green (2014) are focused within three major categories; 1) Nature in the space, 2) Natural Analogues, and 3) Nature of the space. Nature In the space pinpoints psychological patterns from a personal interactions and perceptions with biological traits including: 1) visual, 2) sensory: tactile, taste, smell, 3) audible white-noise, 4) distractions and stochastic movements, 5) thermal airflow, and presence of water, 6) lighting, and 7) awareness of natural processes. . Nature of the space distinguishes cognitive elements that define the personal perceptions of the natural environment including: 1) prospect: safety, enclosure, control, cultural, 2) refuge: habitual, separation, uniqueness, obscured views, and 3) mystery: intrigue, exhilaration, excitement, 4) risk and peril. This study will focus specifically on the biophilic patterns of natural analogues. The first being biomorphic forms and patterns which constitute symbolic or metaphorical references to natural elements through two- and three-dimensional application of patterns. The second pattern of Material Connection with Nature through minimal processing reflects the local ecology or geology to create a distinct sense of place. The final pattern of Complexity and Order depicts rich sensory information that adheres to a spatial hierarchy similar to those encountered in nature (Browning 2014).

The field of biophilic design is constantly evolving, and new disciplines such as biophilic design must “abstract its patterns as they appear. It is building its own foundation and logical skeleton, upon which future growth can be supported. Knowing its basic patterns early on will speed up the language’s development, and guide it in the right direction” (Salingaros 2000).

Distinguishing Patterns and Principles of the Natural Environment

The ecological context of the area plays a significant role in the biomimetic patterns and processes. It is important that environmental attributes are appropriately determined, by using bioregional models to influence the boundaries of similar environments instead of following political boundaries. Cultural, historical and mythological aspects are already taken into consideration prompted by political regions. Aspects of the environment measure the boundaries of bioregions: watersheds, topography, geology, ecosystems, and relative elevations (Thayer 1995). Truly understanding the ecology of the design site helps refine the experiential mental database to exclude environments that do not correlate, and cannot contribute to a concept formatted to fulfill all aesthetic, functional and ecological needs (Dubé 1997).

The Earth is a bio-sphere; for the purpose of this report it functions as a closed system, despite the external input of the sun. As a biosphere, the earth's continents and oceans can be aggregated into regions. These regions are categorized by climatic conditions; precipitation, solar influences, wind, ocean currents, air temperature; as well as the geographical context of the space dependent on topography, geology, hydrology, and land cover, or vegetation (Thayer 1995). A regional biome is the largest scale of landform patterns; created throughout history by natural elements related to its regional climatic and geographical context, for example: volcanism, mountain building, weathering/ wind, water and ice, as well as erosive and depositional (Bell 2012).

Scaling down from regional biomes, landscape ecosystems are comprised of animal habitats and plant communities. In nature, ecosystems are structured similar to a mosaic,

comprised of an assortment of patches, defined by boundaries, connected by corridors, maintained by the movement of energy within the surrounding matrix. The mosaic matrix can be evaluated in terms of pattern and scale (Dramstad 1996). The most distinguishable scales are macro/ regional scale, meso/ landscape ecosystem scale, and micro/ site scale. Patches are identified as vegetated or non-vegetated landscapes, forms, or enclosures that act as a node or local habitat. These patches are visible in Figure 1 (Patch Variance) and are distinguished from the way in which they have changed over time. Remnant contains elements of the original native landscape as well as built elements. Introduced is predominantly non-native elements. Disturbance occurs when humans or a natural disturbance eliminates the majority of elements. 'Environmental resource' define and limits change.

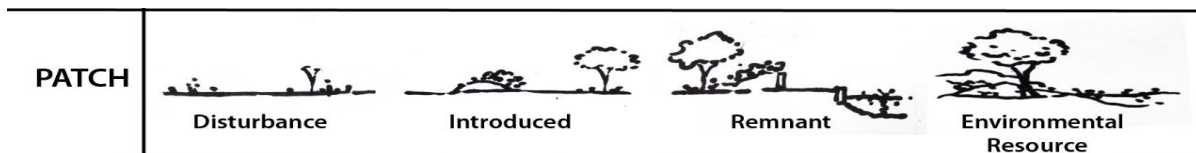


FIGURE 1: VARIANCE OF PATCHES: THIS SHOWS THE VARIANCE OF PATCHES THROUGH VISUAL REPRESENTATION USED FOR DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS

Corridors describe the linear movement or connections between the patches for animals, water, and energy within the environment (Bell 2012). This movement does not always remain within one matrix but may interconnect with others, forming a network that presents circuitry and the size of the regional natural fabric (Dramstad 1996). All corridors link and separate spaces, yet they can be linear, the width can vary, strands can break off and reconnect, the corridor might meander or be discontinuous. Examples of which are visible in Figure 2.



FIGURE 2: VARIANCE OF CORRIDORS: THIS SHOWS THE VARIANCE OF CORRIDORS THROUGH VISUAL REPRESENTATION USED FOR THE DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS

The matrix provides a dynamic equilibrium of natural influences regulating the landscape; these two mechanisms are identified as heterogeneity: landform, moisture, soil structure, nutrients, climate, and natural disturbances: fire, wind, sandstorm, tornados, insect pests, and fungal diseases (Bell 2012). Similarly, these regulating factors generate an assortment of edge types which delineate patches and corridors which are displayed in Figure 3; hard, wavy, bays and ridges as well as emergent.



FIGURE 3: VARIANCE OF EDGES: THIS SHOWS THE VARIANCE OF EDGES THROUGH VISUAL REPRESENTATION USED FOR THE DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS

Comparison of distant regional biomes and ecosystems may seem unrelated, but the interaction of natural patterns within the ecosystem matrices are spatially, structurally, and compositionally heterogeneous at any scale. All ecosystems are dynamic and complex, continually adapting and fluctuating; yet the function of its features: matrices, patches, edges, corridors and energy flow are continually interacting and determining the state of productivity of the ecosystem. Either positive, organisms are thriving; or negative, life is declining; or neutral, a system is in balance (Jorgensen 1986). These landscape features differ in characteristics including shape, size, and form:

- shape of edge - geometric or organic (fractal)
- contrast of edge - hard (typically human activity) or soft (ecotones) typically natural
- level of contrast of patch composition
- contrast of structure

- shape (as a result from creation) (Bell 2012)

Equilibrium of a matrix is established by the flow of energy or stress which is not necessarily visible, but inferred from the relationship between mosaic landscape features. Variations of mosaic landscape features were documented and grouped into a limited number of categories, known as the Graph Theory. These categories are: spiders, lines, graph cells, candelabra and rigid cells visible in Figure 4 (Dramstad 1996).

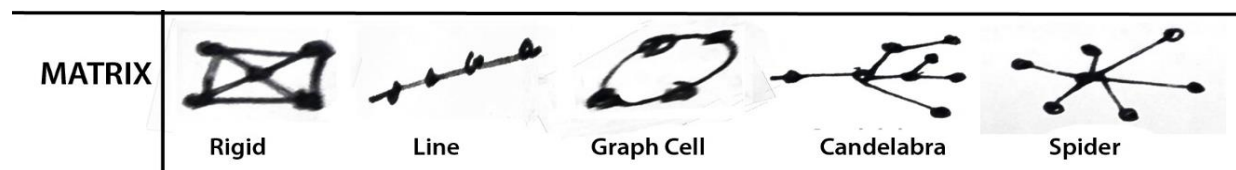


FIGURE 4: VARIANCE OF MATRICES: THIS SHOWS THE VARIANCE OF MATRICES THROUGH VISUAL REPRESENTATION USED FOR THE DOCUMENTATION OF LANDSCAPE CONFIGURATION PATTERNS

In 1974, Stevens recognized that characteristics of mosaic landscape features were heterogeneous, and developed a set of basic patterns that generalized natural forms and landscape patterns seen in Figure 5 (Stevens 1974).

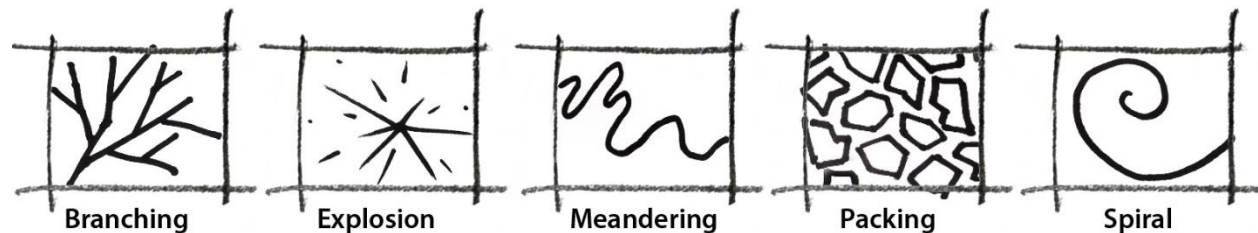


FIGURE 5: GENERAL LANDSCAPE PATTERNS: THIS SHOWS THE FIVE GENERAL LANDSCAPE PATTERNS THROUGH VISUAL REPRESENTATION USED FOR THE DOCUMENTATION

1. Spirals: growth or deformation due to gradient of energy, stress or stimulant
 - a. Two-dimensional: archimedean (radius proportional to the angle) or logarithmic (radius not proportional to the angle), as well as parabolic and hyperbolic

- b. Three-dimensional: helix
- 2. Meanders: oscillations or wave like forms both two-dimensional and three-dimensional
 - a. On a plane
 - b. Flows of energy
 - c. Opposing forces
 - d. Opposing strengths
- 3. Branches: flows break in multiple directions and order
- 4. Explosions: radiate outward from a central point, determined by density and distance
- 5. Packing/ cracking: non-linear objects in space with geometric characteristics of;

uniformity, space filling, overall length, directness
(Stevens 1974)

Recognition of natural features within an environment allow for society to construct a classification of forms and patterns through observation and experience (Bell 2012). These five basic patterns are characterized through the functionality of the landscape and act as large tiles within the regional landscape. Smaller tiles that refine the detail of the mosaic are the landscape features creating a unique matrix within the regional landscape. This layering of the tiles within the mosaic landscape demonstrates how the patterns interact and can justify each other, from the top down or bottom up. More simply stated; “form follows function” (Koeper 1958). A given landscape was formed by the function which created it, confirming form is the diagram of force (Dramstad 1996). Refine the regional form of the landscape to its basic pattern (one of the five), and function with the natural process in which the landscape originated; therefore pattern follows process. Consider the mosaic landscape over time, the pattern of the landscape will change due to natural disturbances and climatic influences, or processes. Yet

regional landscapes are not all susceptible to the same natural processes; this is due to the environment's geography, topography, geology, and hydrology; or regional pattern, proving processes follow patterns (Bell 2012). With the dynamics of the landscape recognized; notice scale is dependent of the system.

Patterns progress from two-dimensional patterns, to functions, to processes and finally into systems and networks of systems, visible in a natural ecosystem or a biome. Ecosystems are emergent, or a complex of systems that are composed of interworking patterns and functions through scoping scales or nested patterns. Within these emergent systems nature has optimized the transfer of nutrients, materials and energy cycle throughout the scales (Smith 2015). The human world of built environment is no different, it is still a part of the system (Meyers 2014). Adopting an emergent synergy, adaptive and self-organizing, existent in natural systems allows the constructed world to change from static to dynamic (Smith 2015).

Landscape ecology concludes that landscapes change in patterns over time through a series of flows and movements (Dramstad 1996). This demonstrates that patterns, both natural and designed, indicate the processes that created them, and the way they will function within ecological evolution (Bell 2012). If patterns are used in a manner where they contain geological, hydrological, or environmental information, they can be harnessed to function in the same manner as said natural processes. Where ecological features within matrices and natural processes intertwine through vegetation, wildlife populations, species richness, wind, water, wetlands and aquatic communities (Dramstad 1996), then the applicable designs should function as an 'organism' and 'adapt' within its environment (M'Closkey 2013).

Realization of how human development and construction has impacted the natural mosaic will dictate the manner in which ecological integrity and land degradation can be amended. Culture sets human patterns apart from natural patterns (Bell 2012) through dimensions of economics, aesthetics, community social patterns, recreation, transportation, and waste management. Human spatial patterns determine the arrangement of landscape features and natural resources through planning, conservation, design, management and policy. Spatial processes are dynamic, yet human development can expedite 1) fragmentation, 2) dissection, 3) perforation, 4) shrinkage, and 5) attrition (Dramstad 1996). Structure is the spatial arrangement of elements, relating to where patches and corridors fall within the matrices. Functioning is the movement and flows of animals, plants, water, wind, materials and energy through the structure; change is the dynamics or alteration of spatial pattern over time. Societal impact on a region is visible through the ecological health based on its connectivity of natural systems present through corridors and flow of resources (Dramstad 1996).

Motivation and Speculation

The purpose of biophilic design is not to recreate an aesthetic equivalent to nature; it is essential to human health and well-being in the built environment (Garvin 2015). Humans have evolved alongside nature; functionally people operate at a higher level when natural elements are present (Wilson 1995). Through bio-innovation resources can be redirected to support human prosperity and health without damaging the ecosystems on which society depends. In addition to optimizing human productivity, healing time, learning functions, and social cohesion, biophilic design supports the restoration of local ecosystems (Browning 2014). This shift in the urban design paradigm would have to occur over a period of time, not all at once

(Beck 2013). One logical place to begin is urban spaces that have a high level of visibility to society as well as the potential for adopting biophilic patterns and landscape configuration principles. This study will focus on urban public parks and plazas, which act as areas of community congregation and are universally accessible.

CHAPTER 3: RESEARCH METHODS

Convergent Principles

This study acts as a synthesis between biophilic design patterns set forth by Terrapin Bright Green (2014), landscape ecology principles outlined by Forman (1996), and natural landform patterns derived by Stevens (1974) and elaborated on by Dubé (1997). A consolidation of these three pattern-based design formulas was applied to existing landscapes to evaluate the integration and association of natural elements currently within the built environment. Site photos depicted the dynamic landscape configuration of the space through visual evaluation of the urban landscape's spatial characteristics (Dubé 1997). Each site's predominant configuration feature was then cross-evaluated against the instance of biophilic patterns using principle component analysis (Browning 2014). Determining the attributes in the built environment with the greatest metaphorical translation of the native landscape exemplifies the current extent of inadvertent ecological integration- in otherwords, unintentional design reminiscent of the regional landscape. Additionally, the areas lacking connections depict the range of potential implementation as well as society's limited connection to nature.

Research Design

To state it simply the test will consist of four main tasks:

- 1) Collect the visual data
 - a. Parks and Plazas; using corresponding techniques
- 2) Documenting the patterns
 - a. Ecological, Biophilic and Landscape Configurations
- 3) Run the statistical data

- a. Code existing patterns and extract principle components
- 4) Interpret the relationships
 - a. Between extracted components

To elaborate the details of this process:

1) Collect the visual data: This work employs pictorial, comparative and analytical research methods. The collection of pictorial data in the field was conducted utilizing techniques expressed in *A Guide to the Study of Ordinary Buildings and Landscapes* (Carter 2005). A broad spectrum of land-use categories allowed for the spaces documented to express the local design and community style. Photographs consistently cataloged the spaces, ensuring the use of a high resolution camera at an eye-level perspective. Furthermore, the images capture the essence of the particular space through details, materials, forms, general size and enclosure of the site (Carter 2005). The representative sample included park space and plazas. The accumulation of

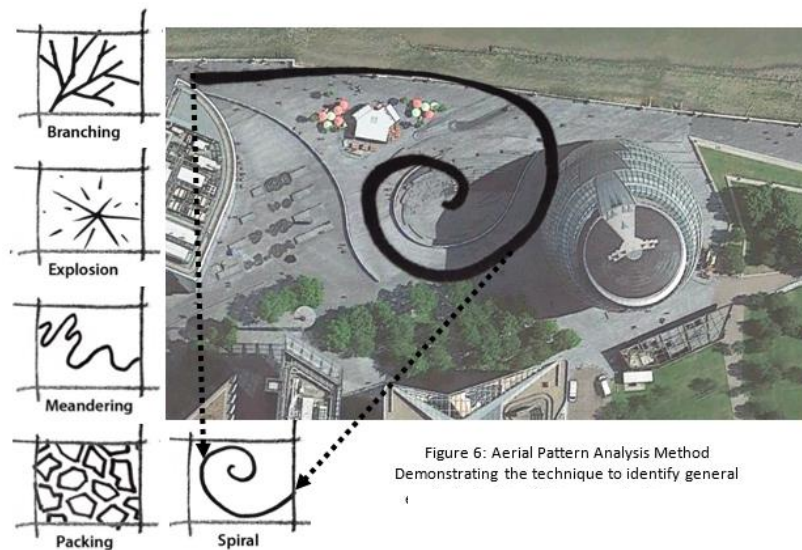


FIGURE 6: LANDSCAPE PATTERN DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY USED TO DOCUMENT ECOLOGICAL LANDSCAPE PATTERNS

photographs took place over a three-month period, within five European cities: Barcelona, London,

Paris, Rotterdam, and Stockholm. At the site scale the pattern identification was repeated to infer if the site was derivative of the regional landscape pattern (Stevens 1974).

The images selected were randomized clusters from the total locations surveyed (Carter 2005). Research founded in analytical framework surpasses a simplistic inquiry, through the organization and assembly of distinctive evidence in addition to the gathering process (Kirkwood 1999). The age of construction, metropolitan area, and relative surroundings influenced the inclusion of sites in the study. Although the sites' degree of development and comparative size varied between locations, these factors were considered mediating variables and did not restrict the test sample. In order to assure approximate data consistency, the relative time, visual format, and technology used for documentation was determined before the data was collected (Kirkwood 1999).

2) Documenting the patterns: Once sites were determined, the observation and documentation techniques devised by Dubé (1997) were applied. The derivation rubric consisted of the following steps:

1. Relax and refer to your instincts
2. Regard the image
3. Reverse your Perspective
4. Catalog the Attributes
5. Outline the Pattern Form (Dubé 1997)

This process reveals characteristics of the landscape that are distinguishable as principles of landscape ecology. The site's spatial hierarchy was determined using landscape configuration principles to define and categorize its edges, corridors, patches, and matrix. Once the analytical

research was completed, all the site images were classified by their most distinctive landscape configuration feature, illustrated for each principle in Figures 7- 10.

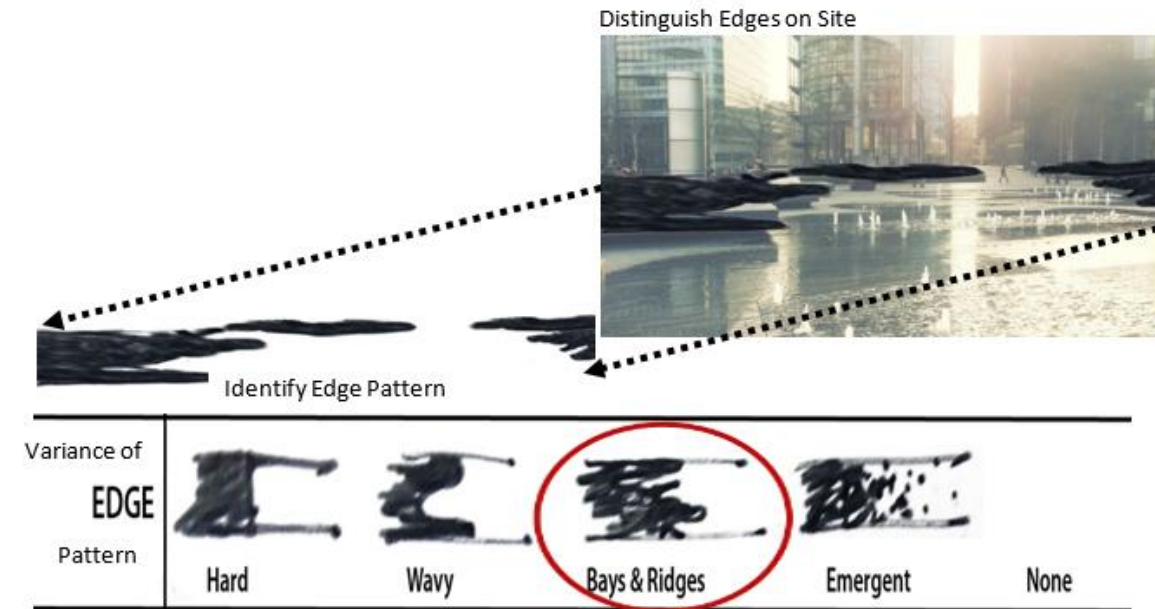


FIGURE 7: LANDSCAPE EDGE DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF EDGE PATTERN

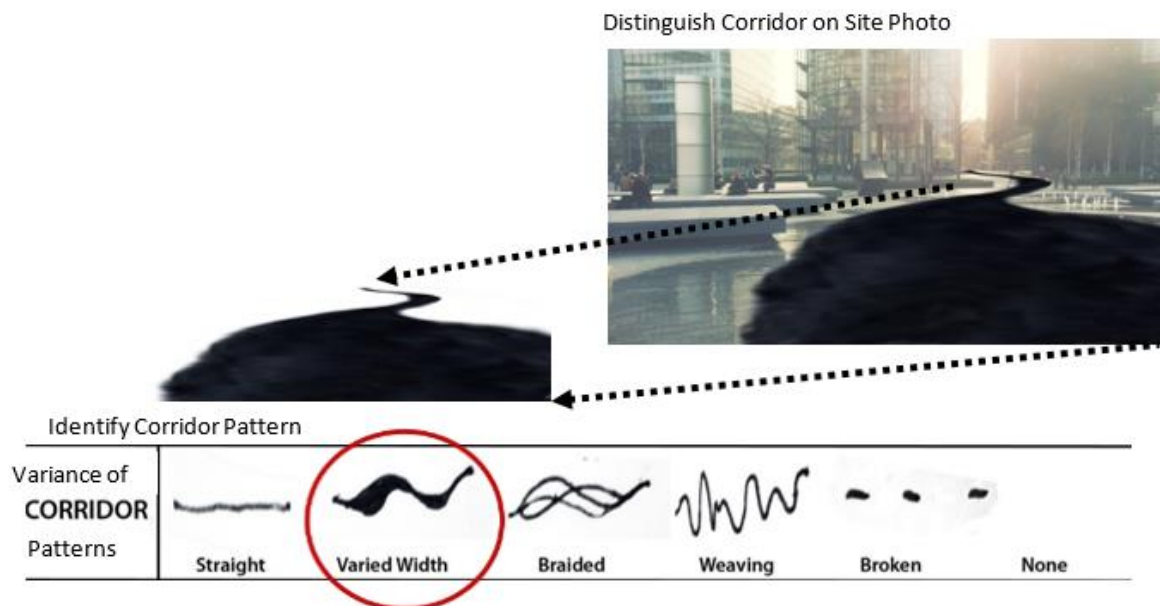


FIGURE 8: LANDSCAPE CORRIDOR DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF CORRIDOR PATTERN

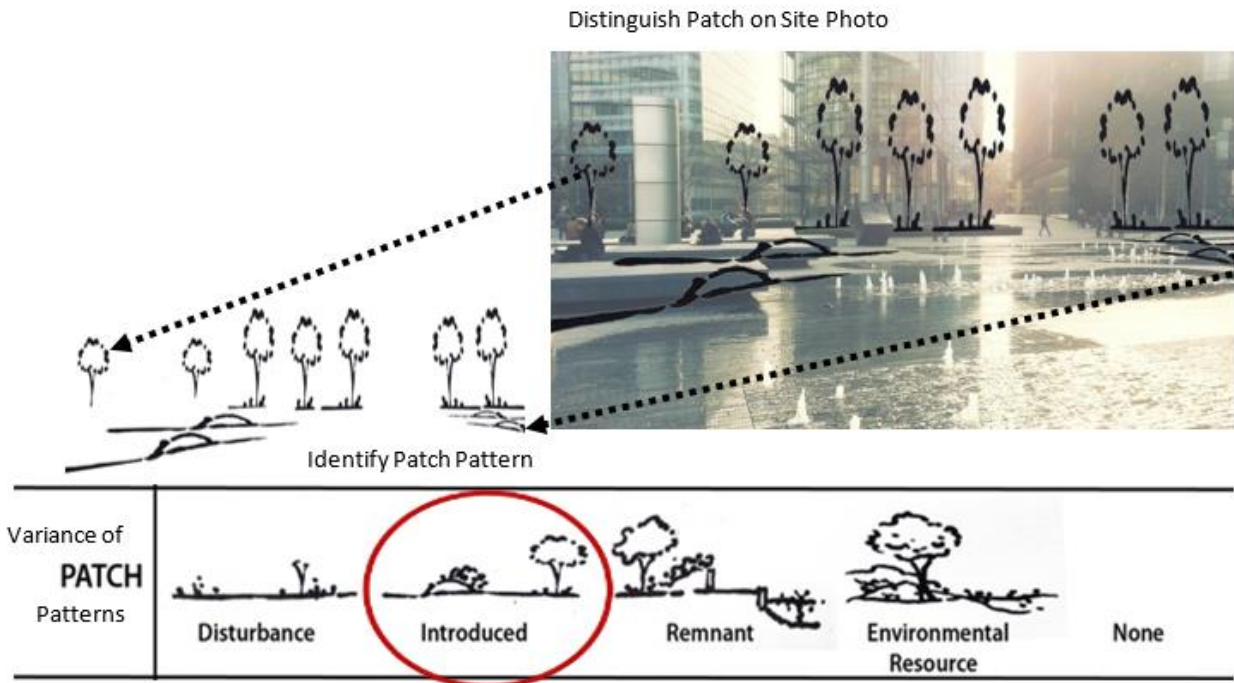


FIGURE 9: LANDSCAPE PATCH DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF PATCH PATTERN

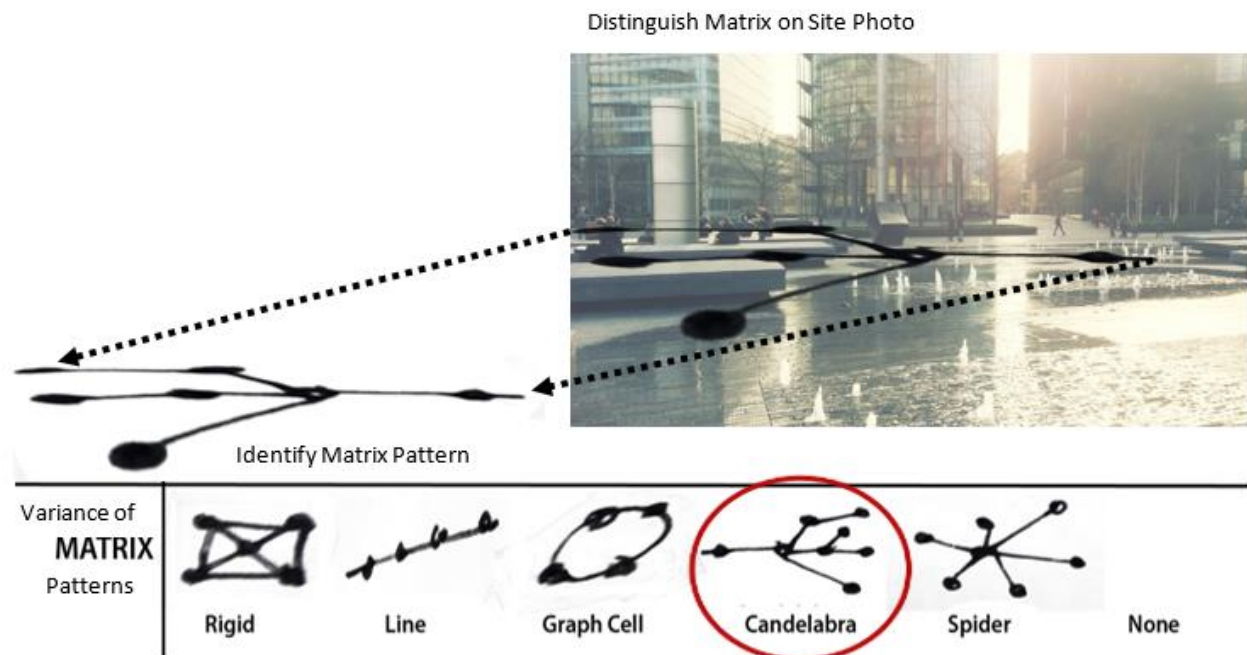


FIGURE 10: LANDSCAPE MATRIX DOCUMENTATION: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE LANDSCAPE CONFIGURATION CHARACTERISTIC OF MATRIX PATTERN

Data Analysis

3) Run the statistical data: For the qualitative data to be compared statistically, the design principles, and patterns discerned from the built environment were arranged as ordinal and nominal variables. The first step was the binary coding of the aerial images at site scale to a) to compare landscape patterns at the site scale to the regional landscape geography patterns between cities as well as b) within each city, c) to contrast the associated patterns of hard and soft urban spaces across Europe, and d) to quantify the totals of each landscape pattern.

TABLE 1: CODING OF EXISTANCE OF REGIONAL ECOLOGICAL LANDSCAPE PATTERNS

This shows the coding of documented regional pattern London City Hall Plaza.

City	Spiral	Branching	Meandering	Explosion	Packing
London-City Hall Plaza	1	0	1	0	0



FIGURE 11: LANDSCAPE PATTERN CODING: THIS VISUALLY SHOWS THE METHODOLOGY OF DOCUMENTING THE REGIONAL PATTERN FROM AN AERIAL PHOTO.

Subsequently, the landscape configurations (edge, patch, corridor, and matrix) were classified using ordinal evaluation from harsh characteristics to gradient ecotones. This was achieved by encoding the abrupt features with a low digit (1) and progressively ranking upward to (5) representing the most organic features. In cases where the image contained no such feature, 0 denoted the absence of a corresponding pattern. Assessment of ordinal variables from the qualitative configuration patterns is visible from the diagram in Figure 12.

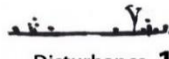
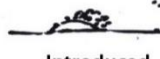
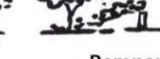
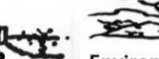
	Distinct Contrast Typically caused by disturbance				Gradual Succession Typically by natural processes	
EDGE	 Hard 1	 Wavy 2	 Bays & Ridges 3	 Emergent 4	None 0	
CORRIDOR	 Straight 1	 Varied Width 2	 Braided 3	 Weaving 4	 Broken 5	None 0
PATCH	 Disturbance 1	 Introduced 2	 Remnant 3	 Environmental Resource 4	None 0	
MATRIX	 Rigid 1	 Line 2	 Graph Cell 3	 Candelabra 4	 Spider 5	None 0

FIGURE 12: LANDSCAPE CONFIGURATION PATTERN CHART: THIS VISUALLY SHOWS THE VARIANCE OF THE LANDSCAPE CONFIGURATION PATTERN CHARACTERISTICS AND THEIR RANGE OF SEVERITY

Biophilic patterns as statistical data are dichotomous variables, coded from the site photos where biomorphic forms, material connection to nature, complexity, and order are each either portrayed or absent in the built environment. Instances where a biophilic pattern is successfully portrayed is coded with a (1) and images where a biophilic pattern is not evident or is absent are coded with a (0). An example of coding both the landscape configurations and the biophilic patterns can be seen in Table 2.

TABLE 2: ORDINAL CODING OF LANDSCAPE CONFIGURATION, DOMINANCE AND BINARY BIOPHILIC PATTERNS

This shows the visual analysis and coding of London City Hall Plaza.

London-City Hall Plaza	Edge Order	Corridor Order	Patch Order	Matrix Order	Dominant Feature	Biomorphic forms and patterns	Material connection with nature	Complexity	Order
L1	1	1	2	2	Corridor	0	1	0	1
L2	2	2	1	3	Patch	0	0	1	1
L3	1	1	1	2	Corridor	0	0	0	1
L4	4	2	2	5	Patch	0	1	1	0
L5	1	2	1	3	Edge	1	0	0	1
L6	3	2	1	4	Corridor	1	1	0	1
L7	1	2	1	1	Patch	0	0	0	1
L8	3	2	2	4	Corridor	1	1	1	1

In the sciences, principal component analysis (PCA) is used to cluster non-normalized statistical data and determine the relationships among variables using SPSS- IBM's Statistics Software Editor (Ringner 2008). PCA correlated the ordinal landscape configuration variables and the dichotomous biophilic pattern variables, using an oblique rotation to relate different types of categorical variables (Takane 2014). The rotation chosen was direct oblimin, a common method among the social sciences (Maribor 2012). PCA is beneficial when analyzing spatial and ecological data with different units of measurement (Murray 2002). In the field of ecology, it is typical to encounter multivariate datasets and use PCA as a method of data ordination. PCA uses a multivariate statistical technique to plot samples in two or more dimensions to represent as much of the variation as possible from the data set. Most of the original relationships are maintained between variables as information or as explained variance (Maribor 2012). Despite the different number of ordinal variables between the five describing edge/patches and the six depicting corridor/matrix, the scope across all landscape configuration features is analogous. Consequently, normality was not assumed; also, normalization was found to reduce the degree of correlation in ordinal landscape configuration metrics (Xianli Wang 2011).

In order to run PCA for the dominant landscape configuration features, the ordinal variables were reorganized as (1) for dominant or (0) for supporting. This transformation to

binary nominal variables allowed PCA to explain the variables interdependencies and extract principal components. Once the dominant landscape configurations were converted to nominal variables, the data set could be split between hardscapes or plazas and softscapes or parks within the built environment.

4) Interpret the relationships: This distinction provides further comparison between extracted components and their relationships. Principal components define particular relationships between patterns of biophilia, landscape configuration features, and/or dominant configurations features in the context of urban community space. These relationships could explain inverse associations, conditional groupings, special occurrences, and fundamentals of urban public spaces.

CHAPTER 4: DATA RESULTS

Overall Comparisons

Interpretation of the human connection to nature, biophilia, reflects society's understanding of their natural surroundings and geography's influence on the original spatial layout of European cities. Analysis of the aerial imagery and the identification of geographical landscape patterns indicated minimal correlation between the macro scale aerials of each city and the site specific aerials among all cities in the study and between scales within each city. In order to determine if geographical patterns have any influence on landscape patterns at the site scale, further studies would be needed. Since this data presented negligible relevance, it was not included with the statistical analysis of landscape configuration and biophilic pattern correlation at the site scale.

TABLE 3: AERIAL LANDSCAPE PATTERNS OF EUROPEAN CITIES

This shows that there is little to no correlation between regional patterns and site scale patterns.

City	Spiral	Branching	Meandering	Explosion	Packing
Barcelona-					
Diagonal Mar	0	1	0	1	0
Park Guell	0	0	1	0	0
London-					
City Hall Plaza	1	0	1	0	0
Hyde Park	0	1	0	0	1
Paris-					
La Grand Arc	0	1	0	0	1
Parc Citroen	0	0	0	0	1
Rotterdam-					
Museumplein	0	0	0	0	1
Het Park	0	0	1	0	1
Stockholm-					
King's Garden	0	0	0	0	1
Longholmen	0	0	1	0	1

TABLE 4: LANDSCAPE CONFIGURATION DATA

This shows how the visual analysis of landscape configuration was coded.

City/ Site	Img Code	Edge Order	Corridor Order	Patch Order	Matrix Order	Dominant Feature
Barcelona-Diagonal Mar	B1	4	2	1	3	Patch
	B2	2	1	3	2	Corridor
	B3	1	3	2	3	Edge
	B4	2	1	2	1	Matrix
	B5	3	1	2	2	Corridor
	B6	4	2	3	4	Corridor
	B7	1	1	2	2	Edge
	B8	3	3	2	4	Patch
Park Guell	Bg1	2	3	3	3	Edge
	Bg2	2	2	2	4	Patch
	Bg3	1	5	2	3	Edge
	Bg4	4	3	1	5	Patch
	Bg5	3	3	2	5	Patch
	Bg6	1	2	2	2	Edge
	Bg7	2	4	2	2	Matrix
	Bg8	1	1	2	2	Corridor
London- City Hall Plaza	L1	1	1	2	2	Corridor
	L2	2	2	1	3	Patch
	L3	1	1	1	2	Corridor
	L4	4	2	2	5	Patch
	L5	1	2	1	3	Edge
	L6	3	2	1	4	Corridor
	L7	1	2	1	1	Patch
	L8	3	2	2	4	Corridor
Hyde Park	Lh1	4	1	3	2	Corridor
	Lh2	3	1	2	2	Corridor
	Lh3	4	1	3	1	Corridor
	Lh4	2	4	2	3	Patch
	Lh5	1	3	2	1	Matrix
	Lh6	2	4	2	3	Patch
	Lh7	3	5	4	3	Patch
	Lh8	4	2	3	3	Corridor
Paris- La Grand Arc	P1	1	0	1	3	Edge
	P2	4	4	2	5	Patch
	P3	4	3	2	5	Patch
	P4	3	2	2	1	Matrix
	P5	1	1	1	1	Patch
	P6	1	1	2	2	Corridor
	P7	1	1	2	2	Corridor
	P8	1	1	1	3	Patch

TABLE 4 (CONT'D):

City/ Site	Img Code	Edge Order	Corridor Order	Patch Order	Matrix Order	Dominant Feature
Parc Andre Citroen	Pc1	3	1	2	2	Corridor
	Pc2	1	1	2	2	Edge
	Pc3	4	1	2	2	Corridor
	Pc4	2	1	2	2	Corridor
	Pc5	3	4	2	4	Patch
	Pc6	1	1	2	1	Matrix
	Pc7	2	2	2	4	Patch
	Pc8	3	1	2	2	Corridor
Rotterdam- Museumplein	R1	4	1	3	5	Corridor
	R2	1	1	2	1	Matrix
	R3	1	0	1	3	Patch
	R4	1	1	2	2	Corridor
	R5	3	4	3	3	Patch
	R6	4	3	3	5	Patch
	R7	1	5	3	3	Edge
	R8	1	0	2	3	Edge
Het Park	Rh1	4	5	3	3	Patch
	Rh2	3	1	2	2	Corridor
	Rh3	2	1	3	3	Corridor
	Rh4	3	4	3	3	Matrix
	Rh5	2	5	3	3	Edge
	Rh6	4	5	3	2	Matrix
	Rh7	2	4	2	5	Patch
	Rh8	2	1	2	2	Corridor
Stockholm- Kings Garden	S1	4	1	1	4	Patch
	S2	4	0	1	3	Patch
	S3	1	1	3	4	Edge
	S4	4	1	2	2	Corridor
	S5	1	3	2	4	Edge
	S6	2	2	2	3	Matrix
	S7	3	3	2	1	Matrix
	S8	1	3	2	1	Matrix
Longholmen	Sl1	2	0	4	3	Edge
	Sl2	2	5	4	3	Edge
	Sl3	3	1	2	3	Corridor
	Sl4	2	2	3	4	Corridor
	Sl5	2	1	3	2	Corridor
	Sl6	2	3	2	4	Patch
	Sl7	2	4	4	2	Matrix
	Sl8	1	1	3	2	Edge

TABLE 5: BIOPHILIC PATTERN DATA

This shows how the visual analysis of biophilic patterns were coded.

City/ Site	Img Code	Biomorphic forms and patterns	material connection with nature	Complexity	Order
Barcelona-Diagonal Mar	B1	1	1	1	0
	B2	1	1	0	1
	B3	1	1	0	1
	B4	0	1	0	0
	B5	1	1	1	1
	B6	1	1	0	1
	B7	1	1	1	1
	B8	1	1	0	1
Park Guell	Bg1	1	1	1	1
	Bg2	1	1	1	1
	Bg3	1	1	0	1
	Bg4	1	0	0	1
	Bg5	1	1	1	1
	Bg6	1	1	0	1
	Bg7	1	1	0	1
	Bg8	1	1	0	1
London- City Hall Plaza	L1	0	1	0	1
	L2	0	0	1	1
	L3	0	0	0	1
	L4	0	1	1	0
	L5	1	0	0	1
	L6	1	1	0	1
	L7	0	0	0	1
	L8	1	1	1	1
Hyde Park	Lh1	1	1	0	1
	Lh2	1	1	0	1
	Lh3	1	1	0	0
	Lh4	0	1	0	1
	Lh5	0	1	0	1
	Lh6	1	1	0	1
	Lh7	1	1	0	1
	Lh8	1	1	0	1
Paris- La Grand Arc	P1	0	1	0	1
	P2	1	0	0	1
	P3	1	0	0	1
	P4	1	1	1	0
	P5	1	1	0	1
	P6	0	1	0	1
	P7	0	1	0	1
	P8	1	0	0	1

TABLE 5 (CONT'D):

City/ Site	Img Code	Biomorphic forms and patterns	material connection with nature	Complexity	Order
Parc Andre Citroen	Pc1	0	1	0	1
	Pc2	0	1	0	1
	Pc3	1	1	0	1
	Pc4	1	1	0	1
	Pc5	1	1	1	1
	Pc6	0	1	0	1
	Pc7	1	1	0	1
	Pc8	0	1	0	1
Rotterdam- Museumplein	R1	1	1	0	1
	R2	0	1	0	1
	R3	0	0	0	1
	R4	1	1	1	1
	R5	0	1	1	1
	R6	1	1	0	1
	R7	1	1	0	1
	R8	1	1	0	1
Het Park	Rh1	0	1	0	1
	Rh2	1	1	0	1
	Rh3	0	1	0	1
	Rh4	0	1	0	1
	Rh5	0	1	0	1
	Rh6	0	1	0	1
	Rh7	0	1	0	1
	Rh8	0	1	0	1
Stockholm- Kings Garden	S1	0	1	0	1
	S2	1	0	0	1
	S3	1	1	0	1
	S4	1	0	0	1
	S5	0	1	0	1
	S6	0	0	0	1
	S7	0	1	0	1
	S8	0	1	1	1
Longholmen	Sl1	0	1	0	1
	Sl2	1	1	0	1
	Sl3	0	1	0	1
	Sl4	0	1	0	1
	Sl5	0	1	0	1
	Sl6	0	1	0	1
	Sl7	1	1	0	1
	Sl8	0	1	0	1

Natural Patterns in Urban Public Spaces

The preliminary PCA included both types of urban public space, (hardscape and softscape), the Kaiser-Meyer-Olkin sampling adequacy determined more test samples were required to substantiate the statistical results and adequately represent these correlations, reflecting a type 2 error. Three components were extracted which demonstrated relationships between a) the elements of the landscape configuration, b) patch order and material connection to nature, and c) complexity and order, which can be seen in table 6. The

TABLE 6: PRINCIPAL COMPONENT ANALYSIS OF URBAN PUBLIC SPACES

This shows the extracted components and the relationship between variables.

	Component Matrix ^a		
	Component		
	Ecological System	Process Integration	Optimum Proportions
Edge Order	.657	-.349	-.060
Corridor Order	.619	.247	.273
Patch Order	.541	.690	-.003
Matrix Order	.587	-.368	.435
Biomorphic Forms	.458	-.345	.001
Material Connection	.287	.681	-.438
Complexity	.264	-.321	-.566
Order	-.140	.243	.784

Extraction Method: Principal Component Analysis.

correlation between patch order and material connection to nature display how natural materials are most commonly introduced within a site. Complexity and order have an inverse relationship within the built environment revealing urban spaces can either recreate the complexities of the natural systems or their order structure.

PCA of urban parks (softscape) extracted four components a) matrix order, material connection to nature and complexity, b) edge order and the biophilic pattern of order, c)

corridor order, patch order and material connection to nature, and d) complexity. The extracted components are shown in table 7 below. The correlation of matrix order displays an inverse relationship with material connection to nature as well as a positive relationship with

TABLE 7: PRINCIPAL COMPONENT ANALYSIS OF URBAN PARKS (SOFTSCAPES)

This shows the extracted components and the relationship between variables.

Component Matrix ^{a,b}				
	Component			
	1	2	3	4
Edge Order	.313	-.675	.107	-.362
Corridor Order	.440	.227	.582	-.346
Patch Order	-.310	-.087	.791	-.241
Matrix Order	.816	.254	.082	-.139
Biomorphic Forms	.446	-.463	.131	.447
Material Connection	-.566	.218	.513	.426
Complex	.578	.051	.247	.635
Order	.227	.784	-.097	-.089

complexity. This shows that complex matrices had minimal natural materials. The inverse relationship between edges and order exhibited that softer edges (in comparison to abrupt hard edges) emulated the biophilic pattern of natural order better. The third component presented that natural materials were most commonly found in both patches and corridors of parks. Complexity as a sole component might explain that parks across all sites demonstrated the biophilic pattern of replicating the complexity of natural systems.

Three components were extracted in the PCA of urban plazas (hardscapes) which is displayed in table 8. The relationships extracted included: a) all aspects of landscape configurations and biomorphic forms and patterns, b) matrix order, material connection to nature, complexity and order, and c) edge order, patch order, material connection to nature, and the biophilic pattern of order. Interpretation of the first component represents the appearance of biomorphic forms and patterns within all aspects of the landscape of urban

plazas. Matrices inverse relationship with both material connection to nature and complexity demonstrates the rigidity of urban plazas lack the integration of natural materials and emulation of the complexity of natural systems. The positive relationship between matrices and order shows that the rigidity of plazas reflects the spatial hierarchy and order of the natural

TABLE 8: PRINCIPAL COMPONENT ANALYSIS OF URBAN PLAZAS (HARDSCAPES)

This shows the extracted components and the relationship between variables.

	Component		
	1	2	3
Edge Order	.707	.111	-.507
Corridor Order	.577	.032	.196
Patch Order	.642	-.095	.620
Matrix Order	.651	.500	-.187
Biomorphic Forms	.520	.254	-.067
Material Connection	.328	-.596	.517
Complexity	.239	-.691	-.279
Order	-.199	.668	.502

environment. The final component clarifies that natural materials and spatial hierarchy (the biophilic pattern of order) are visible in the patches and not edges of plazas. Together the interpretation, quantity, and record of patterns types at a contextual built environmental scale display minimal relation to the surrounding natural environment while the human scale demonstrates principles of biomorphic patterns and the complex nature of spatial hierarchy of landscape configuration features.

CHAPTER 5: DISCUSSION

Patterns in the Built Environment

This study focused on European cities rather than American due to their history and nature of creation. Metropolitan areas in Europe developed organically, lacking formal land planning until centuries after the city framework was in place, unlike most American cities which were master-planned from the beginning. Pre-dating medieval times, cultures in Europe oriented their cities around natural features; existing waterways, topography, and regional landscape geography (Branch 1997). These cities were chosen due to their regional geography; which in aerial view provided an overview of the site surroundings at the meso scale, where general landscape patterns were extracted. Together these cities comprised each of the five general landscape patterns: spiral, meandering, explosion, branching, and packing. Perception and imitation of these regional patterns at the human scale does not necessarily contribute to the human benefit or ecology of a specific site. Although, it could be beneficial for designers to be aware of the framework that guides and connects urban ecosystems. Landscape configuration is not limited to the four features studied; by widening the scope of environment, matrices interconnected and form a network that can be studied at the regional or city-wide scale. This relates the aerial landscape pattern to a series of sites' matrix patterns. In this scenario, a city is a closed system where society would strive to maintain negative feedback loops that guide a stable urban ecosystem (Beck 2013).

Within the environment, characteristics of the landscape range from harsh to gradient ecotones creating a woven fabric (Dramstad 1996). The configuration of these characteristics govern how the space can be used, which indicates the importance of landscape configuration

patterns to the evaluation of the urban environment. Analysis of these existing configurations will demonstrate how people design their environment in comparison to natural evolution. Even though human development tends to have harsh distinctive characteristics; a few given features could be naturalized and the landscape dynamic would shift. Change in land use cover was identified as a direct driver of ecological advancement (Millennium Ecosystem Assessment 2005). Altering the characteristics of the landscape without changing the spatial configuration of the built environment would allow for adaptability (King 2014). Softer edges would not affect the size of gathering spaces- patches, or roadways- corridors. Humans would benefit from increased access to nature as well as opportunity to biophilia (Garvin 2015).

Community or public spaces, specifically a plaza or a park within an urban environment, have high potential for biophilic patterns and use of imitating nature for ecological and human benefits (Center for Neighborhood Technology 2010). Biophilic patterns can be identified through visual analysis of the urban environment at the micro/ human scale. These landscape characteristics distinguish the occurrence of biomorphic forms and patterns, material connections to nature, and spatial hierarchy reminiscent of the natural environment's complexity and order. *14 Patterns of Biophilic Design* (Browning 2014) exemplifies real-world applications of biomorphic forms and patterns which metaphorically translate a three-dimensional form or two-dimensional pattern found in the surrounding region's ecology to an aspect of the built environment. Another biophilic pattern, material connection to nature, is fairly self-explanatory: an element of the space is made out of a natural material. The last biophilic pattern of focus is the concept of complexity and order, where the site is spatially

organized to imitate the structure as well as the elaborate functions that exist in the natural landscape (Browning 2014).

Overview of Existing Patterns

Interpretation of the statistical data from existing landscape configuration principles and relation to biophilic patterns demonstrates the current level of designed integration of natural elements within urban public space. This establishes a need for further research of integrating both visual metaphoric and dynamic spatial natural elements into usable human space within the built environment. Currently, patches within urban parks and plazas represent the 'human habitat' or gathering space among the built environment which might explain the high usage of natural materials through vegetation, stone, wood, and water features. Urban public spaces demonstrate a peculiar emulation of nature, differentiating between the integration of functional natural systems, which have complex ecological dynamics, and the visual implementation of structural order and spatial hierarchy. Parks that emulated stronger ecotones, allowing organic movement within the space, and tended to use more natural materials. Furthermore, the adoption of natural edges exemplified the biophilic pattern of natural order. The use of natural materials is more evident in parks, due to higher usage of vegetation in patches. This occurred both literally, as lawn and canopy cover, as well as metaphorically, in the organic shape and material of pathways. Unlike plazas, parks exhibited integration of complex natural systems, allowing ecological processes to occur within the built environment. Plazas metaphorically integrated natural elements into their design, visible through biomorphic forms and patterns; this displays reductive biomimicry. Additionally, plazas with more rigid or geometric designs featured fewer natural elements in their materials,

resulting in a disassociation with complex ecosystems. Despite the physical disconnect with natural materials and systems, plazas spatially imitated nature through reductive biomimicry through the hierarchy of site elements, specifically within patches and gathering spaces, not edges.

Applied Patterns in Design

These correlations between landscape configuration and biophilia expose three concepts; 1) public space as a paradox, 2) ecological authenticity, and 3) metaphorical biophilia. Public space is a third-place, away from home or work within the urban environment that provides the community space to recreate, relax, and gather. Parks and plazas are both public space and offer similar amenities, even though they have adverse components. Parks show biophilic complexity in matrices and edges while plazas are spatial ordered patches and corridors. Moreover, all landscape configuration features in plazas exhibit biomorphic patterns while parks display none. This could be interpreted parks and plazas as opposite forms of public space. Softscapes or urban parks' extracted a principle which presents a spatial hierarchy gradient edges, through an inverse correlation between edge and natural order. The negative edge means that it has natural characteristics and a positive correlation with natural order shows occurrence. Park edges provide varying levels of enclosure and are visibly complement the landscape. This analysis emulates the authenticity of natural ecology typically found in parks'. Hardscapes or urban plazas' component relationship demonstrates a rigid spatial hierarchy while also manufactured simplicity. This can be understood by the positive components of matrices- harsh, and occurrence of natural order, as well as the negative component occurrence of natural complexity- simplicity, and natural materials- manmade.

Plazas by design are large open areas for social events; understandably why the component relationship demonstrates lack of complexity and strong spatial order. Even though, the disintegration of natural materials is not necessary to the design of a plaza. Accordingly, this indicates plazas' visual metaphors for natural elements- biophilia.

Consequently, these correlated relationships show their respective characteristics of parks and plazas and allow for comparison. While the ability to derive common traits from urban public space is enjoyable, this method could be used for the synthesis of large urban areas for potential design applications. For example, using natural materials to soften the rigidity of the space. By extracting distinguishable attributes from the analysis, positive or negative, designers can create integrative design solutions. Future analysis could test the occurrence of additional biophilic patterns to specific characteristics of landscape configuration. The increase of variables has the potential to distinguish additional correlations and potentially incorporate multiple aspects for a dynamic design.

General Design Application

Conceptually humans function similarly to other animals within the natural landscape, yet are fundamentally removed and generally exist within a sterile and static (built) environment (Wilson 1995). Urban ecology recognizes that human structures, economic trends, and social processes are explicitly incorporated with biophysical forces, demonstrated through the principles of biophilia (Bejan 2012). Thus human-driven systems interact with ecological elements in a spatially heterogeneous manner, which determines the characteristics and behavior of the urban ecosystem (Beck 2013). Following along the metaphor of natural dynamics, designers have the ability to act as regulating services, or as external forces, upon the

natural ecosystem or city. By selecting specific characteristics of the built environment which are resilient, adaptable, and will survive over time, the urban ecosystem has the means to evolve. With this mentality, it is plain to see how designing with landscape configurations allows for the integration of organic features into the built environment. Through utilization of landscape configuration principles, nature can be directed in manners conducive to both biophilic needs of people, as well as sustainability (Gamage 2012).

Ecologists offer scientific means to socially improve the human quality of life in addition to incorporating environmental measures in cities, to create functional urban ecosystems (Beck 2013). The dynamics of natural systems can be applied to designing urban systems, through categorization of human spaces as elements of landscape configuration and application of scientific reasoning of functional and contextual adaptations (Gamage 2012). The statistical results indicate the lack of connection to the surrounding ecosystem and that manipulation of these existing landscape configuration patterns (edge, patch, corridor, matrix) will determine how humans are able to connect to urban ecosystem. For example, biomorphic forms and patterns, while reductive in design could apply functions processes from the natural landscape to work with the site ecology, rather than against it. This could be accomplished through materials; constructed from natural resources without waste product. Locally-sourced materials are not only ecological but also reflect place identity, which contributes to community and culture.

From this analysis of urban public space, their designs indicate that the integration of nature is limited to the reductive use of nature as a metaphorical in two- or three-dimensional elements in plazas or through emulation/preservation of natural ecosystems in parks. This

demonstrates the reductive approach designers have adopted as technology has developed, resulting from human divergence from nature, especially evident in the urban environment (Wilson 1995). Biophobia has perpetuated minimal natural contributions within urban spaces and validated the need to further integrate nature into the design (Born 2001). Human development has always been dictated by culture, metaphysical and aesthetic rather than functionality, unlike animal construction which focuses on functionality, ecological adaptability, structural strength, efficiency of energy systems, beauty and precision (Woolley-Barker 2013).

The Future of Patterns

Increased urbanization and their associated environmental problems demand changes toward creating a sustainable future (Browning 2014). Especially changes for the conservation value of land within the built environment, and even more so in Europe due to its long history of development (Beck 2013). The first step, in order to be effective, is to understand the heterogeneity of urban ecosystems, including the interactions between social and ecological factors. On a broad scale, best management practices have less impact than designs tailored to the physical surroundings and social environment. People, just as all organisms, are a part of the ecosystem and impact the patch dynamics. Implementation of landscape configuration principles into the design method can adapt and improve the ecological function of the space. Nested patches connect the built environment to the surrounding regional landscape through ecological nodes of activity which allow energy and organisms to move throughout as needed (Beck 2013). Built landscapes can help protect regional biodiversity when and if it permits the urban landscapes to evolve and adapt over time. “Nature must be thought of, not as of a luxury

to be made available if possible, but as a part of our inherent indispensable biological need” (Todd 1982).

Currently urban landscapes, as evidenced from this study, are designed for aesthetics and include a variety of societal programmatic elements, and at most incorporate reductive biomimicry. True incorporation of biophilia requires landscapes to function as ecosystems; provide ecological services and fulfill the human attraction of natural wonders (Wilson 1995). In order to do so, nature should be integrated through a variety of biological and physical elements including plants, animals, and microorganisms at different trophic levels. This would produce a landscape “so intelligently designed and constructed that it mimics nature at every step, a symbiosis of company, consumer, and ecology” (Hawken 1993). Responsive interactions with the native biome, that maintain the life of that area, are better than the generic lawns and trees found in typical urban spaces (Beck 2013).

Complex adaptive natural systems are diverse, aggregated, nonlinear, and connected by flows throughout all (micro, meso, and macro) scales. The interaction between scales allows the biological elements to develop their own arrangements within the built environment, adapt and change over time. Conceptually integrating natural elements into urban design at a variety of scales; from the top down, bottom up, and middle out, should accelerate the consolidation of the urban ecosystem and the environment (Maser 2012). This type of complex adaptive urban ecosystem would allow emergent properties to become established within the built environment. These emergent properties carry great importance because they include ecosystem services which humans as well as many other species depend on (Beck 2013).

Biomimicry and biophilia work hand in hand as principles of ecological design. These methods are a process, and sustainability is the final product (Woolley-Barker 2013). This creates cyclical development based in the concept of biophilia and the human need for access to nature, continued through design inspired by nature. Biomimicry at a systematic scale (not solely reductive or to solve a singular function) incorporates regional connections with the surrounding natural systems within the urban environment. These designed urban ecosystems provide a new approach for humans to interact with nature in their built environment (King 2014). However, designed landscapes do not necessarily function in the entirely same manner as natural ecosystems. The urban ecosystem must accommodate both the biological processes that arise from the interactions between living organisms, as well as human needs and desires. Adaptive management that prioritizes conservation in the planning process helps to keep an urban ecosystem dynamic over time (Beck 2013). Successful urban ecosystems have the potential to reach and maintain a stable dynamic, hypothetically more self-sustaining and regenerative than alternative mediating solutions, including green infrastructure and best management practices (Gamage 2012).

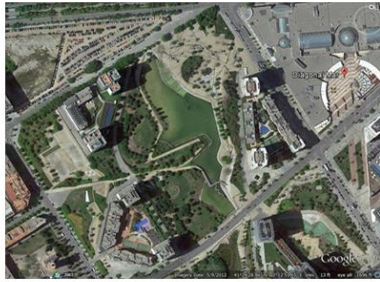
Adopt, Apply and Adapt

For landscape architects, the idea that ‘design is in the details’; indicates the contextual applicability of knowledge to the practice of design (King 2014). While “everything exists within the landscape,” (Benyus 2009) designers must determine the scope of their work: from the natural (restoration) to the urban (plazas). Urban spaces range from reconstructing landscape systems to the application of site elements, or simultaneously providing multiple overlapping functions of ecology and utility (Goldstein 2015). This maneuvers landscape architects, and the

design profession, to the instigator position of ecological integration of urban spaces (Thompson 2003). Even the densest cities, acting as urban ecosystems, have interactions between biophysical forces and social and economic trends (Bejan 2012). The shift from reductive aesthetic design to environmental design appropriately accommodates the exchange of culture through nature and adoption of living elements instead of the use of static materials (King 2014). The disintegration of society from nature can be remediated by looking to nature (Wilson 1995). “All life evolves by the differential survival of replicating entities” (Dawkins 1976). Where there is life, there must be replicators. Conceptually, evolution embodies a continuous exchange of information between organisms and the environment; where replicators in nature share information through repetition, replication or imitation of an idea (Gleick 2011). In order for the widespread adoption of ecological design practices in the urban environment, society must replicate information transfer as it happens in nature (Woolley-Barker 2013). The underlying solution: propagation of biomimicry (generalization of the concept allows for greater mass attention to both biophilic patterns and landscape configuration) as a cultural meme and driving force (Gleick, J., et al. Smithsonian Magazine 2011).

APPENDICES

Appendix A: Aerial Site Photos for General Ecological Patterns



Barcelona: Diagonal Mar



Barcelona: Parc Guell



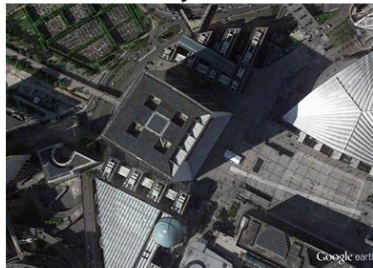
London: Hyde Park



London: City Hall Plaza



Paris: Parc Andre Citroen



Paris: La Grand Arc



Rotterdam: Het Park



Rotterdam: Museumplein



Stockholm: King's Garden



Stockholm: Longholmen

FIGURE 13: GENERAL LANDSCAPE PATTERNS: THIS SHOWS THE FIVE GENERAL LANDSCAPE PATTERNS OF LONDON CITY HALL PLAZA

Appendix B: Perspective Photos for Landscape Configuration and Biophilic Patterns



B1



B5



B2



B6



B3



B7



B4



B8

FIGURE 14: BARCELONA (HARDSCAPE): DIAGONAL MAR



BG1



BG5



BG2



BG6



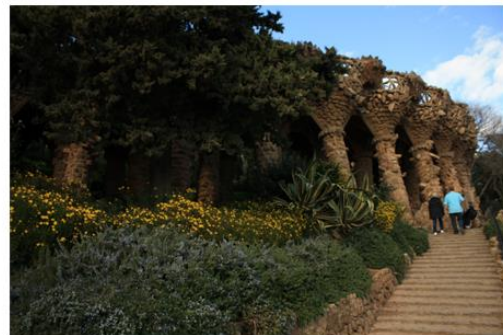
BG3



BG7



BG4



BG8

FIGURE 15: BARCELONA (SOFTSCAPE): PARC GUELL



L1



L5



L2



L6



L3



L7



L4



L8

FIGURE 16: LONDON (HARDSCAPE): CITY HALL PLAZA



LH1



LH5



LH2



LH6



LH3



LH7



LH4

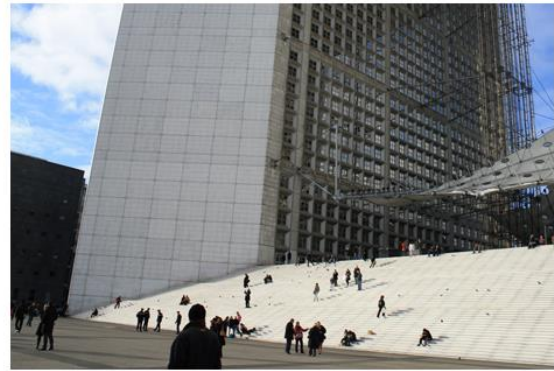


LH8

FIGURE 17: LONDON (SOFTSCAPE): HYDE PARK



P1



P5



P2



P6



P3



P7



P4



P8

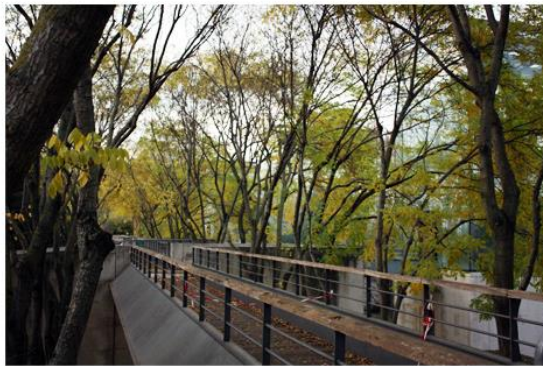
FIGURE 18: PARIS (HARDSCAPE): LA GRAND ARCHE



PC1



PC5



PC2



PC6



PC3



PC7



PC4



PC8

FIGURE 19: PARIS (SOFTSCAPE): PARC ANDRE CITROEN



R1



R5



R2



R6



R3



R7



R4



R8

FIGURE 20: ROTTERDAM (HARDSCAPE): MUSEUMPLEIN



RH1



RH5



RH2



RH6



RH3



RH7



RH4

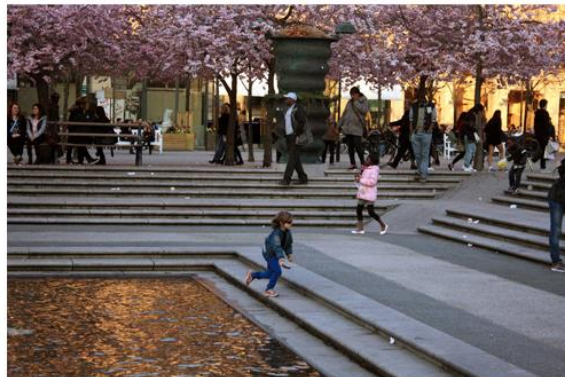


RH8

FIGURE 21: ROTTERDAM (SOFTSCAPE): HET PARC



S1



S5



S2



S6



S3



S7



S4



S8

FIGURE 22: STOCKHOLM (HARDSCAPE): KING'S GARDEN



SL1



SL5



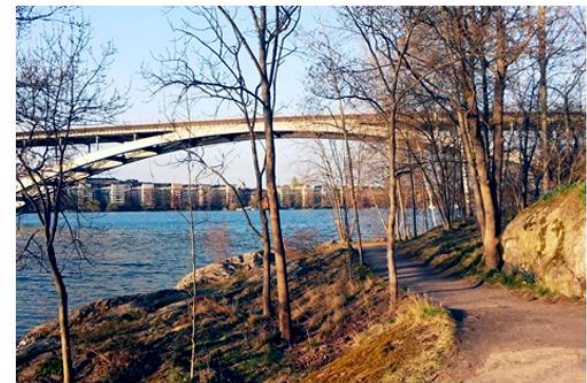
SL2



SL6



SL3



SL7

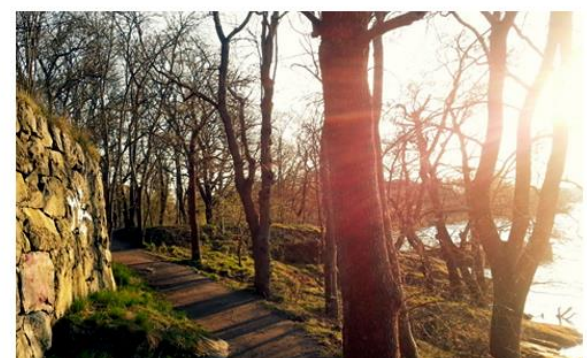


FIGURE 23: STOCKHOLM (SOFTSCAPE): LONGHOLMEN

Appendix C: Statistical Data Adequacy and Relevance

TABLE 9: SAMPLING ADEQUACY FOR PUBLIC PARKS AND PLAZAS

This shows a type 2 error requiring a larger test group

Kaiser-Meyer-Okin Measure of Sampling Adequacy.		.493
Bartlett's Test of Sphericity	Approx. Chi-Square	82.061
	df	28
	Sig.	.000

TABLE 10: VARIANCE EXPLAINED FOR PUBLIC PARKS AND PLAZAS

This shows that the extracted components explain 60% of the total variance.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative	Total
1	1.832	22.899	22.899	1.632	22.899	22.899	1.736
2	1.539	19.235	42.135	1.539	19.236	42.135	1.630
3	1.394	17.421	59.556	1.394	17.421	59.558	1.125
4	.902	11.275	70.831				
5	.359	10.739	81.570				
6	.635	7.932	89.502				
7	.452	5.774	95.276				
8	.378	.724	100.00				

TABLE 11: VARIANCE EXPLAINED FOR PUBLIC PLAZAS (HARDSCAPES)

This shows a type 2 error requiring a larger test group

Kaiser-Meyer-Okin Measure of Sampling Adequacy.		.535
Bartlett's Test of Sphericity	Approx. Chi-Square	54.298
	df	28
	Sig.	.002

TABLE 12: VARIANCE EXPLAINED FOR PUBLIC PLAZAS (HARDSCAPES)

This shows that the extracted components explain 63% of the total variance.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative	Total
1	2.144	26.798	26.798	2.144	26.798	26.798	1.971
2	1.615	20.192	46.990	1.615	20.192	46.990	1.558
3	1.316	16.448	63.438	1.316	16.448	63.438	1.667
4	.921	11.511	74.949				
5	.744	9.294	84.243				
6	.533	6.669	90.912				
7	.408	5.103	96.014				
8	.319	3.986	100.00				

TABLE 13: SAMPLING ADEQUACY FOR PUBLIC PARKS (SOFTSCAPES)

This shows a type 2 error requiring a larger test group

Kaiser-Meyer-Okin Measure of Sampling Adequacy.			.473
Bartlett's Test of Sphericity	Approx. Chi-Square		44.918
	df		28
	Sig.		.022

TABLE 14: VARIANCE EXPLAINED FOR PUBLIC PARKS (SOFTSCAPES)

This shows that the extracted components explain 73% of the total variance.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative	Total
1	1.960	24.499	24.499	1.960	24.499	24.499	1.620
2	1.458	18.228	42.727	1.458	18.228	42.727	1.430
3	1.334	15.577	59.404	1.334	15.577	59.404	1.523
4	1.120	14.004	73.408	1.120	14.004	73.408	1.431
5	.735	9.187	82.595				
6	.597	7.455	90.060				
7	.485	5.039	95.120				
8	.310	3.830	100.00				

REFERENCES

REFERENCES

- Allen, W. 2012. "Advancing Green Infrastructure at All Scales: From Landscape to Site." *Environmental Practice* 17-25.
- Baird, G. 2009. "Incorporating User Performance Criteria into Building Sustainability Rating Tools for Buildings in Operation." *Sustainable Development* 1069- 1086.
- Beck, T. 2013. *Principles of Ecological Landscape Design*. Washington D.C.: Island Press and Center for Resource Economics.
- Bejan, A., J.P. Zane. 2012. *Design in Nature: How the Constructural Law Governs Evolution in Biology, Physics, Technology, and Social Organization*. New York: Penguin Random House.
- Bell, S. 2012. *Landscape Pattern, Perception, Process*. New York: Routledge.
- Benjamin, D., interview by Metropolis Magazine. 2011. Q&A (April 14).
- Benyus, J. 2009. *Biomimicry: Innovation Inspired by Nature*. New York: Harper Collins.
2005. *Biomimicry's Surprising Lessons from Nature's Engineers*. Directed by TED. Performed by J. Benyus.
- Berardi, U. 2012. "Sustainability Assesment in the Construction of Sector Rating Systems and Rated Buildings." *Sustainable Development* 411-424.
- Biomimicry Guild. 2014. *Learning from Termites How to Create Sustainable Buildings*. November.
- Born, R.J., G. Van Den. 2001. "The New Biophilia: An Exploration of Visions of Nature in Western Countries." *Environmental Conservation* 65-75.
- Branch, Melville C. 1997. *An Atlas of Rare City Maps: Comparative Urban Design 1830-1842*. New York : Princeton Architectural Press.
- Browning, W.D., C.O. Ryan, J.O. Clancy. 2014. *14 Patterns of Biophilic Design*. New York: Terrapin Bright Green.
- Buckminster Fuller, R. 1972. *Buckminster Fuller to the children of Earth*. Garden City: Doubleday.
- Carter, T., E.C. Cromle. 2005. *Invitation to Vernacular Architecture: A Guide to Study Ordinary Buildings and Landscapes*. Nashville: University of Tennessee Press.
- Center for Neighborhood Technology. 2010. "The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental and Social Benefits."
- Columbia Law School. 2014. *Environmental Commissioner of the EU Addresses Global Responsibility For a Sustainable Economy*. New York, September 17.

- Cumming, G., A. Buerkert, E. Hoffmann, E. Schlecht, S. VonCramon-Taubadel & T. Tschardtke. 2014. "Implications of Agricultural Transitions and Urbanization for Ecosystem Services." *Nature: International Weekly Journal of Science* 50-57.
- Dawkins, R. 1976. *The Selfish Gene*. Oxford: Oxford University Press.
- Dramstad, W.E., J.D. Olson, R.T.T. Forman. 1996. *Landscape Ecology Principles: in Landscape Architecture and Land-Use Planning*. Washington D.C.: Harvard University Graduate School of Design.
- Dubé, R. 1997. *Natural Pattern Forms: A Practical Sourcebook for Landscape Design*. New York: Van Nostrand Reinhold.
- Felson, A. 2015. *Transformational Learning: Integrate Ecological Research into Design*. Chicago: American Society of Landscape Architects, November 8.
- Felson, A., M. Pavao-Zuckerman, T. Carter, F. Montalto, B. Shuster, N. Springer, E. K. Stander, and O. Starry. 2013. "Mapping the Design Process for Ecology Researchers." *BioScience* 854- 865.
- Forest Research. 2010. *Benefits of Green Infrastructure*. Farnham: Forest Research.
- Frosh, R.A., N.E. Gallopoulos. 1989. "Strategies for Manufacturing." *Scientific American* 144-152, 261.
- Gamage, A., R. Hyde. 2012. "A Model Based on Biomimicry to Enhance Ecologically Sustainable Design." *Architectural Science Review* 224-235.
- Gartner, T. K. DiFrancesco. 2015. "From Gray to Green: Investing in Natural Infrastructure to Address Water, Food and Energy Challenges." *World Resources Institute*, August 11.
- Garvin, C. 2015. *Designing for a Moving Target: Ensuring Human Health in a Changing Climate*. New York, August 11.
- Gleick, J., et al. Smithsonian Magazine. 2011. *What Defines a Meme?* May.
- Global Sustainable Development Report. 2015. *Improved Science Needed for Sustainable Development Decision-Making*. New York: Lowe-Martin.
- Goldstein, J., E. Johnson. 2015. "Theory, Culture, and Society." *University of Exeter, and Virginia Commonwealth University* 61-81.
- Harmon, D. 2013. *Collected Online Writings of Dan Harmon*. August 30.
- Hawken, P. 1993. *The Ecology of Commerce: A Declaration of Sustainability*. New York: HarperBusiness.
- Ingels, B., interview by Louisiana Channel. 2015. *Advice to the Young* (January 8).

- Isenmann, R. 2003. "Industrial Ecology: Shedding More Light on its Perspective of Understanding Nature as a Model." *Sustainable Development* 143-158.
- Jobs, S., interview by W. Isaacson. 2011. *Biography & Autobiography* (October 24).
- Jorgensen, S.E., et al. 1986. *Ecosystem Ecology: A New Synthesis*. Ulanowicz: CRC Press.
- King, J. 2014. *Landscape + Urbanism: Bio-innovation, Biomimicry, and Biological Design*.
- Kirkwood, N. 1999. *The Art of Landscape Detail- Fundamentals, Practices and Case Studies*. New York: John Wiley & Sons.
- Koeper, H.F. 1958. *Louis Sullivan American Architect*. July 15.
- Lawson, B. 2006. *How Designers Think*. New York : Routledge.
- Lazarus, M. A., C. Crawford. 2011. "Returning Genius to Place." *Architectural Design* 48-53.
- Loise, N., C. Boks. 2012. "The Use of Biomimicry as a Useful Tool for the Industrial Designer." *Sustainable Development* 189-199.
- M'Closkey. 2013. "Synthetic Patterns: Fabricating Landscapes in the 'Age of Green'." *Journal of Landscape Architecture* 16-27.
- Maribor, F.J., et al. Tone Novak University of Maribor. 2012. *PCA- A powerful Method for Analyze Ecological Niches*. Maribor, Slovenia: Department of Biology, Natural Sciences and Mathematics.
- Marsh, A., A. Khan. 2011. "Future of Design Tools." *Journal of Architectural Design* 82-91.
- Maser, C. 2012. *Decision-Making for a Sustainable Environment: A Systematic Approach*. Boca Raton: CRC Press.
- McDonough, W., M. Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. Farrar, Straus, and Giroux.
- Meyers, W. 2014. *BioDesign*. New York: The Museum of Modern Art.
- Millennium Ecosystem Assessment. 2005. *Synthesis*. Washington D.C.: Island Press.
- Mostafavi, Mohsen. 2010. "Why Ecological Urbanism? Why Now?" *Harvard Design Magazine* 10-22.
- Murray, S.N., R.F. Ambrose, M.N. Dethier. 2002. *Methods for Performing Monitoring, Impact, and Ecological Studies on Rocky Shores*. Final Technical Summary Study Report, Santa Barbara: Southern California Educational Initiative Marine Science Institute.
- Peters, T. 2011. "Experimental Green Strategies: Redefining Ecological design Research." *Architectural Design* 14-19.

- Peters, T. 2011. "Nature as Measure." *Architectural Design* 44-47.
- Ringner, M. 2008. "What is Principle Component Analysis?" *Nature Biotechnology* 303-304.
- Rocha, L.A.O., S. Lorente, A. Bejan. 1997. *Constructural Law, Design in Nature, and Complexity*.
- Salinger, N. 2000. "The Structure of Pattern Languages." *Architectural Research Quarterly* 149-161.
- Smith, C.A., A. Bennett, E. Hanson, C. Gavin. 2015. *Tapping into Nature*. New York: Terrapin Bright Green.
- Stevens, P.S. 1974. *Patterns in Nature*. London: Penguin Book Ltd.
- Takane, Y. 2014. *Constrained Principle Component Analysis and Related Techniques*. Boca Raton: CRC, Taylor & Francis Group.
- Thayer, R.L. Jr. 1995. *LifePlace: Bioregional Thought and Practice*. University of California Press.
- Thompson, I. 2003. *Ecology, Community and Delight: An Inquiry into Values of Landscape Architecture*. Routledge.
- Todd, J.E. 1982. *Fredrik Law Olmsted*. New York: Scribner.
- Tzoulas, K., K. Korpela, S. Venn, V. Yli-Pelkonen, A. Kazmierczak, P. James. 2007. "Promoting Ecosystem and Human Health in Urban Areas Using Green Infrastructure: A Literature Review." *Landscape and Urban Planning* 167-178.
- UNEP. 2015. *The United Nations Environment Programme and the 2030 Agenda: Global Action for People and the Planet*. Report N.p., Web.
- Vincent, J. 2009. "Biomimetric Patterns in Architectural Design." *Architectural Design* 74-82.
- Wilson, E.O. 1995. *The Biophilia Hypothesis*. Washington D.C.: Island Press.
- Woolley-Barker, T. 2013. *Injecting Green with Biomimicry for Sustainability*. September 9.
- Xianli Wang, Steven G. Cumming. 2011. "Measuring Landscape Configuration with Normalized Metrics." *Landscape Ecology* 723-736.